MARINE SCIENCE AND TECHNOLOGY BULLETIN

Volume 12 - Issue 3 - YEAR 2023

e-ISSN: 2147-9666

PRENSIP

www.masteb.com
dergipark.org.tr/en/pub/masteb

MARINE SCIENCE AND TECHNOLOGY BULLETIN

2023 • VOLUME: 12 • ISSUE: 3

PRENSIP

Prensip Publishing and Consultancy Ind. Trade. Co. Ltd.
Kuzeykent Mah. Orgeneral Atilla Ateş Paşa Cad. No: 15 CD İç kapı no:31
37150 Merkez, Kastamonu, Türkiye
info@prensip.gen.tr
prensip.gen.tr

AIM & SCOPE

Marine Science and Technology Bulletin is a double-blind peer-reviewed and open-access journal publishing high-quality papers that original research articles, short communications, and reviews for scientists engaged in all aspects of marine sciences and technology, fisheries and aquatic sciences, and food processing technologies.

Research areas include (but not limited):

Marine Sciences
Marine Technology,
Fisheries and Aquatic Sciences,
Environmental Science and Technology,
Oceanography,
Marine Biology,
Marine Ecology,
Marine Geology,
Marine Geochemistry,
Marine Chemistry,
Marine Engineering,
Ocean Engineering,
Aquaculture,
Fish Nutrition,
Disease and Treatment,
Fisheries Technology,
Aquatic Food Processing,
Microbiology,
Algal Biotechnology,
Petrology and Sedimentation,
Remote Sensing & GIS
Climate Change & Sea Level Changes,
Protection of Organisms Living in Marine Habitats,
Marine Pollution,
Maritime,
Maritime Organizations,
Marine/Maritime Affairs,
Management and Economics,
Naval Architecture,
Offshore and Underwater Technology,
Unmanned Surface/Underwater Vehicles.

AUTHOR GUIDELINES

Manuscripts must be submitted to the journal in electronic version only via online submission system following the Instructions for Authors at https://dergipark.org.tr/en/pub/masteb/writing-rules

Types of Paper

- Original research papers; review articles; short communications.
- *Original research papers*; original full-length research papers which have not been published previously and should not exceed 7500 words or 25 manuscript pages (including tables and illustrations)
- *Review articles*; on topical subjects and up to 10,000 words or 25 manuscript pages (including tables and figures)
- *Short communications*; describing work that may be of a preliminary nature (preferably no more than 3000 words or 10 manuscript pages including tables and figures).

Article Processing Charges (APC)

Marine Science and Technology Bulletin does not charge any article submission, processing, or publication fees.

Publication Frequency

The journal includes original scientific articles on a variety of different subjects in English and is published four times a year in March, June, September and December.

Preparation of Manuscripts

Papers must be written in English. Prepare your text using word-processing software and save it in *".doc"* or *".docx"* formats. You can **download the full paper template** from **here**. Manuscripts must be structured in the following order;

- Title page (Separate file)
  - Title
  - Author names, affiliations
  - Corresponding author's e-mail, Telephone
  - ORCID iD and e-mail addresses for all authors
- Main text
  - Abstract
  - Keywords
  - Introduction
  - Material and Methods
  - Results
  - Discussion
  - Conclusion
  - Acknowledgement (if required)
  - Compliance with Ethical Standards
    - Authors' Contributions
    - Conflict of Interest
    - Statement on the Welfare of Animals
    - Statement of Human Rights
    - Data availability
  - References
- Table(s) with caption(s) (on appropriate location in the text)
- Figure(s) with caption(s) (on appropriate location in the text)
- And appendices (if any)

Use a 12-point font (Times New Roman preferred), including the references, table headings and figure captions, double-spaced and with 25 mm margins on all sides of A4 size paper throughout the manuscript. The text should be in single-column format. In particular, do not use hyphenated words. The names of genera and species should be given in *italics* and, when first mentioned in the text, should be followed by the authority. Authors should consult a recent issue of the journal for style if possible.

Title Page

The title page should be included;

- Concise and informative title. Avoid abbreviations and formulae
- The first name(s) and surname(s) of the author(s) (The corresponding author should be identified with an asterisk and footnote. All other footnotes (Author(s) affiliation address(es)) should be identified with superscript numbers)
- Author(s) affiliation address(es) (followed by institution, faculty/school, department, city with postcode, and country) of each author(s))
- The e-mail address, phone number, fax number of the corresponding author
- ORCID iD and e-mail addresses for all authors

Main Text

- Abstract (should be between 150 and 500 words. References and abbreviations should be avoided)
- Keywords (provide a maximum of 6 keywords)
- Articles must be structured in the conventional format such as Introduction, Material and Methods, Results, Discussion, Conclusion, Acknowledgments, Compliance with Ethical Standards (Authors' Contributions, Conflict of Interest, Statement of Welfare of Animals/Human Rights, Data Availability Statement) and References.
- Each page must be numbered, and lines must be consecutively numbered from the start to the end of the manuscript.
- Do not justify on the right-hand margin.
- The first line of each paragraph must be indented. Do not put a blank line between paragraphs.
- The first mention in the text of any taxon must be followed by its authority including the year.
- Use italics for emphasis.
- Use only SI (international system) units.

Acknowledgements
Keep these to the absolute minimum and placed before the reference section.

Compliance with Ethical Standards
The corresponding author will include a summary statement in the text of the manuscript in a separate section before the reference list. See below examples of disclosures:

a) Authors' Contributions
Please provide the contributions of the authors for the paper. Use the first letters of the names and surnames of the authors. See below for an example.

SA: Designed the study. Carried out the field study.
SB: Wrote the first draft of the manuscript.
SK: Performed laboratory experiments and managed statistical analysis.

All authors read and approved the final manuscript.
or

SA: Manuscript design, Field sampling, Draft checking.
SB: Writing, Draft checking, Reading, Editing.
SK: Laboratory experiments, Statistical analyses.

All authors read and approved the final manuscript.

b) Conflict of Interest
Any existing conflict of interest should be given here.
If no conflict exists, the authors should state:

Conflict of Interest: The authors declare that there is no conflict of interest.

c) Statement on the Welfare of Animals
If animals used in the study;
The welfare of animals used for research must be respected. When reporting experiments on animals, authors should indicate the following statement:

Ethical approval: All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.
Or, for retrospective studies; a summary statement in the text of the manuscript should be included as follow:

Ethical approval: For this type of study, formal consent is not required.

d) Statement of Human Rights
When reporting studies that involve human participants, authors should include the following statement:

Ethical approval: The studies have been approved by the appropriate institutional and/or national research ethics committee and have been performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.
Or, for retrospective studies; a summary statement in the text of the manuscript should be included as follow:

Ethical approval: For this type of study, formal consent is not required.

e) Data Availability Statements
Data Availability Statements should be placed in the back matter of the manuscript, just before References.

Examples of Data Availability Statements

- The data that support the findings of this study are available from the corresponding author, [author initials], upon reasonable request.
- Data availability is not applicable to this article as no new data were created or analyzed in this study.
- The authors confirm that the data supporting the findings of this study are available within the article [and/or its supplementary materials].
- The data that support the findings of this study are openly available in [repository name] at http://doi.org/[doi], reference number [reference number].
- The data that support the findings of this study are available from [third party]. Restrictions apply to the availability of these data, which were used under license for this study. Data are available [from the authors / at URL] with the permission of [third party].
- Raw data were generated at [facility name]. Derived data supporting the findings of this study are available from the corresponding author [initials] on request.
- The data that support the findings of this study are available on request from the corresponding author, [initials]. The data are not publicly available due to [restrictions e.g., their containing information that could compromise the privacy of research participants].
- The data that support the findings of this study will be available in [repository name] at [URL/DOI link] following a [3 month] embargo from the date of publication, to allow for the commercialization of research findings.

References
<u>*Citation in text;*</u>
Please ensure that each reference cited in the text is also presented in the reference list. Cite literature in the text in chronological, followed by alphabetical order like these examples "(Mutlu et al., 2012; Biswas et al., 2016; Kale, 2017a, 2017b; Yanık & Aslan, 2018)". If the cited reference is the subject of a sentence, only the date should be given in parentheses. Formatted like this example: "Sönmez (2017)" or "Kale (2017a, 2017b)".

- Single author: the author's name and the year of publication;
- Two authors: both authors' names and the year of publication;
- Three or more authors: first author's name followed by "et al." and the year of publication.

<u>*Citation in the reference list;*</u>
References should be listed first alphabetically and then further sorted chronologically at the end of the article. More than one reference from the same author(s) in the same year must be identified by the letters a, b, c, etc. placed after the year of publication.
The citation of articles, books, multi-author books and articles published online should conform to the following examples:

<u>Article:</u>
Yamasaki, J., Miyata, H., & Kanai, A. (2005). Finite-difference simulation of green water impact on fixed and moving bodies. *Journal of Marine Science and Technology*, *10*(1), 1-10. https://doi.org/10.1007/s00773-005-0194-1

Yanık, T., & Aslan, İ. (2018). Impact of global warming on aquatic animals. *Pakistan Journal of Zoology*, *50*(1), 353-363. https://doi.org/10.17582/journal.pjz/2018.50.1.353.363

Sönmez, A. Y., Kale, S., Özdemir, R. C., & Kadak, A. E. (2018). An adaptive neuro-fuzzy inference system (ANFIS) to predict of cadmium (Cd) concentration in the Filyos River, Turkey. *Turkish Journal of Fisheries and Aquatic Sciences*, *18*(12), 1333-1343. https://doi.org/10.4194/1303-2712-v18_12_01

Preprint Article References:

- Ideally, use and cite the final, published version of a work. However, if you used the preprint version of a work, cite that version, as shown in the following examples.
- Preprint versions of articles may or may not be peer-reviewed or may be the author's final, peer-reviewed manuscript as accepted for publication.

- Two common repositories for preprint articles are PsyArXiv and PubMed Central. Follow the same format for other preprint archives.

Zhu, L., Liu, Q., Liu, X., & Zhang, Y. (2021). *RSST-ARGM: A Data-Driven Approach to Long-term Sea Surface Temperature Prediction*. Researchsquare, *Preprint*. https://assets.researchsquare.com/files/rs-468686/v1_stamped.pdf

Hampton, S., Rabagliati, H., Sorace, A., & Fletcher-Watson, S. (2017). *Autism and bilingualism: A qualitative interview study of parents' perspectives and experiences*. PsyArXiv, *Preprint*. https://doi.org/10.31234/osf.io/76xfs

Hetland, B., McAndrew, N., Perazzo, J., & Hickman, R. (2018). *A qualitative study of factors that influence active family involvement with patient care in the ICU: Survey of critical care nurses*. PubMed Central, *Preprint*. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5736422/?report=classic

Articles in non-English languages:

Acarlı, D., Kale, S., & Kocabaş, S. (2020). *TCSG-132 Gemi Batığı Yapay Resifinin (Gökçeada, Kuzey Ege Denizi) Biyoçeşitliliği* [Biodiversity of TCSG-132 Shipwreck Artificial Reef (Gökçeada, North Aegean Sea)]. *Acta Aquatica Turcica*, *16*(3), 313-329. https://doi.org/10.22392/actaquatr.677175

Book:

Brown, C., Laland, K., & Krause, J. (Eds.) (2011). Fish Cognition and Behavior. 2nd ed. Wiley-Blackwell.

Chapter:

Langston, W. J. (1990). Toxic effects of metals and the incidence of marine ecosystems. In Furness, R. W. (Ed.), *Rainbow Heavy Metals in the Marine Environment* (pp. 102-l22). CRC Press.

Vassallo, A. I., & Mora, M. S. (2007). Interspecific scaling and ontogenetic growth patterns of the skull in living and fossil ctenomyid and octodontid rodents (Caviomorpha: Octodontoidea). In Kelt, D. A., Lessa, E., Salazar-Bravo, J. A., & Patton, J. L. (Eds.), *The Quintessential Naturalist: Honoring the Life and Legacy of Oliver P. Pearson* (pp. 945-968). 1st ed. University of California Press.

Thesis and Dissertation:

Sönmez, A. Y. (2011). *Karasu ırmağında ağır metal kirliliğinin belirlenmesi ve bulanık mantıkla değerlendirilmesi* [Determination of heavy metal pollution in Karasu river and its evaluation by fuzzy logic]. [Ph.D. Thesis. Atatürk University].

Conference Proceedings:

Notev, E., & Uzunova, S. (2008). A new biological method for water quality improvement. *Proceedings of the 2nd Conference of Small and Decentralized Water and Wastewater Treatment Plants*, Greece, pp. 487-492.

Institution Publication:

FAO. (2016). *The State of World Fisheries and Aquaculture: Contributing to food security and nutrition for all*. Rome. 200 pp.

Report:

FAO. (2018). *Report of the ninth session of the Sub-Committee on Aquaculture*. FAO Fisheries and Aquaculture Report No. 1188. Rome, Italy.

Internet Source:

Froese, R., & Pauly, D. (Eds.) (2018). FishBase. World Wide Web electronic publication. Retrieved on January 11, 2018 from http://www.fishbase.org.

TurkStat. (2019). Fishery Statistics. Retrieved on December 28, 2019 from http://www.turkstat.gov.tr/

Table(s)

Tables, numbered in Arabic, should be in separate pages with a short descriptive title at the top. Place footnotes to tables below the table body and indicate them with superscript lowercase letters (or asterisks for significance values and other statistical data). Avoid vertical rules. The data presented in tables do not duplicate results described elsewhere in the article.

Figure(s)

All illustrations should be labelled 'Figure' and numbered in consecutive Arabic numbers, Figure 1, Figure 2 etc. in the text. If panels of a figure are labelled (a, b, etc.) use the same case when referring to these panels in the text. Figures are recommended for electronic formats such as PNG, JPEG. TIFF (min. 300 dpi) should be also arranged in available dimensions. All figures or tables should be presented in the body of the text. Font sizes size should be from 9 to 11 points.

Download Copyright Form

ETHICAL PRINCIPLES AND PUBLICATION POLICY

Marine Science and Technology Bulletin follows certain ethical standards for publication, existing to ensure high-quality scientific publications, public trust in scientific findings, and due credit for original ideas. *Marine Science and Technology Bulletin* is connected to the Committee on Publication Ethics (COPE), abides by its Code of Conduct, and aims to adhere to its Best Practice Guidelines.

Committee on Publication Ethics (COPE). (2011, March 7). Code of Conduct and Best-Practice Guidelines for Journal Editors. Retrieved from https://publicationethics.org/files/Code_of_conduct_for_journal_editors_Mar11.pdf

Authors who submit papers to *Marine Science and Technology Bulletin* certify that his/her work is original and is not published or under publication consideration elsewhere. Also, the authors confirm that submitted papers have not been copied or plagiarized, in whole or in part, from other papers or studies. The authors certify that he/she does not have potential conflicts of interest or partial benefits associated with their papers.

The editorial team and/or reviewers of the *Marine Science and Technology Bulletin* will check for plagiarism in all submitted articles prior to publication. If plagiarism is detected at any stage of the publication process, the author will be instructed to rewrite the manuscript. Every submission will be scanned by *iThenticate*® to prevent plagiarism. If any manuscript is 30% plagiarized, the article will be rejected and the author will be notified. We strongly recommend that authors check the paper's content before submitting it for publication. Plagiarism can also be checked by using free online software.

Marine Science and Technology Bulletin is committed to objective and fair blind peer reviews of submitted papers and the prevention of any actual or potential conflicts of interest between writers and reviewers.

RESPONSIBILITIES OF EDITORS AND THE EDITORIAL BOARD

Editorial Responsibilities and Independence

All editors of *Marine Science and Technology Bulletin* are independent in their evaluations and decisions in the journal. No external and/or internal factor can affect their decisions. If the editors are exposed to any kind of positive and/or negative constraints, they keep the right to take legal action against those involved in the constraint. On the other hand, editors are responsible for their decisions in the journal. The editor-in-chief is the only person responsible for journal content and on-time publishing.

Privacy and Conflict of Interest
Editors and members of the Editorial Board of the journal are forbidden to share submitted materials with third parties other than section editors, statistical editors, Language editors, copy editors, design editors and ombudsman when needed, and to use the submitted materials themselves. If there is a conflict of interest among an editor and an author or institution of the author in terms of cooperation or competition, then another member of the Editorial board is assigned to manage the evaluation process.

Publishing Decisions
Editors provide peer review of submitted manuscripts by assigning at least two reviewers expert in the field. The editor-in-chief is responsible for the decision of publishing a manuscript considering the importance of the manuscripts for researchers and readers, reviewer reports, plagiarism and copyright infringement as legal issues. Editor-in-chief can discuss with other editors and reviewers for his/her decision.

RESPONSIBILITIES OF REVIEWERS

Contribution to the Editor's Decision
Peer-reviewing of a submitted manuscript is the control of its scientific content, scientific layout and suitability according to the principles of the journal, and delivery of the reviewer's opinion for unsuitable manuscript content to ensure suitability. The reviewing process, not only enables reviewers to forward their evaluations about the manuscripts to the editors but also gives them the opportunity to improve the contents of the manuscripts.

Quickness
If a reviewer assigned for evaluation of a manuscript is of an expert in a field of science other than the manuscript content, is far to the subject of the manuscript, is short of time for evaluation or possess a conflict of interest, then he/she should inform the assigning editor and ask his/her withdrawal. If the content of the manuscript fits the expertise field of the reviewer, then he/she should complete the evaluation and send the report to the editor as soon as possible.

Privacy
Reviewers assigned for evaluation of manuscripts approve in advance that the manuscripts are secret documents and do not share any information about these documents with third parties except the editors involved in the evaluation. Reviewers continue to not to share information even after the manuscripts are accepted or rejected for publication.
If it is suspected of using an idea in the manuscript that is sent for evaluation to the reviewer without permission, the flowchart of COPE "What to do if you suspect a reviewer has appropriated an author's ideas or data?" is followed.

Standards of Objectivity
Reviewers should construct their criticisms on scientific background and include scientific evidence in their statements. All comments raised by the reviewers to improve the manuscripts should be clear and direct and written in a manner far away from disturbing the author's feelings. Insulting and derogatory statements should be avoided.

Suitability of the Cited References
Reviewers should determine quotations in the manuscripts used without citing a reference. Statements, observations, conclusions or evidence in published articles should be quoted with the citation of the related reference. Reviewers should also be sure about the reality of the presence of quotations in the cited reference(s).

Conflict of Interests
If a reviewer is in a situation by being involved in one or more interests with the author(s), he/she should inform the editor of the assigning editor and ask his/her withdrawal.

RESPONSIBILITIES OF THE AUTHORS

Reporting Standards
Authors of original research articles should present the results and discuss them with them in a proper way. Since the methodological contents of the articles should be reproducible, the authors should be clear in their statements and should not purposely report wrong or missing data. Authors of review type articles are not recommended to write such articles if they are not an expert in the field of their review topics or when they do not have enough background information or related former studies.

Data Accessing and Retainment
Authors may be asked to present their raw data when needed (ethical cases etc.). Therefore, raw data of the manuscripts should be kept in safety to present if needed. The storage period of raw data following publications should be at least 10 years.

Originality and Plagiarism
The authors of submitted manuscripts should be sure that their manuscripts are original or include cited references for quotations.

Multiple, Repeated, Unnecessary or Simultaneous Submissions
It is not an approved way to produce more than one publication reporting on the same research. The authors should pay attention to such cases and they should not submit the same manuscript to different journals simultaneously.

Authorship of Manuscripts
Only the following persons should be included in the manuscripts as responsible authors:
• Researchers providing a major contribution to the concept, design, performing, data collection and/or analysis of a study,
• Researchers involved in the preparation or critical revision of manuscripts,
• Researchers approved the latest version of the manuscripts and accepted their submission.
Contributors other than the above list (technical assistance, helpers in writing and editing, general contributions, etc.) should not be involved in the authors' list but can be listed in the acknowledgements section. The corresponding authors of manuscripts should provide a separate listing of contributors as authors and those to be involved in the acknowledgements section.

Changes in Authorship
Any changes to the list of authors after submissions, such as addition, deletion, or changes in the order of authors, must be approved by each author. The editors of Acta Natura et Scientia are not in a position to investigate or judge authorship disputes before or after publishing. Such disputes between authors that cannot be resolved should be directed to the relevant institutional authority.
If you request to add, delete or rearrange the authors of the accepted article:
Before online publication: The corresponding author must contact the Journal Editor-in-Chief/Co-Editor and provide (a) the reason for the change and (b) the written consent of all co-authors, including removed or added authors. Please note that your article will not be published until changes are agreed upon.
After online publication: Requests to add, delete, or reorder author names in an article published in an online issue will follow the same policies outlined above and result in a Corrigendum.

Conflict of Interests

Authors should clearly declare any kind of conflict of interest in their manuscripts. The absence of conflict of interest about the topic of the manuscripts should also be declared. The most common types of conflict of interest are financial support, education or other types of funds, personal or institutional relations and affiliations. All sources of financial support (with their grant or other reference numbers) for the studies should be declared.

Acknowledgement of References

Authors should not use personally obtained information (conversations, correspondences or discussions with bystanders) unless they have the permission of their sources. Information about private documents or refereeing of grant applications should not be used without the permission of the authorities providing the related service.

Peer-Review

Authors are obliged to be involved in the peer-review process and should cooperate by responding to raw data, evidence for ethical approvals, patient approvals and copyright release form requests of editors and their explanations. Authors should respond in either a positive or a negative way to revision suggestions generated by the peer-review process. They should be sure to include their counter views in their negative responses.

Submitting authors must confirm the following:

1. Manuscripts must be the original work of the submitting author.
2. Submitted manuscripts must be unpublished.
3. There should be no conflict of interest. If it exists, it must be clearly stated.
4. The authors should cite all data sources used in the preparation of the manuscript.

Note: It is unethical to submit a manuscript to more than one journal concurrently.

Reviewers must confirm the following:

1. Manuscripts are reviewed fairly based on the intellectual content of the paper regardless of gender, race, ethnicity, religion, citizenship or political view of the author(s).
2. Any observed conflict of interest during the review process must be sent to the editor.
3. Information pertaining to the manuscript is kept confidential.
4. Information that may be a cause for rejection of publication must be sent to the editor.

Editors must confirm the following:

1. Manuscripts are reviewed fairly based on the intellectual content of the paper regardless of gender, race, ethnicity, religion, citizenship or political view of the author(s).
2. Information pertaining to manuscripts is kept confidential.
3. Any observed conflict of interest pertaining to manuscripts must be disclosed.

Ethical Guidelines for the Use of Animals in Research

Marine Science and Technology Bulletin endorses the ARRIVE guidelines for reporting experiments using live animals. Authors and reviewers can use the ARRIVE guidelines as a checklist, which can be found at **https://arriveguidelines.org/arrive-guidelines/experimental-animals**

Manuscripts containing original research on animal subjects must have been approved by an ethical review committee. The project identification code, date of approval and name of the ethics committee or institutional review board must be cited in the Methods Section.

For research involving animals, any potentially derived benefits must be significant in relation to the harm suffered by participating animals. Authors should particularly ensure that their research complies with the commonly accepted "3Rs":

• Replacement of animals with alternatives wherever possible,
• Reduction in the number of animals used, and
• Refinement of experimental conditions and procedures to minimize the harm to animals.

Kindly see the ethical principles flow chart of ULAKBIM-TR DIZIN at https://dergipark.org.tr/en/pub/masteb/policy.

Statement on the Welfare of Animals

If the animals used in the study;

The welfare of animals used for research must be respected. When reporting experiments on animals, authors should indicate the following statement:

Ethical approval: All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

Or, for retrospective studies; a summary statement in the text of the manuscript should be included as follow:

Ethical approval: For this type of study, formal consent is not required.

Statement of Human Rights

When reporting studies that involve human participants, authors should include the following statement:

Ethical approval: The studies have been approved by the appropriate institutional and/or national research ethics committee and have been performed in accordance with the ethical standards.

Or, for retrospective studies; a summary statement in the text of the manuscript should be included as follow:

Ethical approval: For this type of study, formal consent is not required.

Corrections & Retractions

*Marine Science and Technology Bulleti*n issues post-publication editorial decisions (e.g. corrections & retractions) only after we carefully consider the issues raised, all materials and information received in follow-up discussions, and how the case details align with COPE guidance and the journal's policies and publication criteria. In accordance with COPE guidance, the journal attempt to discuss concerns with the article's corresponding author before coming to an editorial decision.

After a post-publication editorial decision has been communicated to the authors, the decision is held during a brief commenting period in which authors can respond to the decision or notice the text. After the commenting period's end date, which is specified in the decision notification letter, the decision will proceed.

Corrections

Marine Science and Technology Bulletin should consider issuing a correction if:

- A small part of an otherwise reliable publication reports flawed data or proves to be misleading, especially if this is the result of honest error.
- The author or contributor list is incorrect (e.g. a deserving Author has been omitted or someone who does not meet authorship criteria has been included).

Corrections to peer-reviewed content fall into one of three categories:

- **Erratum (Publisher correction):** to notify readers of a significant error made by publishing/journal staff (usually a production error) that has a negative impact on the publication record or the scientific integrity of the article or the reputation of the authors or the Journal.
- **Corrigendum (Author correction):** to notify readers of a significant error made by the Authors that harms the

publication record, the scientific integrity of the article, or the reputation of the Authors or the Journal.

- **Addendum:** an addition to the article by its Authors to explain inconsistencies, expand the existing work, or otherwise explain or update the information in the main work.

Whether a correction should be issued is made by the Editor (s) of a journal, sometimes with advice from Reviewers or Editorial Board members. Handling Editors will contact the authors of the paper concerned with a request for clarification, but the final decision about whether a correction is required and, if so, which type rests with the Editors.

Retraction

A retraction is carried out if an article is indicated to have an Infringement of scientific or ethical codes, such as double submissions, false claims of authorship, plagiarism, fraudulent use of data, fake authors, etc. A retraction notice will be issued where a major error (e.g. in the analysis or methods) invalidates the conclusions in the article, or where research misconduct or publication misconduct has taken place (e.g. research without required ethical approvals, fabricated data, manipulated images, plagiarism, duplicate publication, etc.). The decision to issue a retraction for an article will be made in accordance with COPE guidelines and will involve an investigation by the editorial staff in collaboration with the editor. Authors and institutions may request a retraction of their articles if their reasons meet the criteria for retraction.

The COPE retraction guidelines can be found on the COPE website at https://publicationethics.org/node/19896

Retraction will be considered:

- If there is clear evidence that the findings are unreliable, either as a result of misconduct (e.g., data fabrication or image manipulation) or honest error (e.g., miscalculation or experimental error).
- If the findings have previously been published elsewhere without proper cross-referencing, permission, or justification (e.g. cases of redundant publication or duplicate publication).
- If the research constitutes plagiarism.
- Where there is evidence of fraudulent authorship.
- Where there is evidence of compromised peer review.
- If there is evidence of unethical research.

Where the decision has been taken to retract an article before the article is published, the Editor will return the manuscript to the author accompanied by a retraction letter from the Editor-in-Chief.

Where the decision has been taken to retract an article after the article is published, the journal will:

- Add a “retracted” watermark to the published version of the article.
- Issue a separate retraction statement, titled "Retraction: [article title]", that will be linked to the retracted article.
- Paginate and make available the retraction statement in the online issue of the journal.

Please note that retraction means that the article is maintained on the platform watermarked “retracted” and the explanation is provided in a note linked to the watermarked article.

ETHICAL GUIDELINES FOR THE USE OF ANIMALS IN RESEARCH

More detail can be found at https://dergipark.org.tr/en/pub/masteb/page/5979

OPEN ACCESS POLICY

Marine Science and Technology Bulletin is an open-access journal publishing high-quality papers that original research articles, short communications, technical notes, reports and review papers. All authors and readers have free access to all papers. All published papers are freely available, and openly accessible. The journal does not charge any article submission, processing or publication charges.

Marine Science and Technology Bulletin follows the guidelines presented by the **Budapest Open Access Initiative (BOAI)** regarding Open Access. It means that articles published in *Marine Science and Technology Bulletin* have free availability on the public internet, permitting any users to read, download, copy, distribute, print, search, or link to the full texts of these articles, crawl them for indexing, pass them as data to software, or use them for any other lawful purpose, without financial, legal, or technical barriers other than those inseparable from gaining access to the internet itself.

Please visit the given links below for more information about the Budapest Open Access Initiative.

https://www.budapestopenaccessinitiative.org/read
https://www.budapestopenaccessinitiative.org/boai-10-recommendations
https://www.budapestopenaccessinitiative.org/boai15-1

The base URL for our repository can be found at https://dergipark.org.tr/en/pub/masteb/lockss-manifest

LOCKSS system has permission to collect, preserve, and serve this open access Archival Unit.

Original Budapest Open Access Initiative Declaration

An old tradition and a new technology have converged to make possible an unprecedented public good. The old tradition is the willingness of scientists and scholars to publish the fruits of their research in scholarly journals without payment, for the sake of inquiry and knowledge. The new technology is the internet. The public good they make possible is the worldwide electronic distribution of peer-reviewed journal literature and completely free and unrestricted access to it by all scientists, scholars, teachers, students, and other curious minds. Removing access barriers to this literature will accelerate research, enrich education, share the learning of the rich with the poor and the poor with the rich, make this literature as useful as it can be, and lay the foundation for uniting humanity in a common intellectual conversation and the quest for knowledge.

The literature that should be freely accessible online is that which scholars give to the world without expectation of payment. Primarily, this category encompasses their peer-reviewed journal articles, but it also includes any unreviewed preprints that they might wish to put online for comment or to alert colleagues to important research findings. There are many degrees and kinds of wider and easier access to this literature. By "open access" to this literature, we mean its free availability on the public internet, permitting any users to read, download, copy, distribute, print, search, or link to the full texts of these articles, crawl them for indexing, pass them as data to software, or use them for any other lawful purpose, without financial, legal, or technical barriers other than those inseparable from gaining access to the internet itself. The only constraint on reproduction and distribution, and the only role for copyright in this domain, should be to give authors control over the integrity of their work and the right to be properly acknowledged and cited.

While the peer-reviewed journal literature should be accessible online without cost to readers, it is not costless to produce. However, experiments show that the overall costs of providing open access to this literature are far lower than the costs of traditional forms of dissemination. With such an opportunity to save money and expand the scope of dissemination at the same time, there is today a strong incentive for professional associations, universities, libraries, foundations, and others to embrace open access as a means of advancing their missions. Achieving open access will require new cost recovery models and financing mechanisms, but the significantly lower overall cost of dissemination is a reason to be confident that the goal is attainable and not merely preferable or utopian.

To achieve open access to scholarly journal literature, we recommend two complementary strategies.

I. Self-Archiving: First, scholars need the tools and assistance to deposit their refereed journal articles in open electronic archives, a practice commonly called, self-archiving. When these archives conform to standards created by the Open Archives Initiative, then search engines and other tools can treat the separate archives as one. Users then need not know which archives exist or where they are located in order to find and make use of their contents.

II. Open-access Journals: Second, scholars need the means to launch a new generation of journals committed to open access, and to help existing journals that elect to make the transition to open access. Because journal articles should be disseminated as widely as possible, these new journals will no longer invoke copyright to restrict access to and use of the material they publish. Instead, they will use copyright and other tools to ensure permanent open access to all the articles they publish. Because price is a barrier to access, these new journals will not charge subscription or access fees, and will turn to other methods for covering their expenses. There are many alternative sources of funds for this purpose, including the foundations and governments that fund research, the universities and laboratories that employ researchers, endowments set up by discipline or institution, friends of the cause of open access, profits from the sale of add-ons to the basic texts, funds freed up by the demise or cancellation of journals charging traditional subscription or access fees, or even contributions from the researchers themselves. There is no need to favor one of these solutions over the others for all disciplines or nations, and no need to stop looking for other, creative alternatives.

Open access to peer-reviewed journal literature is the goal. Self-archiving (I.) and a new generation of open-access journals (II.) are the ways to attain this goal. They are not only direct and effective means to this end, they are within the reach of scholars themselves, immediately, and need not wait on changes brought about by markets or legislation. While we endorse the two strategies just outlined, we also encourage experimentation with further ways to make the transition from the present methods of dissemination to open access. Flexibility, experimentation, and adaptation to local circumstances are the best ways to assure that progress in diverse settings will be rapid, secure, and long-lived.

The Open Society Institute, the foundation network founded by philanthropist George Soros, is committed to providing initial help and funding to realize this goal. It will use its resources and influence to extend and promote institutional self-archiving, to launch new open-access journals, and to help an open-access journal system become economically self-sustaining. While the Open Society Institute's commitment and resources are substantial, this initiative is very much in need of other organizations to lend their effort and resources.

We invite governments, universities, libraries, journal editors, publishers, foundations, learned societies, professional associations, and individual scholars who share our vision to join us in the task of removing the barriers to open access and building a future in which research and education in every part of the world are that much more free to flourish.

For various reasons, this kind of free and unrestricted online availability, which we will call open access, has so far been limited to small portions of the journal literature. But even in these limited collections, many different initiatives have shown that open access is economically feasible, that it gives readers extraordinary power to find and make use of relevant literature, and that it gives authors and their works vast and measurable new visibility, readership, and impact. To secure these benefits for all, we call on all interested institutions and individuals to help open up access to the rest of this literature and remove the barriers, especially the price barriers, that stand in the way. The more who join the effort to advance this cause, the sooner we will all enjoy the benefits of open access.

More detail can be found at https://dergipark.org.tr/en/pub/masteb/page/9532

ARCHIVING POLICY

Marine Science and Technology Bulletin uses the LOCKSS system offered by DergiPark. You will be able to access the Journal archive at https://dergipark.org.tr/en/pub/masteb/lockss-manifest. For more information, please visit the LOCKSS website.

LICENSE

Authors retain copyright and grant the journal right of first publication with the work simultaneously licensed under a Creative Commons Attribution License that allows others to share the work with an acknowledgement of the work's authorship and initial publication in this journal.

Authors are able to enter into separate, additional contractual arrangements for the non-exclusive distribution of the journal's published version of the work (e.g., post it to an institutional repository or publish it in a book), with an acknowledgement of its initial publication in this journal.

Authors are permitted and encouraged to post their work online (e.g., in institutional repositories or on their website) prior to and during the submission process, as it can lead to productive exchanges, as well as earlier and greater citation of published work (See The Effect of Open Access).

REVIEW PROCESS

Double-Blind Review and Evaluation Process

Double-Blind Review is a method applied for publishing scientific publications with the highest quality. This method forms the basis of an objective evaluation of scientific studies and is preferred by many scientific journals.

The views of referees have a decisive place in the publication quality of *Marine Science and Technology Bulletin*.

Marine Science and Technology Bulletin uses the double-blind review method, which means that both the reviewer and author identities are concealed from the reviewers, and vice versa, throughout the review process, in the evaluation process of all studies. For this reason, the authors are asked to erase their names while uploading the articles to the system.

All the studies submitted to *Marine Science and Technology Bulletin* are evaluated by double-blind review method according to the following steps.

1. Initial Evaluation Process

The studies submitted to *Marine Science and Technology Bulletin* are first evaluated by the editor. At this stage, studies that are not in line with the aim and scope of the journal, are weak in terms of language and narrative rules in English contain scientifically critical mistakes, are not original worthy and cannot meet publication policies are rejected. Authors of rejected studies will be notified within one month at the latest from the date of submission. Eligible studies are sent to the field editor to which the study is relevant for pre-evaluation.

2. Pre-Evaluation Process

In the pre-evaluation process, the field editors examine the studies, introduction and literature, methods, findings, results, evaluation and discussion sections in detail in terms of journal publication policies, scope and authenticity of study. Study which is not suitable as a result of this examination is returned to the author with the field editor's evaluation report within four weeks at the latest. The studies which are suitable for the journal are passed to the referee process.

3. Referee Process

The studies are sent to the referees according to their content and the expertise of the referees. The field editor examining the study may propose at least two referees from the pool of Marine Science and Technology Bulletin Advisory Board or referee pool according to their field of expertise or may propose a new referee appropriate to the field of study.

The editors evaluate the referee's suggestions coming from the field editor and the studies are submitted to the referees. Referees are obliged to guarantee that they will not share any process or document about the study they are evaluating.

4. Referee Evaluation Process

The period given to the referee for the evaluation process is 15 days. Proposals for corrections from referees or editors must be completed by the authors within 1 month according to the "correction instruction".

Referees can decide on the suitability of the study by reviewing the corrections and may also request multiple corrections if necessary.

Referee Reports

Referee evaluations are based in general on the originality of the studies, the method used, and the conformity with the ethical rules, the consistent presentation of the findings and results, and the examination of the literature.

This review is based on the following elements:

1. Introduction and Literature: The evaluation report contains the presentation and purpose of the problem addressed in the study, the importance of the topic, the scope of the relevant literature, the timeliness and the originality of the study.

2. Methodology: The evaluation report includes information on the suitability of the method used, the choice and characteristics of the research group, validity and reliability, as well as on the data collection and analysis process.

3. Findings: The evaluation report includes opinions on the presentation of the findings obtained in the frame of the method, the correctness of the analysis methods, the aims of the research and the consistency of the findings, the presentation of the required tables, figures and images and the conceptual evaluation of the tests used.

4. Evaluation and discussion: The evaluation report includes the opinion on the subject based on findings, relevance to research questions and hypotheses, generalizability and applicability.

5. Conclusion and suggestions: The evaluation report contains the opinion on the contributions to the literature, future studies and recommendations for the applications in the area.

6. Style and narration: The evaluation report includes compatibility of the headline with the content, appropriate use of English in the study, and references in accordance with the language of the study and APA rules.

7. Overall evaluation: The evaluation report contains opinion on the authenticity of the study as a whole, its contribution to the educational literature and the applications in the area.

The journal considers that scientists should avoid research which kills or damages any species of fish which, using IUCN criteria, is regarded as threatened or is listed as such in a Red Data Book appropriate for the geographic area concerned. In accordance with this view, papers based on such research will not be accepted by the Journal, unless the work had clear conservation objectives.

Plagiarism Detection

The editorial team and/or reviewers of the *Marine Science and Technology Bulletin* will check for plagiarism in all submitted articles prior to publication. If plagiarism is detected at any stage of the publication process, the author will be instructed to rewrite the manuscript. Every submission will be scanned by *iThenticate®* to prevent plagiarism. If any manuscript is 30% plagiarized, the article will be rejected and the author will be notified. We strongly recommend that authors check the paper's content before submitting it for publication. Plagiarism can also be checked by using free online software.

Proofs

Proof documents will be sent to the corresponding authors via online submission system. Proofs should be checked immediately and responses should be returned back within 15 working days. It is the responsibility of the authors to check carefully the proofs. No changes will be allowed at this stage.

DISCLAIMER

The publisher and editor or members of the editorial board are not responsible for the author's opinions and manuscript contents. Authors are responsible for the ethical originality of and possible errors in their manuscripts. They are also responsible for all errors based on page editing before their proofreading. On the other hand, errors taking place after proofreading are in the responsibility of the journal directors.

Note: The corresponding author should make corrections in 2 months, otherwise the paper will be rejected.

Note: The Editorial Board takes responsibility for making publication decisions on submitted manuscripts based on the reviewer's evaluation of the manuscript, policies of the journal editorial board, and legal efforts to prevent plagiarism, libel, and copyright infringement.

INDEXING

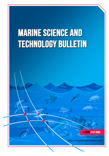
Marine Science and Technology Bulletin is indexed by "*Zoological Record (Web of Science Clarivate Analytics), TR Dizin (TÜBİTAK-ULAKBİM), EBSCO, CABI Direct, CAB Abstracts, Global Health (CABI), Nutrition and Food Sciences (CABI), Food Science and Technology Abstracts (FSTA; Web of Science Clarivate Analytics), FAO/AGRIS, Leisure Tourism (CABI), Directory of Open Access Journals (DOAJ), Scientific Literature (Scilit), ScienceGate, Index Copernicus, Directory of Research Journals Indexing (DRJI), CiteFactor, Eurasian Scientific Journal Index (ESJI), Scientific Journal Impact Factor (SJIF), COSMOS IMPACT FACTOR, Scientific Indexing Services (SIS), ASOS INDEX, General Impact Factor, International Innovative Journal of Impact Factor (IIJIF), Genamics JournalSeek, International Institute For Research Impact Factor Journals (IFJ), Academic Resource Index-ResearchBib, ACADEMIC JOURNAL INDEX (AJI), Bielefeld Academic Search Engine (BASE), International Institute of Organized Research (I2OR), AcademicKeys, Root Indexing, Journal Factor, International Citation Indexing (ICI), Paperity, Systematic Impact Factor, Journals Impact Factor (JIFACTOR), WorldCat, International Impact Factor Services (IIFS), EuroPub, Open Academic Journals Index (OAJI), Google Scholar*"

MARINE SCIENCE AND TECHNOLOGY BULLETIN 2023 • VOLUME 12 • ISSUE 3

TABLE OF CONTENTS

Mar. Sci. Tech. Bull. (2023) 12(3): 252-258
e–ISSN: 2147–9666
info@masteb.com

dergipark.org.tr/en/pub/masteb
www.masteb.com
DOI: 10.33714/masteb.1299692



Marine Science and Technology Bulletin

PRENSIP
https://prensip.gen.tr/

RESEARCH ARTICLE

A case study on the variable frequency drive for ship engine room ventilation

Omer Berkehan Inal[1*] • Gazi Koçak[1]

[1] *Istanbul Technical University, Maritime Faculty, Marine Engineering Department, Tuzla, Istanbul, Türkiye*

ARTICLE INFO

Article History:
Received: 25.05.2023
Received in revised form: 29.06.2023
Accepted: 23.07.2023
Available online: 28.09.2023

Keywords:
Ship energy efficiency
Variable frequency drive
Electric motors
Engine room ventilation

ABSTRACT

Increasing ship energy efficiency is essential to reducing fuel consumption and ship-based harmful emissions. In a ship's engine room, there are a lot of electric motors, and their energy consumption is remarkable. The effective operation of these electric motors becomes significant when taking into account ship energy efficiency with regard to the effects on the environment and climate change. The electrical, mechanical, and operational efficiencies of electric motors can be improved with a variable frequency drive. In order to improve the ship's overall energy efficiency, the electric motors used for engine room ventilation are examined in this paper using variable frequency drives for two different ambient temperatures. Energy consumption of the engine room ventilation fans is calculated and the change in the efficiency depending on the air temperature is analyzed. By using data from actual crude oil tanker ships, the outcomes are compared with those of the traditional system. The results indicate an energy consumption reduction of more than 80% is achievable by using VFD electric motors for engine room fans. The result corresponds to 153.279 kWh of energy instead of 613.116 kWh annually.

Please cite this paper as follows:

Inal, O. B., & Koçak, G. (2023). A case study on the variable frequency drive for ship engine room ventilation. *Marine Science and Technology Bulletin*, *12*(3), 252-258. https://doi.org/10.33714/masteb.1299692

Introduction

Maritime transportation is a vital component of global trade, accounting for approximately 90% of its share (Deniz & Zincir 2016; Inal & Deniz, 2020). The most important component of maritime trade is ships, which are powered by marine diesel engines. Therefore, considering its environmental effects, the amount of fossil fuel consumed becomes substantial. The maritime industry is facing increasing pressure of reducing ship-sourced harmful emissions, and enhance sustainability (IMO, 2020). From this perspective, energy efficiency plays a critical role for ships, and cannot be overstated with many benefits ranging from cost savings to sustainability. The International Maritime Organization (IMO), a United Nations agency responsible for the maritime industry, has implemented a series of rules and regulations aimed at addressing shipping emissions and promoting

* Corresponding author
E-mail address: inalo@itu.edu.tr (O. B. Inal)

increased energy efficiency in ships (IMO, 2021). For instance, the Energy Efficiency Design Index (EEDI) sets energy efficiency requirements for new ships, while the Ship Energy Efficiency Management Plan (SEEMP) encourages ship operators to implement energy-saving measures. Adhering to these regulations is essential for ships to maintain compliance and ensure access to ports worldwide. Ships are responsible for significant global greenhouse gas emissions and air pollutants (Dere & Deniz, 2019). By embracing energy-efficient practices, ships can minimize their carbon footprint, reduce harmful emissions, and contribute to the global fight against global warming and climate change. Energy-efficient practices can reduce emissions such as CO_2, SO_x, NO_x, or PM, helping meet international emission reduction targets and regulatory requirements (Inal, 2018; Inal & Deniz, 2021).

The energy efficiency of the ships can lead to many advantages, such as cost savings, environmental sustainability, fuel consumption reduction, and improved operational performance. Therefore, energy-efficient practices and technologies are essential for the maritime industry to move forward through the challenges of the future and achieve a more sustainable and efficient shipping sector. Electric motors are one the most important electricity consumers of ships, and they can play a critical role in improving the overall energy efficiency of ships (Schroer et al., 2022). Electric motors are used for propulsion purposes in almost all machinery systems on ships. On a ship, electric motors are utilized in the circulation of various fluids, including those that need to be generated, used, required, treated, or considered waste (such as centrifugal pumps, bilge separators, ballast systems, and sewage systems). They are also employed in the transfer of cargo (using centrifugal, gear, screw, or piston pumps), as well as in ventilation, heating, and cooling systems (such as air conditioning, refrigerators, and fans), and pumping systems. For instance, based on the examinations conducted on the Engine Room Simulator of Kongsberg MC-90v, the total load on the generators during the slow ahead condition of the main engine is 789.7 kW, of which 694.16 kW is attributed to electric motors. This means that electric motors account for 87.9% of the total load on the generator. Similarly, during the full ahead condition of the main engine, the total load on the generators is 802.24 kW, with electric motors constituting 674.68 kW of that load. This indicates that electric motors account for 84.1% of the generator's load. As a result, it can be understood that by achieving efficiency in electric motors, the fuel consumption of the generators can also be reduced.

VFD drives are substantial topics for more efficient air conditioning systems in the previous literature. Some of them are summarized as follows: Pérez-Lombard et al. (2011) analyzed the development of building energy codes concerning Heating, Ventilation and Air-Conditioning (HVAC) systems and concentrated on energy efficiency of HVAC systems of non- residential buildings. Awbi (2017) studied the air quality and energy efficiency of building mechanical ventilation and distribution systems and compares the traditional and some new type systems. SeppĘnen (2008) studied ventilation strategies for good air quality and energy efficiency and described several strategies such as control of air rates by air quality, efficient air distribution and local control of indoor climate. Sharapov et al. (2019) studied energy efficiency of mechanical ventilation systems based on microclimate parameter analysis. They propose to improve efficiency through heat recovery of ventilation emissions. Giama (2022) carried out a review study aiming to analyze ventilation technologies considering energy consumption and environmental issues using the life cycle approach focusing on the parameters related to the efficient technical design and sufficient maintenance of mechanical ventilation systems. Lönnberg (2007) studied energy savings in hospitals HVAC systems using variable speed drives and showed that the ventilation fan motor power factor at 40% flow of air dampers can be increased from 0.4 to 0.8. Tolvanen (2008) claim that the energy efficiency of pump and fan systems can be improved by 50% using variable speed drives and show the results of a case study for a food manufacturer which reached the annual saving of £30000 in electricity cost. Saidur et al. (2012) studied variable speed drives for increasing energy efficiency of electrical motors. They show the relation of speed reduction with potential energy saving and claim that the energy saving can be increased to 89% at 60% of speed reduction. One of the important conclusions of their study is that application of variable speed drives to HVAC systems provide excellent opportunities to reduce energy consumption.

In this paper, a case study has been conducted to examine the energy efficiency capacity that would result from operating the electric motor of fans used in ship engine room ventilation more efficiently with VFD (Variable Frequency Drive). By using data from actual two crude oil tanker ships, the outcomes are compared with those of the traditional system.

Lastly, the paper is organized as follows: the second section provides a review of VFD drivers, the third section presents the case study and discusses the results, and lastly, the final section concludes the paper by summarizing the findings and providing suggestions for future research.

VFD Drivers

Variable Frequency Drives (VFDs) play a crucial role in enhancing the performance and efficiency of electric motors

(Gritter et al., 2005; Kocak & Durmusoglu, 2017; Su et al., 2014). There are several important reasons of VFDs for electric motors:

- Energy Efficiency
- Soft Start and Smooth Operation
- Speed Control and Flexibility
- Improved Motor Protection
- Reduced Mechanical Stress and Wear
- Process Optimization and Control
- Energy Cost Savings

Energy Efficiency: By altering the frequency and voltage of the electricity supplied to the motor, VFDs provide precise control of motor speed and torque. VFDs reduce energy waste and maximize motor efficiency by adjusting motor speed to the actual load requirements. As a result, there is a significant reduction in energy consumption, operational expenses, and environmental impact.

Soft Start and Smooth Operation: VFDs give electric motors a soft start and smooth acceleration. VFDs progressively increase the voltage and frequency rather than starting at maximum speed and voltage, preventing unnecessary mechanical stress and wear on the motor and related equipment. This functionality is crucial for motors moving high loads or for situations where damage could be done by a sudden start.

Speed Control and Flexibility: With VFDs, the speed of electric motors can be easily adjusted within a wide range. This flexibility allows precise control of the motor operation to meet specific process requirements. Whether it's maintaining a constant speed, varying speeds for different tasks, or ramping up and down as needed, VFDs provide the ability to adapt motor performance to changing conditions.

Improved Motor Protection: VFDs offer advanced motor protection features. They monitor motor parameters such as current, voltage, and temperature, providing real-time feedback and allowing for quick response to any abnormalities. VFDs can detect issues like overload, phase loss, overvoltage, under voltage, and excessive heat, triggering protective actions to prevent motor damage and costly downtime.

Reduced Mechanical Stress and Wear: By controlling motor speed and torque, VFDs minimize mechanical stress on the motor and connected equipment. Belts, gears, couplings, and other mechanical components have a longer lifespan and require less maintenance because to the progressive acceleration and deceleration offered by VFDs.

Process Optimization and Control: With the help of VFDs, motor speed may be precisely controlled, allowing for process optimization and enhanced system performance. VFDs can adapt motor speed to the needed flow rate or load in applications like pumps, fans, and conveyors, maximizing system efficiency and maintaining stable performance even under changing circumstances.

Energy Cost Savings: In energy-intensive applications, VFDs can result in significant cost savings by improving motor efficiency and lowering energy usage. Energy is used effectively when motor speed can be adjusted based on demand, preventing wasteful energy use during periods of low load or idle operation.

Case Study and Analysis

As is known, ships are constantly in motion and continuously change their position. While changing their position, they also encounter different weather conditions, including different seawater temperatures and different air temperatures. However, regardless of the air temperature, the parameters of the machines on the ship always operate at the same values. Unfortunately, operators have not been able to fully utilize this situation to their advantage. If this situation is explained through a fan application, an ordinary electric motor will operate at the same speed, so the fan will operate at the same speed regardless of the temperature in the area where the ship is located. However, a fan with a VFD controlled electric motor, with a temperature sensor placed in the engine room, it will detect the ambient temperature and bring it to the temperature range determined by the manufacturer's software. If the temperature in the engine room increases due to various reasons (machines operating under heavy load, ambient temperature variation due to the sailing area, or work performed on the engines, etc.), the electric motor will start drawing more current and accelerate. When the temperature in the machinery space reaches the designated range in the software, the electric motor will start drawing less current, slow down, and attempt to maintain the environment at the same temperature. However, if the machinery space cools down due to various reasons (machines being shut down, transitioning to a port position, or sailing in a cold geography, etc.), there will be no need for the electric motor to operate at high power. Therefore, it will operate with much less current, at lower frequencies, and naturally consume much less power. In this analysis, crude oil tanker ship data is used to show the energy efficiency of the VFD drivers for engine room ventilation. Two different ambient temperatures are benchmarked for two different systems. The electric motor data is given in Table 1.

The pictures have been taken from onboard the ship which show the motor current and frequency at 35.9°C and at 30.2°C ambient temperatures are shown in Figure 1 and Figure 2, respectively. The left pictures at the figures shows the frequency of the electric motors of the ventilation that are 50 and 27 Hertz, respectively, while the right ones show the motor currents as 21.1 and 10.4 Amperes, respectively.

The case ship loads its cargo at the Hatay port within 2 days (48 hours), then takes a 2-day (48-hour) voyage in the Mediterranean Sea (Antalya Gulf) before reaching the Çanakkale Strait. After passing through the Çanakkale Strait, it continues its voyage for 12 hours and finally reaches the discharge port of Kocaeli, where it takes approximately 30 hours to discharge the cargo. Throughout this journey, the tanker is constantly in different positions for certain periods of time, either sailing or in loading/discharging status, and it is also affected by different sea water and air temperatures. The operation details according to duration are given in Table 2.

Table 1. Electric motor data for different conditions

Parameter	Value
Motor Power and Frequency	22 kW and 60 Hz
Daily Operation Time	24 hours
Motor Load without VFD at all temperature	100% Load and 22 kW
Motor Load with VFD at 35.9°C and 50 Hz	84% Load, 10.5 kW and 21.1 Amper
Motor Load with VFD at 30.2°C and 27 Hz	45% Load, 1.1 kW and 10.4 Amper

Figure 1. Electric motor frequency and current at 35.9°C ambient temperature

Figure 2. Electric motor frequency and current at 30.2°C ambient temperature

Table 2. Summary of operation profile of the case ship

Operation	Duration (hours)
Loading	48
Sailing	60
Before Çanakkale Strait Sailing	48
After Çanakkale Strait Sailing	12
Discharge	30
Total Operation	138

Table 3 resumes the results of the electric motor energy consumption with VFD and without VFD. Two columns are separated into 3 sub-columns by showing the voyage hours, motor loads, and energy consumptions. The electric motors are the same with a power of 22 kW. Energy consumption are calculated by the multiplication of operation time and power requirement.

If the values are compared, an electric motor without VFD continuously running at the same speed consumes 3036 kWh of energy throughout the journey, while an electric motor with VFD consumes only 603 kWh which means that more than 80% decrease in energy consumption, as shown in Figure 3. This indicates that if an operator decides to use VFD, they can save 2433 kWh of energy from just one electric motor in a single journey. Assuming this ship makes the same journey 63 times a year, it will save a total of 153.279 kWh of energy annually. In the mentioned case ship, there are a total of 4 fans, and all the motors read the temperature from the same sensor, so they operate at the same load. Therefore, a total savings of 613.116 kWh (153.279×4) can be achieved. Thus, it can be said that in today's technological conditions, the use of VFD in machinery space fans on ships has become not a luxury but a necessity. The fuel consumption of marine diesel generators onboard the ship is 205 g/kWh. According to the previously calculated energy deficit, approximately 125 tons less marine diesel oil will be consumed, yearly. Since the carbon factor of diesel fuel is 3.206, there is a 402 tons reduction in carbon dioxide emissions.

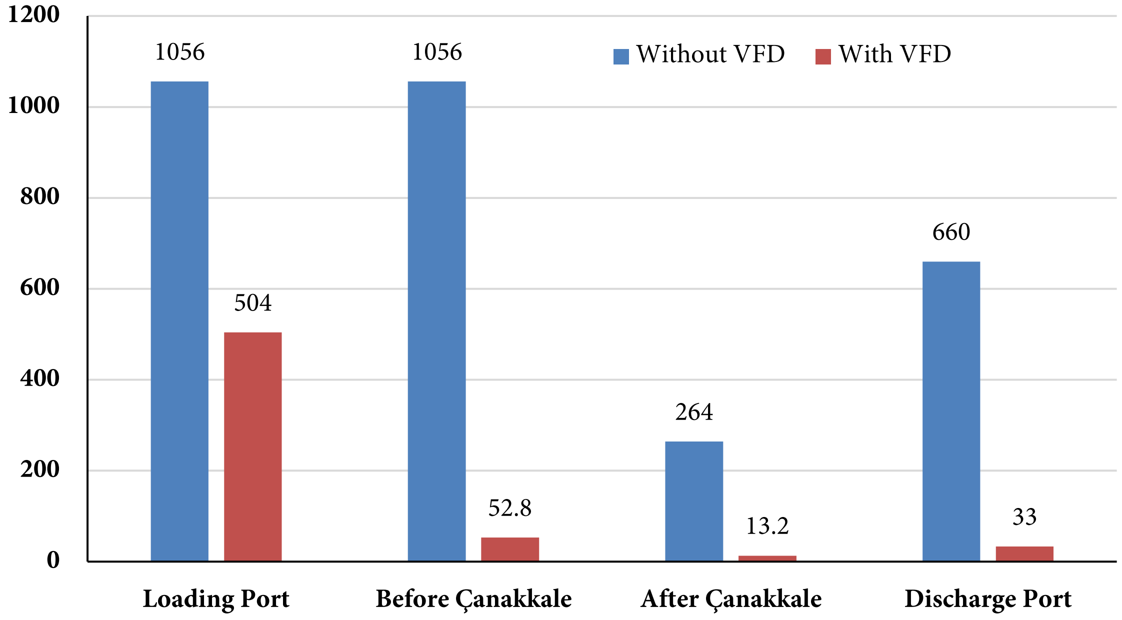


Figure 3. Ventilation fan energy consumption (kWh)

Table 3. 22 kW electric motor data with and without VFD

Ship's Position	Electric Motor without VFD			Electric Motor with VFD		
	Voyage (hours)	*Load (%)*	*Energy Consumption (kWh)*	*Voyage (hours)*	*Load (%)*	*Energy Consumption (kWh)*
At Loading Port	48	100	1056	48	84	504
Voyage through Çanakkale Strait	48	100	1056	48	45	52.8
Voyage after Çanakkale Strait	12	100	264	12	45	13.2
At Discharge Port	30	100	660	30	45	33
Total	138		3036	138		603

Conclusion

The use of Variable Frequency Drives in ships has emerged as a crucial solution to optimize energy efficiency and performance in marine operations. The continuous movement and changing environmental conditions experienced by ships necessitate the adaptation of machinery systems to varying loads and temperatures. Electric motors may vary their speed and power usage in response to the environment thanks to the sophisticated control mechanisms provided by VFDs, which result in significant energy savings.

Through the case study of a crude oil tanker, it becomes evident that the implementation of VFDs in machinery space fans yields significant energy conservation. The comparison between an electric motor without VFD and one equipped with VFD demonstrates a remarkable reduction in energy consumption during the ship's voyage. When extrapolated to a large-scale fleet, the annual energy savings achieved through VFD utilization exemplify the substantial positive impact on energy efficiency and environmental sustainability.

Moreover, the advantages of VFDs extend beyond energy efficiency. These systems provide enhanced control over engine operations, contributing to improved performance, reduced wear and tear, and increased lifespan of equipment. The ability to adjust motor speed and torque based on real-time conditions enables optimized operation, leading to enhanced reliability and operational safety. In light of these findings, it is evident that the integration of VFDs in ships' electrical systems has transitioned from being a luxury to a necessity. Ship operators and industry stakeholders should recognize the significant benefits of VFD technology and actively promote its adoption across the maritime sector. Government regulations and incentives can play a crucial role in encouraging the widespread implementation of VFDs, leading to a greener and more sustainable maritime industry.

Future studies should examine more VFD technology uses in different maritime systems and assess how they affect the overall performance of the vessel. The effectiveness and dependability of VFD-driven systems on ships can also be improved through the development of sophisticated control algorithms and preventative maintenance techniques. And last, the incorporation of VFDs into ships is a game-changing development in marine engineering, resulting in significant energy savings, enhanced functionality, and environmental sustainability. In the face of environmental difficulties and strict regulatory frameworks, embracing this technology is essential to address the growing need for efficient and environmentally friendly maritime transportation.

Acknowledgements

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Compliance With Ethical Standards

Authors' Contributions

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, and writing of the manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Data Availability Statement

All data generated or analysed during this study are included in this published article.

References

Awbi, H. B. (2017). Ventilation for good indoor air quality and energy efficiency. *Energy Procedia*, *112*, 277-286. https://doi.org/10.1016/j.egypro.2017.03.1098

Deniz, C., & Zincir, B. (2016). Environmental and economical assessment of alternative marine fuels. *Journal of Cleaner Production*, *113*, 438-449. https://doi.org/10.1016/j.jclepro.2015.11.089

Dere, C., & Deniz, C. (2019). Load optimization of central cooling system pumps of a container ship for the slow steaming conditions to enhance the energy efficiency. *Journal of Cleaner Production*, *222*, 206-217. https://doi.org/10.1016/j.jclepro.2019.03.030

Giama, E. (2022). Review on ventilation systems for building applications in terms of energy efficiency and environmental impact assessment. *Energies*, *15*(1), 98. https://doi.org/10.3390/en15010098

Gritter, D., Kalsi, S. S., & Henderson, N. (2005). Variable speed electric drive options for electric ships. *2005 IEEE Electric Ship Technologies Symposium*, *2005*, 347-354. https://doi.org/10.1109/ESTS.2005.1524699

IMO. (2020). Fourth IMO GHG Study 2020.

IMO. (2021). IMO Data Collection System. https://www.imo.org/en/ourwork/environment/pollutionprevention/airpollution/pages/datacollection-system.aspx

Inal, O. B., & Deniz, C. (2020). Assessment of fuel cell types for ships: based on multi-criteria decision analysis. *Journal of Cleaner Production*, *265*, 121734. https://doi.org/10.1016/j.jclepro.2020.121734

Inal, O. B., & Deniz, C. (2021). Emission analysis of LNG fuelled molten carbonate fuel cell system for a chemical tanker ship: A case study. *Marine Science and Technology Bulletin*, *10*(2), 118-133. https://doi.org/10.33714/masteb.827195

Inal, O. B. (2018). Analysis of the availability and applicability of fuel cell as a main power unit for a commercial ship. [MSc. Thesis. Istanbul Technical University].

Kocak, G., & Durmusoglu, Y. (2017). Energy efficiency analysis of a ship's central cooling system using variable speed pump. *Journal of Marine Engineering & Technology*, *17*(1), 43-51. https://doi.org/10.1080/20464177.2017.1283192

Lönnberg, M. (2007). Variable speed drives for energy savings in hospitals. *World Pumps*, *2007*(494), 20-24. https://doi.org/10.1016/S0262-1762(07)70395-4

Pérez-Lombard, L., Ortiz, J., Coronel, J. F., & Maestre, I. R. (2011). A review of HVAC systems requirements in building energy regulations. *Energy and Buildings*, *43*(2-3), 255-268. https://doi.org/10.1016/j.enbuild.2010.10.025

Saidur, R., Mekhilef, S., Ali, M. B., Safari, A., & Mohammed, H. A. (2012). Applications of variable speed drive (VSD) in electrical motors energy savings. *Renewable and Sustainable Energy Reviews*, *16*(1), 543-550. https://doi.org/10.1016/j.rser.2011.08.020

Schroer, M., Panagakos, G., & Barfod, M. B. (2022). An evidence-based assessment of IMO's short-term measures for decarbonizing container shipping. *Journal of Cleaner Production*, *363*, 132441. https://doi.org/10.1016/j.jclepro.2022.132441

SeppĘnen, O. (2008). Ventilation strategies for good indoor air quality and energy efficiency. *International Journal of Ventilation*, *6*(4), 297-306. https://doi.org/10.1080/14733315.2008.11683785

Sharapov, A. I., Myakotina, E. Y., Shatskikh, Y. V., & Peshkova, A. V. (2019). Increase of energy efficiency of the mechanical ventilation system. *IOP Conference Series: Earth and Environmental Science*, *272*(2), 022218. https://doi.org/10.1088/1755-1315/272/2/022218

Su, C. L., Chung, W. L., & Yu, K. T. (2014). An energy-savings evaluation method for variable-frequency-drive applications on ship central cooling systems. *IEEE Transactions on Industry Applications*, *50*(2), 1286-1294. https://doi.org/10.1109/TIA.2013.2271991

Tolvanen, J. (2008). Saving energy with variable speed drives. *World Pumps*, *2008*(501), 32-33. https://doi.org/10.1016/S0262-1762(08)70164-0

Mar. Sci. Tech. Bull. (2023) 12(3): 259-266
e–ISSN: 2147–9666
info@masteb.com

dergipark.org.tr/en/pub/masteb
www.masteb.com
DOI: 10.33714/masteb.1289022

Marine Science and Technology Bulletin

PRENSIP
https://prensip.gen.tr/

RESEARCH ARTICLE

Distribution of *Trachinocephalus trachinus* (Temminck & Schlegel, 1846) (Pisces: Aulopiformes: Synodontidae) along the Arabian Sea and Bay of Bengal coasts of India

Silpa Susanthi[1] • Shashi Bhushan[1] • Annam Pavan Kumar[1] • Anil Mohapatra[2] • Ashok Kumar Jaiswar[1*]

[1] *ICAR- Central Institute of Fisheries Education, Panch marg, Off Yari Road, Mumbai- 400 061, India*
[2] *Estuarine Biology Regional Centre, Zoological Survey of India (ZSI), Gopalpur-on-Sea, Ganjam, Odisha-76100, India*

ARTICLE INFO

Article History:
Received: 25.05.2023
Received in revised form: 26.07.2023
Accepted: 31.07.2023
Available online: 28.09.2023

Keywords:
Synodontidae
Lizardfish
Trachinocephalus myops
Indian coast
DNA barcoding

ABSTRACT

The genus *Trachinocephalus* (Aulopiformes: Synodontidae) was considered to be monotypic and nearly circumtropical in distribution, with single species, *Trachinocephalus myops* (Forster 1801). However, a revision indicated presence of at least three species under the genus – the Atlantic *T. myops*, the Indo-Pacific *T. trachinus*, a new species *T. gauguini* and later again a new species *T. atrisignis* added from Western Indian Ocean. Even though, two species are known from Indian Ocean, the species found in India is still being misidentified as *T. myops.* Thus, to confirm the species inhabiting in Indian waters, the samples were collected from multiple locations along the west (Arabian Sea) and east (Bay of Bengal) coasts of India. The recorded morpho-meristic characters were found to be substantially overlapping between *T. myops* and *T. trachinus.* Further, molecular analysis based on COI gene of mitochondrial DNA confirms the presence of more than four species in the world and the species distributed along the Indian coast as *T. trachinus.* The genetic distance estimated between *T. trachinus* and *T. myops* was found to be 16.9%, which is sufficient to separate the two species. Though, massive genetic divergence was observed, the species exhibited phenotypic stasis that can be the reason for misidentification. In recognition of the critical role of correct taxonomic identification in species conservation and management, an integrated taxonomic study was carried out on *Trachinocephalus* genus along the Indian coast.

Please cite this paper as follows:

Susanthi, S., Bhushan, S., Pavan Kumar, A., Mohapatra, A., & Jaiswar, A. K. (2023). Distribution of *Trachinocephalus trachinus* (Temminck & Schlegel, 1846) (Pisces: Aulopiformes: Synodontidae) along the Arabian Sea and Bay of Bengal coasts of India. *Marine Science and Technology Bulletin*, *12*(3), 259-266. https://doi.org/10.33714/masteb.1289022

* Corresponding author
E-mail address: akjaiswar@cife.edu.in (A. K. Jaiswar)

Introduction

The species of the family Synodontidae (order: Aulopiformes), collectively called lizardfishes, form important demersal fishery resources in tropical and subtropical regions of the world (Najmudeen & Zacharia, 2015). Lizardfishes are marine and bottom-living species, predominantly inhabiting shallow waters. These small to medium-sized fishes are voracious carnivores, with most of them having mottled patterns to mimic their surroundings for protection from predators (Norman, 1935). This group of fishes was considered as bycatch in shrimp trawlers, but now, they are one of the major contributors in the demersal finfish category in India (Zacharia et al., 2019) due to their nutritive value, surimi grade flesh and growing consumer acceptance (Sivakami et al., 2003).

The family is represented by 71 species (Russell, 2022) in four genera across the globe, namely *Harpadon* Lesueur, 1825; *Saurida* Valenciennes, 1850; *Synodus* Scopoli, 1777 and *Trachinocephalus* Gill, 1861. *Trachinocephalus* is distinguished from other genera by a blunt head with a relatively short snout, 8 pelvic rays and a longer anal fin base (with 14 or more rays) than the dorsal fin base (Anderson et al., 1966). It was considered to be a monotypic genus with a single species, *Trachinocephalus myops*, with circumtropical distribution (Briggs, 1960). As a result, all the species identified under the genus were assigned the name *T. myops* without any detailed taxonomic analysis.

Genus *Trachinocephalus* is not commonly targeted in substantial commercial fisheries as it is generally not considered a highly prized food fish, except in Southeast Asia (Kizhakudan & Gomathy, 2007). It primarily inhabits sandy bottoms, with its distribution ranging from the littoral zone to depths of at least 100 meters (Fischer & Bianchi, 1984). Additionally, it can be found in muddy bottoms of bays and coastal waters (Fischer & Whitehead, 1974). According to Harper et al. (2022), *Trachinocephalus* exhibits a distinctive behaviour of burying itself in the sand, leaving only its eyes exposed. This burrowing behaviour is likely an adaptive strategy to conceal itself from potential predators.

However, a recent molecular and morphological study on the specimens of *T. myops* from different parts of the world confirmed the presence of at least three species in this group (Polanco et al., 2016) viz; *T. myops* (Forster, 1801) (type species) with restricted distribution to the Atlantic Ocean, resurrected *T. trachinus* (Temminck & Schlegel, 1846*) as* the valid name for the Indo-West Pacific Ocean species and *T. gauguini* Polanco, Acero & Betancur, 2016, a new species endemic to the Marquesas Archipelago. Further, a new species *T. atrisignis* Prokofiev, 2019 was described by Prokofiev (2019) from the Western Indian Ocean near Socotra Island, which differed from other representatives of the genus by a saturated black spot on the dorsal fin tip, making the number of known species to 4 under genus *Trachinocephalus.*

The present study aims to address the lack of a detailed taxonomic evaluation of the genus *Trachinocephalus* in Indian waters. The primary goal is to identify and confirm the species of *Trachinocephalus* that are found along the Indian coast (Arabian Sea and Bay of Bengal). To achieve this, the study has employed an integrated approach, which involves a combination of morphological and molecular methods.

Material and Methods

A total of 74 individuals of *Trachinocephalus* sp. were collected from eight locations along the Indian coast during January–April 2022. On the west coast (Arabian Sea), the samples were collected from Neendakara (*n*=10) [8°56'11.76" N & 76°32'13.92" E], and Kalamukku harbours (*n*=7) [9°59'0.96" N & 76°14'32.28" E] in Kerala, Dhakke fishing harbour in Karnataka (*n*=20) [12°51'15.84" N & 74°49'59.88" E], and Panjim fishing harbour in Goa (*n*=5) [15°24'48.96" N & 73°47'44.16" E]. On the east coast (Bay of Bengal), the samples were collected from Tuticorin (*n*=11) [8°45'22.68" N & 78°10'44.76" E] and Kasimedu (n=7) [13°7'35.04" N & 80°17'42.72" E] fishing harbours in Tamil Nadu, Visakhapatnam fishing harbour (*n*=6) [17°41'8.16" N & 83°13'6.6" E] in Andhra Pradesh and Arjipalli fishing harbour (*n*=8) [19°10'52.68" N & 84°34'30.72" E] in Odisha (Figure 1).

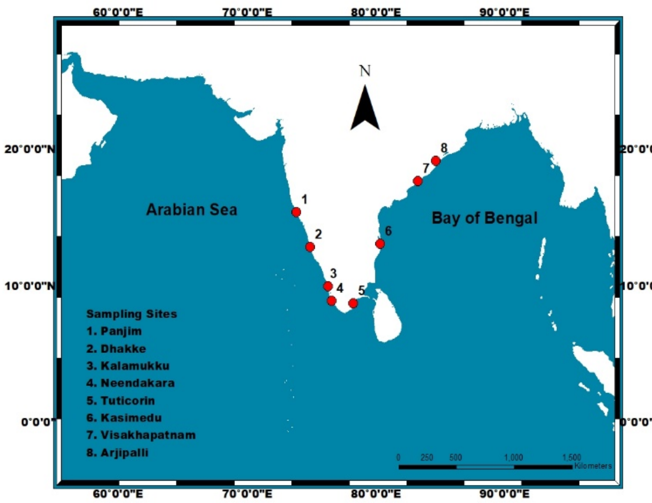


Figure 1. Sampling locations

The specimens were captured by commercial bottom trawls, operated at 150-200m depth range. The specimens were kept in ice and transported to the laboratory in an insulated box. The morphometric characters were measured using a digital Vernier Calliper to the nearest 0.1 mm following Polanco et al.

(2016), followed by counting the meristic traits. Abbreviations used throughout the text include HL (head length) and SL (standard length). Morphometric traits were expressed in percentage of standard length (for body measurements) or percentage of head length (for head measurements).

The total genomic DNA was isolated from muscle tissue following the protocol provided by Sambrook & Russell (2006) with some modifications. The partial mitochondrial cytochrome *c* oxidase subunit I (COI) region was amplified using the reported primers (FishF1 and FishR1) (Ward et al., 2005). The PCR was carried out in a 50 µL reaction 2 µL of 100 ng/ µL of template DNA, 5 µL 10X Taq buffer containing 1.5 mM $MgCl_2$, 1 µL dNTPs (10 Mm), 2 µL forward (10 pmol) and reverse (10 pmol) primers each, 0.5 µL Taq DNA polymerase (5 U/µL) and 37.5 µL of nuclease free water. The thermocycling profile for the reaction was set as initial denaturation at 95°C for 5 minutes, followed by 40 cycles of denaturation at 95°C for 30 seconds, annealing at 54°C for 30 seconds and extension at 72°C for 60 s, with a final extension at 72°C for 10 minutes.

The amplicons were purified and sequenced in both directions using the primers (Agri genome, Kochi). The Phred quality score of each nucleotide was assessed using FinchTV software to ensure the quality of sequences. The sequences' open reading frame (ORF) was predicted using the NCBI ORF finder tool, and the sequences were submitted to the NCBI with accession numbers OQ629671-76.

An additional dataset was prepared for species delimitation by downloading the reported COI sequences of all species of *Trachinocephalus* from the NCBI GenBank. The present study and reported sequences were aligned using the Clustal W programme implemented in the MEGA11 software (Tamura et al., 2021). The pairwise genetic distance values were estimated using the Kimura-2-parameter model using MEGA11. Species delimitation analyses was carried out using Assemble Species by Automatic Partitioning (ASAP) (Puillandre et al., 2021), Poisson Tree Processes (PTP) model and General Mixed Yule Coalescent (GYMC) models using online tools (https://species.h-its.org/ptp/). A neighbour-joining tree was constructed with 100 pseudo replications using MEGA11 software.

Results

During the present study, 74 specimens ranging in size from 99.3-224.8 mm SL (mean: 156.5) were examined for morphological characters. The examined specimens are deposited at the Aquatic Biodiversity Museum and Repository, ICAR-CIFE, Mumbai, India under registration number CF1KA0152. The observed diagnostic characters are described below.

Diagnostic Characters

Body moderately elongated and cylindrical. Head not depressed, with head length 3·1–4·0 times in SL; snout short and blunt, shorter than eye diameter. Eyes placed forward nearer to the anterior end of the upper jaw. Mouth strongly oblique with toothed tongue and closely set teeth, organized in rows. A single row of teeth on upper jaw, visible even when mouth closed. The origin of dorsal fin base slightly nearer to the snout than the origin of the adipose fin. Origin of pelvic fin placed before the tip of pectoral and extend beyond the dorsal fin base. Pelvic fin rays sub-equal, with internal rays longer than external ones. Anal fin base much longer than the dorsal fin base. Proportional measurements of the species are provided in Table 1.

Meristic counts varied, dorsal fin with 11-14 (12) rays, pectoral fin 11-13 (12) rays, anal fin 13-17(16) rays, lateral line 54-58 (56) scales and pre-dorsal 15-18 (16) scales. These counts were found to be overlapping with *T. myops* (Table 2).

Colour

A large dark oval blotch on upper corner of operculum in fresh specimens. Trunk with yellow and blue intercalated longitudinal stripes, belly whitish to pale yellow. Pectoral, caudal and distal part of anal fin dark yellow; proximal part of anal fin pale, dorsal fin with alternating yellow stripes, pelvic fin with an oblique yellow stripe when stretched (Figure 2a). The formalin-preserved specimens look pale in colour (Figure 2b).

Figure 2. Images of *Trachinocephalus trachinus* (a) fresh specimen collected from Visakhapatnam fishing in Andhra Pradesh; SL 213 mm and (b) Formalin preserved collected from Kasimedu fishing harbours in Tamil Nadu, SL 152 mm

Table 1. Morphometric characters of *T. trachinus* compared with previous studies

Authors	**Present study**		**Palanco et al. (2016)**		**Palanco et al. (2016)**	
Species	*T. trachinus*		*T. trachinus*		*T. myops*	
Sample Size	n=74		n=66		n=53	
Morphometric data	**Range**	**Mean ± SD**	**Range**	**Mean ± SD**	**Range**	**Mean ± SD**
Standard length(mm)	99.3-224.8	156.5	65·3–228	137·1	34·8–242	141·3
Depth	15.70-21.88	18.37 ±1.35	10·4–20·7	17·5 ±1·8	12·8–21·7	17·4±2·0
Head length	24.65-32.36	28.21 ±1.42	25·2–31·8	29·1±1·4	24·7–31·3	28·8± 1·2
Snout length	6.30-13.97	8.79 ±1.69	8·9–14·7	12·3±1·3	8·7–14·8	12·1±1·4
Eye diameter	9.06- 21.10	14.06 ±2.18	11·0–22·6	16·6 ±2·1	10·8–21·7	15·7±2·5
Pre-Pelvic length	29.43-36.77	32.60 ±1.66	28·4–35·9	33·0 ±1·7	30·5–40·0	34·5±1·8
Pre-dorsal length	39.05-43.47	40.85 ±1.17	37·4–43·5	40·2±1·5	37·7–45·1	40·8±1·3
Pre-adipose length	80.78-86.75	83.65 ±1.21	-	-	-	-
Pre-anal length	62.53-69.96	67.26 ±1.55	61·4–70·2	65·0 ±2·0	62·6–70·5	66·2±1·9
Dorsal-adipose length	41.07-46.51	43.44 ±1.06	40·3–46·4	42·6±1·4	40·2–46·7	42·5±1·4
Dorsal height	15.78-20.97	18.18 ±1.34	15·8–26·2	19·7 ±1·7	14·1–23·9	18·7±2·4
Pectoral length	9.85-15.40	13.14 ±1.07	10·2–14·0	12·0±0·9	10·5–14·0	11·8±0·8
Pelvic length	21.13-31.21	26.83 ±1.90	22·2–29·3	25·8±1·5	22·3–30·4	25·7±1·4
Dorsal base	15.27-19.29	17.63 ±0.96	15·0–18·7	16·9±0·8	13·8–19·3	16·2±1·3
Anal base	19.22-26.78	23.85 ±1.58	20·6–26·8	24·3±1·4	21·1–27·6	23·8±1·5

Table 2. Meristic data of specimens examined in this study. Data from Polanco et al. (2016) is included for comparison

Authors	**Present study**		**Palanco et al. (2016)**		**Palanco et al. (2016)**	
Species	*T. trachinus*		*T. trachinus*		*T. myops*	
Sample Size	n=74		n=75		n=55	
Meristic data	**Mode**	**Range**	**Mode**	**Range**	**Mode**	**Range**
Dorsal fin rays	12	11-14	12, 13	11-14	12	11-14
Pectoral fin rays	12	11-13	12	11-13	12	11-13
Anal fin rays	16	13-17	16	13-18	15	13-16
Lateral line scales	56	54-58	56, 57	53-58	57	54-60
Pre-dorsal scales	16	15-18	16	14-20	17	15-20

Table 3. Genetic distance values of *Trachinocephalus* species

	Clade 1	**Clade 2**	**Clade3**	**Clade 4**	**Clade 5**	**Clade 6**
Clade 1	0.8					
Clade 2	3.5	0.4				
Clade 3	16.6	17.5	0.4			
Clade 4	16.4	16.7	19.8	0.1		
Clade 5	19.5	19.2	18.6	18.0	10.9*	
Clade 6	16.9	17.0	18.3	18.1	10.8	1.4

Amplification of the mitochondrial COI gene resulted in 650 bp amplicon, and sequencing revealed 600 bases. The poor-quality bases (Q<30) were trimmed using FinchTV software to get the final sequence length of 550 bases. The predicted continuous ORF showed a lack of stop codons, insertions and deletions. Species delimitation analysis using the combined dataset (present & reported study) revealed a neighbour-joining tree with six distinct clades (Figure 3). The present study species clustered in clade-1 along with *T. trachinus,* reported from the Gulf of Oman (OQ199052); sequences named *T. myops,* deposited from the west Indo-Pacific region (Figure 3).

The pair-wise genetic distance values among the clades are more than 3%, suggesting the occurrence of six species (Table 3). The Assemble species by automatic Partitioning (ASAP) analysis also showed the presence of six species (operational taxonomic units) with the lowest asap score of 2.50 (the lower the score, the better the partition). The histogram of the genetic distance value shows the discontinuous distribution ranging from 0 to 0.18 (18%) (Figure 4).

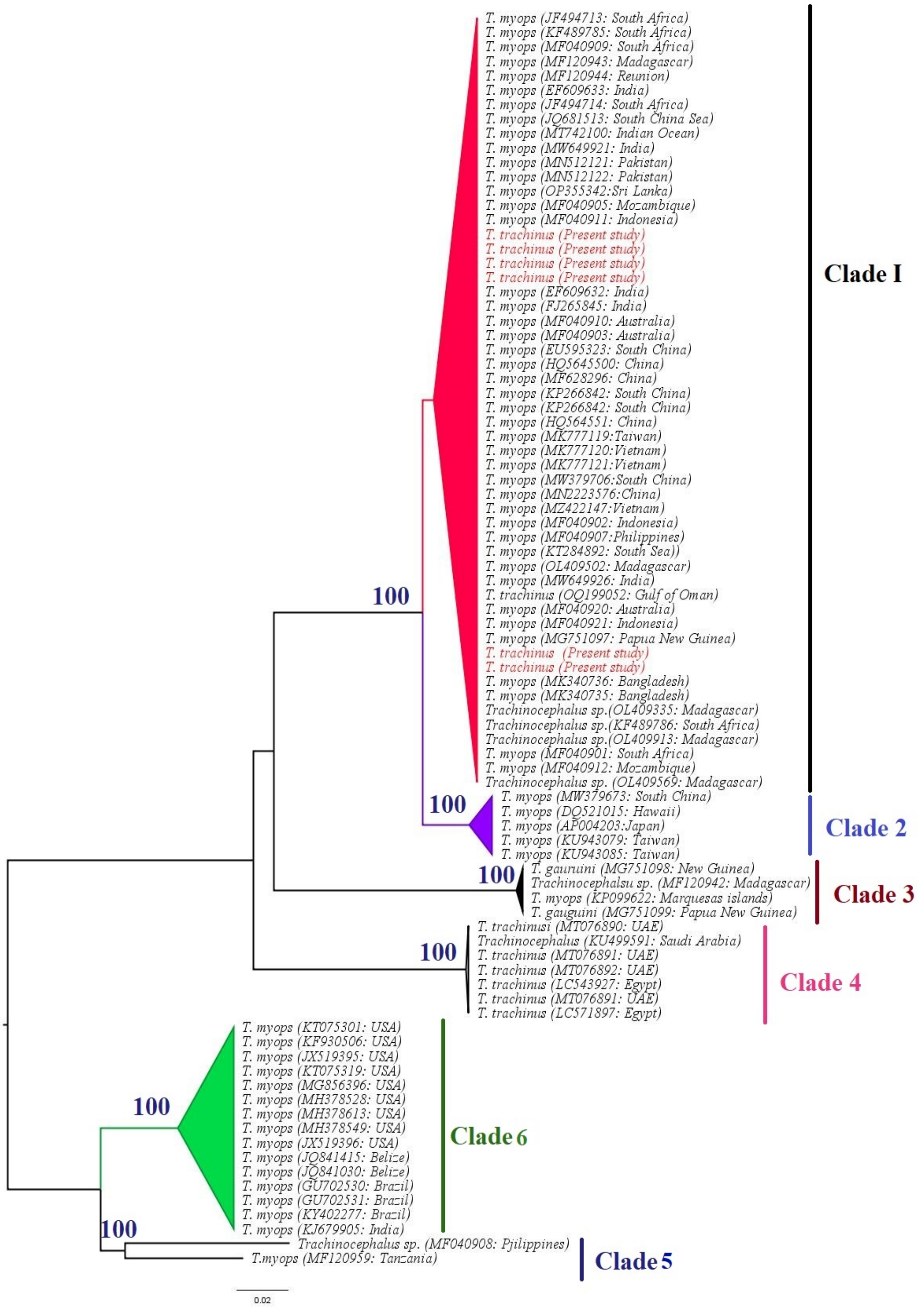


Figure 3. Neighbour-joining tree of the genus *Trachinocephalus* constructed using the COI gene. The values above the nodes represent the bootstrap values

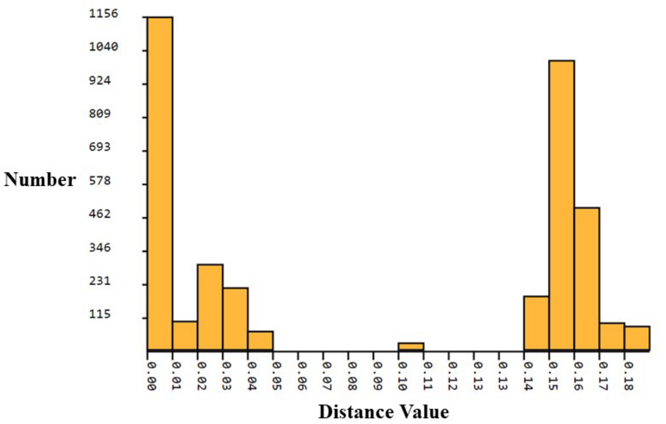


Figure 4. Histogram of pairwise K2P distances between species of *Trachinocephalus*. The horizontal axis shows the pairwise K2P distance, the vertical axis shows the number of pairwise sequence comparisons

Discussion

Taxonomic evaluation during the present study, confirms that the *Trachinocephalus* species inhabiting the Indian waters is *T. trachinus,* which was earlier misidentified as *T. myops* due to morphological similarities. *T. trachinus* was reported from Myanmar waters (Psomadakis et al., 2019) and Iranian waters of the Gulf of Oman (Alavi-Yeganeh & Bozorgchenani, 2023) which was also earlier misidentified as *T. myops***.**

At present, there are four reported species under the genus in the world. *T. trachinus* lack a saturated black spot on the dorsal when compared to *T. atrisignis, while T. gauguini* has reduced snout and broader dark blotch beneath the eye to distinguish from *T. trachinus* (Wang et al., 2018). Most of the morphometric and meristic data show substantial overlap between *T. myops* and *T. trachinus* (Tables 1 & 2). Few meristic characters which showed differences between the species are the modal value of anal fin rays 16 (*vs* 15), lateral line scales 56 (*vs* 57) and pre-dorsal scales 16 (*vs* 17). The colour patterns of the body can also be used to differentiate *T. myops* and *T. trachinus* in fresh condition. Both the species have alternating yellow and bluish stripes on the body, but there are brown rings running on transverse section only on the trunk of *T. myops.*

The results from the species delimitation analysis indicate the occurrence of more than four species with a considerable amount of genetic divergence. This observation is in congruence with the previous study by Polanco et al. (2016). Hebert et al. (2003) reported that a genetic distance value of more than 3% between the sequences could indicate distinct species. In the present study, the genetic distance values among the clades are more than 3%, confirming the occurrence of different species. The sequences named *T. trachinus* in Clade 4 could be a different species, and this observation warrants further study on this group. Accordingly, the genetic distance value between Clade 1 and 4 is more than 3%, i.e., 16.5%. Thus, the sequences/species clustered in the 'Clade-1' can be considered *T. trachinus,* as it includes the sequences from present study and the reported sequence of *T. trachinus* from the Gulf of Oman. Recently, Alavi-Yaganeh & Bozorgchenani (2023) reported the species of *Trachinocephalus* available in the Gulf of Oman as *T. trachinus* using the barcoding approach.

Briggs (1960) included *T. myops* in his checklist of circumglobally/ nearly circumglobally distributed species, as one of the several shore species that is well established in the warm waters of all oceans (except the eastern Pacific Ocean due to the eastern Pacific barrier that obstruct the cosmopolitan distribution of species). But many of such species were later found to split into multiple species like striped mullet *Mugil cephalus* (Rocha-Olivares et al., 2000), crevalle jack *Caranx hippos* (Smith-Vaniz & Carpenter, 2007), crestfish *Lophotus capellei* (Craig et al., 2004). These reports show that identification of widespread (circumtropical) species has been misled by morphological conservatism, cryptic species and taxonomic complexes.

Many recent studies revealed higher species diversity when molecular tools are employed compared to relying only on morphological characters for species identification (Coates et al., 2018). Struck & Cerca De Oliveira (2019) reported that utilization of genetic tools amplifies the description of cryptic species, a terminology used to refer a taxon that cannot be identified morphologically, yet evidence indicates that they are on different evolutionary tracts. In short, cryptic species are species with shallow morphological differences and considerable genetic distance (Struck et al., 2018). Utilization of molecular tools in taxonomic studies in genus *Trachinocephalus* has shown extremely conservative morphologic traits with deep genetic divergence between species.

Morphological conservatism in related species results in incongruent taxonomic identification. Phenotypic stasis and massive genetic divergence like that found in the present study was also observed in a tropical fish *Pantodon buchholzi* (African freshwater butterflyfish) by Lavoué et al. (2011). Neves et al. (2020) reported extreme morphologic conservatism with wide distributions and high genetic divergence in cryptic *Mugil* species. The negligible morphological differentiation and an accelerated rate of evolution in the mitochondrial genome of *Trachinocephalus* demands detailed study for better understanding of extrinsic and intrinsic constraints on phenotypic evolution. At the same time, presence of more than four species in the species delineation analysis demands for a comprehensive taxonomic study of the genus *Trachinocephalus.*

Acknowledgements

The authors are grateful to Dr. Ravishankar C.N – the Director, ICAR-CIFE, Mumbai, for providing vital facilities and continuous assistance throughout the study. Special appreciation is also owed to Dr. Md Sadegh Alavi-Yeganeh from Tarbiat Modares University, Iran, for sharing the sequence from his research, as well as to Dr. Akhilesh K.V. from Calicut Regional Station of ICAR-CMFRI, for his helping hand in sample collection.

Compliance With Ethical Standards

Authors' Contributions

SS: Sample collection, Data collection and analysis, and Manuscript preparation
SB: Sample collection and data analysis
APK: Molecular analysis
AM: Sample collection
AKJ: Overall Guidance and correction of manuscript
All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Data Availability Statement

All data generated or analysed during this study are included in this published article.

References

Alavi-Yeganeh, M. S., & Bozorgchenani, A. (2023). DNA barcoding confirms the bluntnose lizardfish, *Trachinocephalus trachinus* (Temminck and Schlegel 1846) (Aulopiformes: Synodontidae), in the Iranian waters of the Gulf of Oman and the existence of cryptic species within *Trachinocephalus*. *Thalassas: An International Journal of Marine Sciences*, *2023*, 1-5. https://doi.org/10.1007/s41208-023-00530-z

Anderson, W. W., Gehringer, J. W., & Berry, F. H. (1966). *Field guide to the Synodontidae (lizardfishes) of the western Atlantic Ocean* (Vol. 245). US Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries.

Briggs, J. C. (1960). Fishes of worldwide (circumtropical) distribution. *Copeia*, *1960*(3), 171-180. https://doi.org/10.2307/1439652

Coates, D. J., Byrne, M., & Moritz, C. (2018). Genetic diversity and conservation units: dealing with the species-population continuum in the age of genomics. *Frontiers in Ecology and Evolution*, *6*, 165. https://doi.org/10.3389/fevo.2018.00165

Craig, M. T., Hastings, P. A., & Pondella, D. J. (2004). Notes on the systematics of the Crestfish genus *Lophotus* (Lampridiformes: Lophotidae), with a new record from California. *Bulletin of the Southern California Academy of Sciences*, *103*(2), 57-65.

Fischer, W., & Bianchi, G. (1984). FAO species identification sheets for fishery purposes: Western Indian Ocean (Fishing Area 51) vol. 4.

Fischer, W. & P. J. P. Whitehead. (1974). FAO species identification sheets for fishery purposes. Eastern Indian Ocean (fishing area 57) and Western Central Pacific (fishing area 71). Vol. 4.

Harper, L. M., Lefcheck, J. S., Whippo, R., Jones, M. S., Foltz, Z., & Duffy, J. E. (2022). Blinded by the bright: How species-poor habitats contribute to regional biodiversity across a tropical seascape. *Diversity and Distributions*, *28*(11), 2272-2285.

Hebert, P. D., Cywinska, A., Ball, S. L., & DeWaard, J. R. (2003). Biological identifications through DNA barcodes. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *270*(1512), 313-321. https://doi.org/10.1098/rspb.2002.2218

Kizhakudan, S. J., & Gomathy, S. (2007). Unusual landings of the bluntnose lizardfish *Trachinocephalus myops* (Forster, 1801) at Chennai, with a note on some aspects of biology. *Journal of the Marine Biological Association of India*, *49*(2), 250-253.

Lavoué, S., Miya, M., Arnegard, M. E., McIntyre, P. B., Mamonekene, V., & Nishida, M. (2011). Remarkable morphological stasis in an extant vertebrate despite tens of millions of years of divergence. *Proceedings of the Royal Society B: Biological Sciences*, *278*(1708), 1003-1008. https://doi.org/10.1098/rspb.2010.1639

Najmudeen, T. M., & Zacharia, P. U. (2015). Classification of exploited demersal finfishes of India: Pig face breams, lizardfishes and eels. *Summer School on Recent Advances in Marine Biodiversity Conservation and Management, Central Marine Fisheries Research Institute*, 142-152.

Neves, J. M., Almeida, J. P., Sturaro, M. J., Fabre, N. N., Pereira, R. J., & Mott, T. (2020). Deep genetic divergence and paraphyly in cryptic species of *Mugil* fishes (Actinopterygii: Mugilidae). *Systematics and biodiversity*, *18*(2), 116-128. https://doi.org/10.1080/14772000.2020.1729892

Norman, J. R. (1935). 4. A revision of the lizard-fishes of the Genera *Synodus*, *Trachinocephalus*, and *Saurida*. *Proceedings of the Zoological Society of London*, *105*(1), 99-136. https://doi.org/10.1111/j.1469-7998.1935.tb06233.x

Polanco, F, A., Acero, P, A., & Betancur-R, R. (2016). No longer a circumtropical species: revision of the lizardfishes in the *Trachinocephalus myops* species complex, with description of a new species from the Marquesas Islands. *Journal of Fish Biology*, *89*(2), 1302-1323. https://doi.org/10.1111/jfb.13038

Prokofiev, A. M. (2019). A new species of lizardfishes of Genus *Trachinocephalus* from the Western Indian Ocean (Synodidae). *Journal of Ichthyology*, *59*(3), 414-417. https://doi.org/10.1134/S0032945219030159

Psomadakis, P. N., Thein, H., Russell, B. C., & Tun, M. T. (2019). Field identification guide to the living marine resources of Myanmar. *FAO species identification guide for fishery purposes. Food and Agriculture Organization of the United Nation, Rome, FAO and MOALI.*

Puillandre, N., Brouillet, S., & Achaz, G. (2021). ASAP: Assemble species by automatic partitioning. *Molecular Ecology Resources*, *21*(2), 609-620. https://doi.org/10.1111/1755-0998.13281

Rocha-Olivares, A., Garber, N. M., & Stuck, K. C. (2000). High genetic diversity, large inter-oceanic divergence and historical demography of the Striped Mullet. *Journal of Fish Biology*, *57*(5), 1134-1149. https://doi.org/10.1111/j.1095-8649.2000.tb00476.x

Russell, B. C. (2022) Family Synodontidae, Lizardfishes. In P. C. Heemstra et al. 2022 (Eds.), *Coastal fishes of the western Indian Ocean. Volume 2* (pp. 209-221, pls. 31-34).

Sambrook, J., & Russell, D. W. (2006). Purification of nucleic acids by extraction with phenol: chloroform. *Cold Spring Harbor Protocols*, *2006*(1), pdb.prot4455. https://doi.org/10.1101/pdb.prot4455

Sivakami, S., Vivekanandan, E., Raje, S. G., & Kizhakudan, S. J. (2003). Lizardfishes, pomfrets and bullseye, In M. M. Joseph & A. A. Jayaprakash (Eds.), *Status of exploited marine fisheries resources of India* (pp. 141-157). CMFRI.

Smith-Vaniz, W. F., & Carpenter, K. E. (2007). Review of the Crevalle Jacks, *Caranx hippos* complex (Teleostei: Carangidae), with a description of a new species from West Africa. *Fishery Bulletin 105*, 207–233.

Struck, T. H., & Cerca De Oliveira, J. (2019). Cryptic species and their evolutionary significance. *Encyclopedia of Life Sciences*, 1-9. https://doi.org/10.1002/9780470015902.a0028292

Struck, T. H., Feder, J. L., Bendiksby, M., Birkeland, S., Cerca, J., Gusarov, V. I., Kistenich, S., Larsson, K. -H., Liow, L. H., Nowak, M. D., Stedje, B., Bachmann, L., & Dimitrov, D. (2018). Finding evolutionary processes hidden in cryptic species. *Trends in Ecology & Evolution*, *33*(3), 153-163. https://doi.org/10.1016/j.tree.2017.11.007

Tamura, K., Stecher, G., & Kumar, S. (2021). MEGA11: molecular evolutionary genetics analysis version 11. *Molecular Biology and Evolution*, *38*(7), 3022-3027. https://doi.org/10.1093/molbev/msab120

Wang, S. Y., Chen, J. N., Russell, B. C., & Chen, W. J. (2018). First record of Gauguin's blunt-nose lizardfish, *Trachinocephalus gauguini* Polanco, Acero & Betancur 2016 (Teleostei: Synodontidae) outside the Marquesas Archipelago. *Zootaxa*, *4476*(1), 151-156.

Ward, R. D., Zemlak, T. S., Innes, B. H., Last, P. R., & Hebert, P. D. (2005). DNA barcoding Australia's fish species. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *360*(1462), 1847-1857. https://doi.org/10.1098/rstb.2005.1716

Zacharia, P. U., Najmudeen, T. M., & Livi, W. (2019) Decadal trends of Indian demersal fisheries. In S. Bijoy Nandan, P. Priyaja & P. R. Jayachandran (Eds.), *Compendium on Advances in Benthic Studies*: souvenir of the International Conference on Benthos (ICB 2019) (pp. 117-131). Directorate of Public Relations and Publications, Cochin University of Science and Technology.

Mar. Sci. Tech. Bull. (2023) 12(3): 267-281
e–ISSN: 2147–9666
info@masteb.com

dergipark.org.tr/en/pub/masteb
www.masteb.com
DOI: 10.33714/masteb.1313638

Marine Science and Technology Bulletin

PRENSIP
https://prensip.gen.tr/

RESEARCH ARTICLE

Effect of electric vehicle transportation and carbon capture system on concept Ro-Ro ship stability and EEDI

Burak Göksu[1] • Kubilay Bayramoglu[1*]

[1] *Zonguldak Bulent Ecevit University, Maritime Faculty, Department of Marine Engineering, 67300, Zonguldak, Türkiye*

ARTICLE INFO

Article History:
Received: 13.06.2023
Received in revised form: 30.07.2023
Accepted: 08.08.2023
Available online: 28.09.2023

Keywords:
Carbon capture
EEDI
Electric vehicles
Ro-Ro
Stability

ABSTRACT

In terms of their service life, ships may operate for decades. Hence, it depicts the rapid development of machinery and equipment due to the substantial advancement of technology. Indeed, the ship's systems must be updated to accommodate these new instruments. However, the importance of investigating the static-dynamic equilibrium and speed-power demand is a matter of concern as the ships are in motion on the water. There are currently limitations on carbon emissions from ships. To comply with these regulations, either the use of fuels that produce fewer carbon emissions or the use of after-treatment techniques to prevent the release of carbon into the atmosphere are employed. The difficulty of integrating any new system into an existing ship increases the scope of the renovation. This study compares the stability, speed-power, and EEDI values of today's most popular electric vehicles while being transported on a concept Ro-Ro ship with and without a Carbon Capture System (CCS) ship. In the scenario where the ship transports both conventional and electric vehicles, the number of vehicles transported remains constant, but the effects of electric vehicles being heavier are illustrated. A ship with CCS and loaded with electric vehicles has 23.5% less maximum GZ than a regular ship with the traditional vehicles loaded condition by approximately 6% less at an angle of heeling. Also, the EEDI level is approximately one-twentieth of the conventional model, which is an advantage of CCS.

Please cite this paper as follows:

Göksu, B., & Bayramoglu, K. (2023). Effect of electric vehicle transportation and carbon capture system on concept Ro-Ro ship stability and EEDI. *Marine Science and Technology Bulletin*, *12*(3), 267-281. https://doi.org/10.33714/masteb.1313638

* Corresponding author
E-mail address: kubilay.bayramoglu@beun.edu.tr (K. Bayramoglu)

Introduction

Car carriers are ships designed to transport automobiles, lorries, buses, and other wheeled vehicles in combinations (Kang et al., 2012). Roll-on, roll-off (Ro-Ro) ships are a type of these vessels because the loading and unloading processes are similar as well. Pure Car Carriers (PCC) are vessels that transport only cars, whereas Pure Car Truck Carriers (PCTC) transport other forms of wheeled cargo (Yasukawa, 2019). In addition to cargo ships, there are several other varieties of Ro-Ro ships, including ferries and even military tanks (Kennedy, 2023).

Car carriers load and unload without cranes or pumps, unlike other ships. The ramps, usually at the ship's stern or stem (rarely on the side), allow wheeled vehicles to be moved to their specified spots on the ship, and the cargo is unloaded at the planned port by reversing the procedure (Tuswan et al., 2021). It has a different load capacity measurement standard, such as DWT on cargo ships and TEU (Twenty Foot Equivalent Units) on container ships, the total loading length in lanes on Ro-Ro ships, or the total number of vehicles it transports (Sun et al., 2022). The greatest Pure Car Carrier (Höegh Target) is capable of transporting up to 8500 cars on fourteen distinct decks and is designed for trade between East Asia and Europe (Nieuwenhuis, 2017). Despite its highest payload, this ship is not the longest vehicle carrier because it is approximately 200 meters long and 36 meters wide.

Car carriers are readily identifiable from the exterior due to their conspicuously elevated sideboards (Simopoulos et al., 2008). Due to the large surface area of their sides, ships are susceptible to drifting off course in strong winds (Thies & Ringsberg, 2023). Stacking decks on top of each other increases the transport capacity of the vehicle. To prevent cargo space loss, tween decks are arranged to attain maximum loading capacity (Skoupas et al., 2009). In addition, two ramps, one at the bow and one at the stern, are utilized to complete loading and unloading in the shortest amount of time feasible (Sun et al., 2022).

In the atmosphere, gases that absorb and emanate infrared radiation from the sun are referred to as Greenhouse Gases due to their effect (Kavli et al., 2017). Although these gases occur naturally in the atmosphere, variations in their concentrations caused by human activities contribute to global warming (Salinger, 2005). Carbon dioxide has the largest proportion of the greenhouse gases that contribute to global warming (Zhong & Haigh, 2013). Carbon dioxide accounts for the largest portion of greenhouse gas emissions at 74.4%, followed by methane at 17.3% (Shepherd et al., 2015). Others include nitrous oxide, sulfur hexafluoride, hydrofluorocarbons, perfluorocarbons, and NF_3 (nitrogen trifluoride) (Zhou & Feng, 2014). The primary causes of the global increase in greenhouse gas emissions are listed as fossil fuel use (87%), Land-use-related forest loss (9%), industrial processes (4%), breathing, decomposition and dissolution mechanisms, natural causes, ocean discharge, and anthropogenic causes (Mikhaylov et al., 2020).

In addition to these, greenhouse gases are responsible for the fact that the Earth is not a frozen sphere (Kweku et al., 2017). Without the greenhouse effect, the average temperature on Earth would have decreased from 14 degrees Celsius to -18 degrees Celsius (McClintock et al., 2008). Human actions like the natural greenhouse effect have increased greenhouse gas accumulations in the atmosphere, raising global surface temperatures and causing climate change.

The most well-known carbon emission regulation is the Paris Agreement. The aim of the legislation signed by 196 countries on December 12, 2015, is to limit global warming to less than 2 degrees Celsius, preferably 1.5 degrees Celsius (Sachs, 2020). This corresponds to levels before the industrial revolution. The European Green Agreement signed in 2019 sets the goal of reducing EU country emissions by 55 percent by 2030 compared to 1990 and achieving carbon neutrality by 2050 (Perissi & Jones, 2022).

The International Maritime Organization (IMO) has enacted various regulations to decrease carbon emissions from ships. The rules were first put in place in 2008. It also tries to cut carbon emissions gradually (Wang et al., 2021). The main aim is to cut GHG emissions by approximately 50% by 2050 compared to 2008 (Issa et al., 2022). The IMO attempts to meet these goals through a variety of regulations. The regulations became implemented as part of MARPOL Annex VI, primarily aimed to reduce air pollution from ships (IMO, 2022). These standards are the Energy Efficiency Design Index (EEDI), Energy Efficiency Existing Ship Index (EEXI), Energy Efficiency Operational Index (EEOI), Ship Energy Efficiency Management Plan (SEEMP), and Carbon Intensity Index (CII). EEDI attempts to reduce CO_2 emissions per unit of transport by improving ship-carrying capacity during the building phase or by implementing measures to improve energy efficiency (Polakis et al., 2019). EEXI "describes standardized CO_2 emissions based on installed engine power, cargo capacity, and ship speed" and "identifies CO_2 emissions per cargo ton and transport." In other terms, the EEXI establishes a CO_2 emission limit per unit of transportation supply (Rutherford et al., 2020).

New and existing ships must keep a ship-specific Ship Energy Efficiency Management Plan (SEEMP) that can be linked to the Safety Management System. SEEMP will be IMO-compliant. The January 1, 2013 requirements apply to all vessels with a gross tonnage of 400 or greater (Hasan, 2011).

Emissions from ships depend on numerous other variables, such as the fuel type, the ship's machinery, cruising duration, cruising speed, and occupancy rate (Tadros et al., 2022). Low- and medium-speed diesel engines, as well as steam and gas turbine engines to a lesser extent, are what power the majority of commercial vessels (Mihail–Vlad, 2018). In marine shipping, fossil fuels are used in ship machinery. The ecology and human health suffer from these emissions. If we call the pollution seen in people's immediate environment, such as inland water, narrow channels, gulfs, ports, beaches, and seashore settlements, pollution of the immediate environment, we can also refer to the pollution we don't notice but that has global effects on our environment. It's also termed global environmental contamination. Principal forms of emissions from commercial ships are carbon dioxide (CO_2), carbon monoxide (CO), sulfur oxides (SO_X), nitrogen oxides (NO_X), hydrogen chloride (HC), dust or particulate matter (PM), and organic volatile vapors and gases (VOC) (Xing et al., 2020).

In regions with dense ship traffic, emissions from ships are concentrated, and measures are taken to reduce and keep them under control (Ampah et al., 2021). With the implementation of MARPOL Annex VI, the International Maritime Organization (IMO) has enacted several regulations regarding ship emissions of exhaust gases. Many standards regarding nitrogen oxides (NO_X), sulfur oxides (SO_X), and particulate matter are still in effect, assisting to improve air quality.

Ship CO_2 emissions are reduced in several ways. These apps fall under three categories. First, it reduces engine power through energy efficiency. These applications generally involve waste heat recovery, propeller and rudder design optimization, hull shape, and hull pollution (Bøckmann & Steen, 2016). Second, use alternate ship fuels. After 2030, hydrogen and ammonia will replace LNG as ship fuels (Fayaz et al., 2012; Law et al., 2023; Shin & Park, 2023). Finally, if renewable energy sources or alternative fuels are to be used, it is thought that carbon capture systems will have a significant impact on reaching the 2050 IMO targets (Lee et al., 2021).

Since electric vehicles are today's new technology products, they must be transported from the production place to the consumption location. This necessitates an evaluation of both the stability of current ships and compliance with the regulations limiting greenhouse gas emissions, which are primarily caused by the transportation of ships and vehicles and represent the novelty of the study. In this study, the transportation of electric vehicles on Ro-Ro ships was evaluated instead of vehicles using traditional fossil fuels, which play an important role in reducing greenhouse gases. The effects of carrying electric vehicles instead of conventional vehicles on ship stability were explored in the studies. Furthermore, the effect of carbon capture systems on Ro-Ro ship applications on ship stability and EEDI has been assessed for various scenarios. Carbon capture systems are one of the most effective techniques for lowering CO_2 emissions in line with IMO 2050 targets. In this context, the following sections of this study perform EEDI and stability calculations both in the presence and absence of electric vehicles and with and without CCS. Thus, the combined application of electric vehicle transport and carbon capture systems in Ro-Ro ships will be evaluated, which has not been performed before in the literature.

Material and Method

General Specifications of the Concept Ship

A concept design of a PCC-type Ro-Ro ship has been modeled, and features such as the main engine power and type, which are determined based on the approximate calculation of the general weight groups, hydrostatic and stability values, and resistance-power calculations, are completed within the scope of the ship's preliminary design calculations. When calculating stability and resistance power, it is presumed that the ship floats in two drafts, 10.50 m, and 11.11 m. The 10.50 m water draft is required to transport vehicles that have conventional engines. The 11.11 m water draft is required if the entire cargo consists of new-generation electric vehicles. In addition, stability calculations were performed for both the presence and absence of carbon capture equipment, considering that waterlines remained unchanged. Consequently, the resistance-power calculation comprises two combinations, while the stability calculation comprises four. The fundamental characteristics of the ship are detailed in Table 1.

The concept design PCC Ro-Ro ship has 14 vehicle decks and allows for the loading of a total of 7700 cars. The overall design of the ship designed within the scope of this study is depicted in Figure 1, and it is designed to have a conventional propulsion system consisting of a single internal combustion main engine and a propeller.

The weight groups of the ship were calculated using empirical formulas from the literature, and the method of estimating values based on empirical formulas is frequently used within the preliminary design phase of ship construction. In Table 2, weight categories, empirical weight estimation methodologies, and values are listed.

Thus, the weight groups and distributions of the ship, as well as its general characteristics, determine its total displacement. This factor is of the utmost significance when calculating resistance-power, and stability, and it is an indispensable aspect of ship design.

Table 1. The concept ship general specifications

Specifications	**Values**	
Length overall (LOA) [m]	230.0	230.0
Draft Amidships (T) [m]	10.50	11.11
Displacement [t]	53050	56900
Waterline (WL) Length [m]	219.99	220.25
Beam max extents on WL [m]	32.00	32.00
Wetted Area [m²]	8991.1	9300.9
Waterplane Area [m²]	6189.9	6268.9
Prismatic coefficient (Cp)	0.748	0.755
Block coefficient (Cb)	0.700	0.707
Max Section area coefficient (Cm)	0.945	0.948
Waterpl. area coeff. (Cwp)	0.879	0.890

Carbon Capture System (CCS) Specifications

CO_2 emissions are the main contributor to global warming and the greenhouse effect. Carbon capture systems are the most effective approach for reducing CO_2 emissions from ships (M. Wang et al., 2011). Figure 2 shows a carbon capture system and the tanks used to store the stored carbon.

The system consists of a carbon capture column that Absorbs the CO_2 components in the diesel engine exhaust gas, a Stripper that separates the CO_2 from the rich MEA solution, and tanks that store the liquefied CO_2 emissions under high-pressure and low-temperature conditions. Considering the literature data, the optimum operating condition of the CCS system is 45-55 degrees. In this study, it is thought that the exhaust temperature enters the CCS system at 50°C. The reduction of the exhaust gas to these temperatures is generally provided by waste heat recovery systems or scrubber systems (Mores, Rodríguez, et al., 2012; Mores, Scenna, et al., 2012).

Considering the power requirement of the Ro-Ro ship, Considering the power requirements of the Ro-Ro ship, the MAN brand 8S60ME-C10.6 main engine, which produces 19600 kW at full load, was chosen (MAN, 2017). The marine diesel engine used in this study specification is presented in Table 3.

Figure 1. The general view of the concept ship

Table 2. The weight groups, methodologies, and weight values

Weight group	**Calculation method**	**Weight [t]**	
		T=10.50 m	**T=11.11 m**
Construction	Kafalı (1988)	20000	
Main machinery	Barrass (2004)	1800	
Auxiliary machinery	Kupras (1981)	1000	
Outfitting	Kafalı (1988)	4500	
Engine car cargo load	Jia (2007)	11550	-
Electrical car cargo load	Kane (2023)	-	15400
Service requirements	Sun et al. (2022)	14200	
Displacement		25750	29600
Total displacement		53050	56900

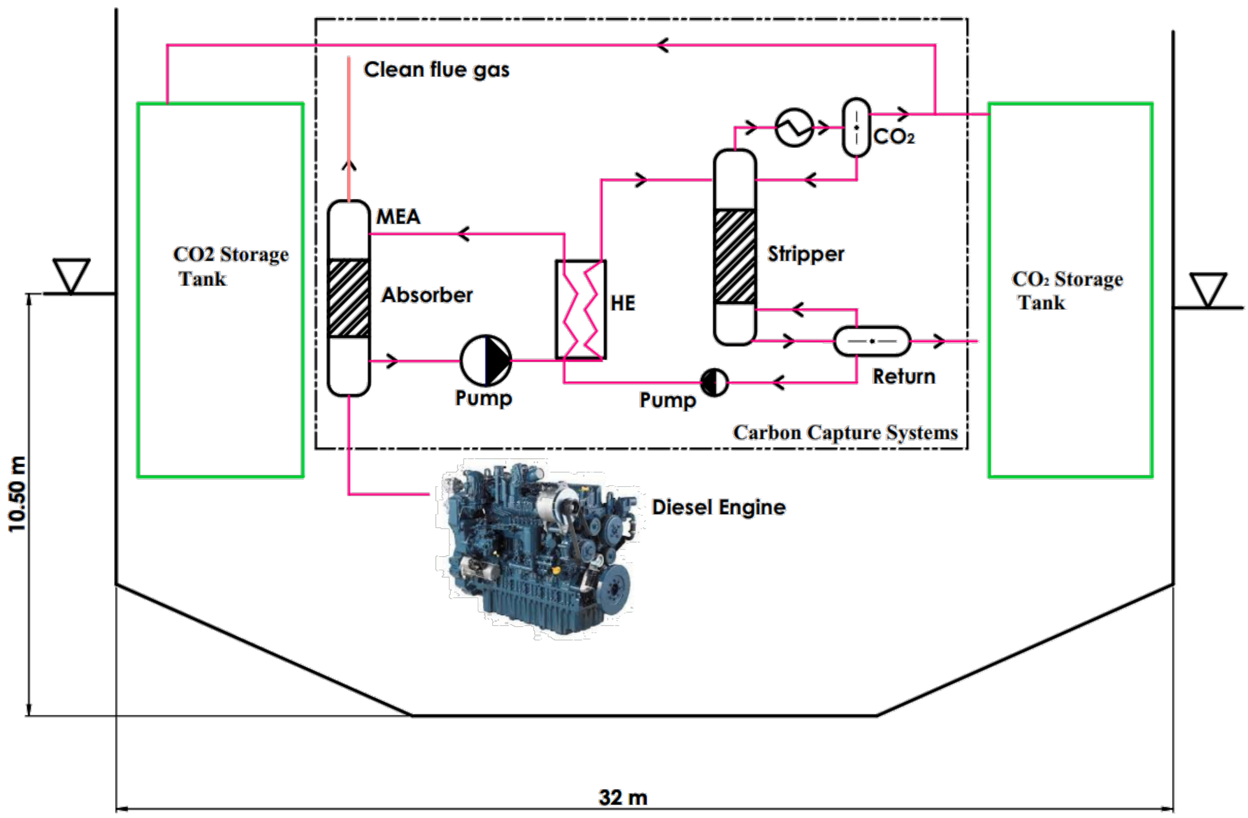


Figure 2. Carbon capture systems on board

Table 3. Specification of diesel engine (unit: kg/s)

Load	Exhaust Mass Flow Rate
100	38.7
85	35.6
75	32.8
50	22.8
25	14

Table 4 summarizes the fractional ratios of the gases in the exhaust gas. Components represent approximate values (Stec et al., 2021).

Table 4. Flue gas composition of diesel engine (unit: Vol%)

Exhaust Gas Composition	Value
H_2O	13
CO_2	12
O_2	3
N_2	72

Stability Parameters

The equilibrium of forces acting on floating bodies like ships has revealed the existence of numerous stability control parameters (Im & Choe, 2021). The expression "metacenter height", which is used to determine initial stability, is the most fundamental of these concepts (Ibrahim & Grace, 2010). This variable term is calculated based on conditions such as displacement, hell, and trim angle. To achieve equilibrium, the sum of an object's forces and moments must be zero. The center of buoyancy and center of gravity of a ship without a heel is in the same direction. If a change occurs that causes the distance between these centers to be greater than zero, the heel motion is observed until the directions of the ship's center of buoyancy and center of gravity are the same again (Shakeel et al., 2022). In this new equilibrium state, the point depicted in Figure 3 that passes from the new buoyancy center of the ship perpendicular to the "B" waterline and intersects the ship's center line is known as the "metacenter point" "M". The distance between the ship's center of gravity "G" and this point "M" on the center line is the ship's "GM" value. This value is a parameter evaluated within the scope of IMO intact stability rules, and stability is mentioned when it is greater than zero (Marlantes et al., 2022). If not, the ship cannot satisfy the floating condition.

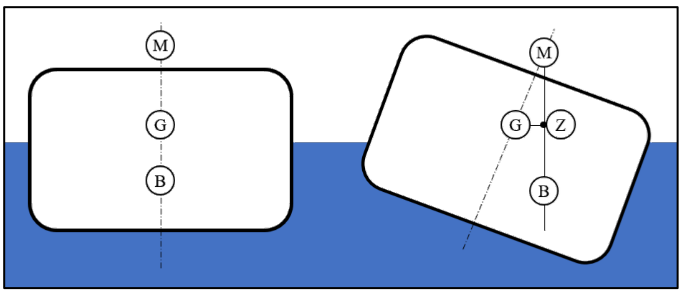


Figure 3. Ship initial stability condition

The term “righting arm – (GZ)” is also utilized when evaluating the stability of ships (Perrault, 2016). The vertical distance from the ship’s center of gravity to the line that passes through B and M and intersects this line at the “Z” point, which serves as the moment arm, depends on the heel angle of the ship. The ships return to their prior positions and assume the initial position because of the moment arm formed here.

Figure 4 shows three patterns of the area under the GZ curve in the IMO stability regulation. The area$_{0\text{-}30deg}$ refers to the area of “a” under the GZ curve between 0 and 30 of the heeling angle, the Area$_{30\text{-}40deg}$ is the area of “b” between 30 and 40 (or flooding angle, whichever is less) and the Area$_{0\text{-}40deg}$ means the area of “a+b” between 0 and 40 (or flooding angle, whichever is less) (Im & Choe, 2021). A typical $GZ - \varphi$ curve has a positive value within a certain range of heeling angles, and the heeling angle at which the value of the curve changes from positive to negative is known as the “stall angle” (Göksu & Bayramoğlu, 2021). When the heel angle exceeds this value, a swaying moment arm forms instead of a righting moment arm, resulting in a ship capsizing. Cargo and passenger ships are required by IMO regulations to meet some criteria. However, ships that meet these stability values are allowed to operate at sea and are physically tested to meet this criterion by means such as strict controls and inclination tests (Irkal et al., 2016).

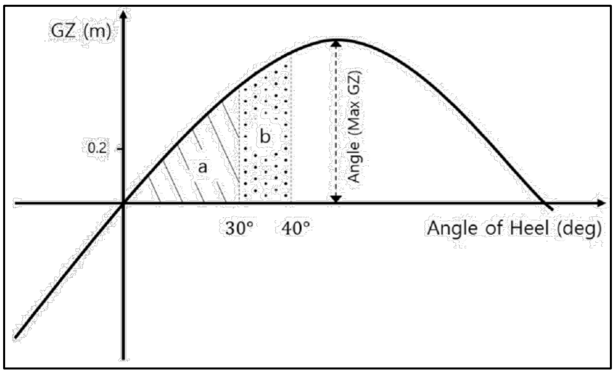


Figure 4. A typical GZ-φ graph (Im & Choe, 2021)

Resistance-Power Calculations

Estimating the resistance of the hull form is one of the most crucial design parameters in ship design (Labanti et al., 2016). The resistance-power calculation is based on the ship’s principal parameters, which vary based on the type of ship being calculated and its geometrical characteristics. In the first stage, empirical formulations are utilized, which are typically derived from the results of numerous systematic model experiments and statistical research (Niklas & Pruszko, 2019). The precision of the calculation to be performed using the theoretical method depends on the similarity between the chosen method’s underlying form and the form available. The arrangement of the method, which J. Holtrop created in 1977 with assistance from G. G. Mennen in 1978, has allowed the Holtrop-Mennen method (Song et al., 2013), which developed on the foundation of conventional cargo ships (Korlak, 2021).

Total ship resistance is expressed as the sum of several resistance components, and Equation (1) incorporates the resistance components used when transforming from model tests to full-scale ship scale (Holtrop & Mennen, 1982; Molland et al., 2017).

$$R_T = R_F(1 + k_1) + R_{APP} + R_W + R_B + R_{Tr} + R_A \qquad (1)$$

where R_T is the total resistance of the ship; R_F is friction resistance according to ITTC, $1 + k_1$ form factor, R_{APP} is the resistance of attachments, R_W is wave making and wave breaking resistance, R_B is bulb pressure resistance, R_{Tr} is stern pressure resistance, R_A is ship-model adaptation resistance. This equation is the basis of the Holtrop-Mennen method and is one of the most frequently used methods in the shipbuilding preliminary design phase (Grabowska & Szczuko, 2015).

The first step in determining the required installed engine power for ships is to determine the total resistance. Then, the power required to tow a ship at V speed is referred to as P_E and can be calculated using Equation (2) (Molland et al., 2017).

$$P_E = R_T * V \qquad (2)$$

Estimating or calculating the amount of power losses that occur on all components from the main engine to the propeller and during propeller rotation is another vital requirement for determining the installed engine power to achieve the necessary thrust from the propeller that propels the ship forward. In this regard, the concept of propulsion efficiency η_T comes into perform, and it is accepted by researchers that 60 percent of the total main machine power is lost on a conventional propulsion system before the power from the main machine is converted into useful power (Charchalis, 2014). In other terms, this issue, also known as the ratio of the hull effective power to the main engine brake power, P_B is illustrated in Equation (3) (Demirel et al., 2017).

$$\eta_T = \frac{P_E}{P_B} \qquad (3)$$

Thus, the selection of the main engine that will enable providing a ship where the total force of resistance can be estimated could be made at the specified speed.

Carbon Capture and EEDI Calculations

The carbon capture device considerably lowers CO_2 emissions in a marine diesel engine that uses fossil fuels. To reduce CO_2 emissions from ship exhaust gas, an amine solution is utilized (Luo & Wang, 2017). The CO_2 capture process was simulated using Aspen Plus software. For the equation of state (EOS), the electrolyte non-random two-liquid model (eNRTL) was applied. The law of the Henry constant and the dielectric constant of each component, which are eNRTL parameters, were taken from the literature to determine the equilibrium constants. The CO_2 capture mechanism of activated MEA is expressed by eight equations (Lee et al., 2021). It uses the common 25 wt% percent ethanolamine (MEA) solvent. MEA solvent was used as 25 wt% in this study.

The EEDI expresses the CO_2 emission per unit of transported cargo by the CO_2 released from the ship's main and auxiliary machinery, and it was implemented to reduce CO_2 emissions from ships. Alternative power requirements and heat recovery systems on the ship provide a reduction of CO_2 emissions (Stec et al., 2021). Carbon capture systems play the main role in reducing CO_2 emissions from ships. The EEDI is computed using Equation (4).

$$EEDI = \frac{P_{ME} \cdot C_{F,ME} \cdot SFOC_{ME} + P_{AE} \cdot C_{AE} \cdot SFOC_{AE}}{V_{ref} \cdot Capacity} \quad (4)$$

Where P is engine power expressed in kW, C_F is the ratio of fuel consumption to CO_2 emissions, SFOC is standard fuel oil consumption expressed in g/kWh, V_{ref} is ship speed defined in kn, and capacity is indicated in tons deadweight reported in dwt. The main and auxiliary engines are denoted by the subscripts *ME* and *AE*, respectively. For all of the situations that were examined, SFOC was set at 200 g/kWh according to the literature. Equation (5) can be used to compute the power of auxiliary engines (MAN, 2014).

$$P_{AE} = 0.05 \cdot MCR_{ME} \quad (5)$$

Results and Discussion

Definition of the Stability Parameters

Throughout their voyages, ships are exposed to highly variable conditions. Although the effects of these conditions on the ship were not completely known before that, their safety is maintained if they comply with the stability requirements established by international conventions and approved by classification societies according to their designs. Ships end up sinking or being damaged because of improper cargo or a failure to observe changes in ship equilibrium during a voyage. There are casualties among seafarers, material losses, and extensive marine and environmental damage. Regardless of the type and size of the ship being designed, it is essential to obtain the hydrostatic values table initially. The relevant values for the hydrostatic calculations of the concept PCC Ro-Ro vessel designed for this study are listed in Table 5.

Table 5. Hydrostatic values of the concept ship

Draft Amidships [m]	**9.50**	**10.00**	**10.50**	**11.00**	**11.50**	**12.00**
Displacement [t]	46763	49877	53050	56221	59442	62691
Heel [deg]	0.00	0.00	0.00	0.00	0.00	0.00
Draft at FP [m]	9.50	10.00	10.50	11.00	11.50	12.00
Draft at AP [m]	9.50	10.00	10.50	11.00	11.50	12.00
Draft at LCF [m]	9.50	10.00	10.50	11.00	11.50	12.00
Trim (+ by stern) [m]	0.00	0.00	0.00	0.00	0.00	0.00
WL Length [m]	219.39	218.96	219.99	220.23	220.25	220.31
Beam max extents on WL [m]	32.00	32.00	32.00	32.00	32.00	32.00
Wetted Area [m^2]	8486.68	8731.17	8991.05	9247.34	9497.87	9745.31
Waterplane Area [m^2]	6046.66	6116.79	6189.96	6256.76	6312.67	6361.34
Prismatic coefficient (Cp)	0.737	0.745	0.748	0.754	0.760	0.766
Block coefficient (Cb)	0.684	0.695	0.700	0.708	0.716	0.723
Max Section area coeff. (Cm)	0.939	0.942	0.945	0.948	0.950	0.952
Waterplane area coeff. (Cwp)	0.861	0.873	0.879	0.888	0.896	0.902

Table 6. Loading conditions for all combinations

Item Name	Long. Arm [m]	Vertical Arm [m]	Total Mass (Conv.) [t]	Total Mass (Conv. +CCS) [t]	Total Mass (EVs) [t]	Total Mass (EVs +CCS) [t]
Construction	110.00	10.00	20000.00	20000.00	20000.00	20000.00
Machinery	28.00	3.00	2800.00	2800.00	2800.00	2800.00
Outfitting	110.00	8.00	4500.00	4500.00	4500.00	4500.00
Car deck 1	110.00	2.70	450.00	365.00	600.00	515.00
Car deck 2	110.00	5.00	450.00	365.00	600.00	515.00
Car deck 3	110.00	7.30	525.00	440.00	700.00	615.00
Car deck 4	110.00	9.60	825.00	740.00	1100.00	1015.00
Car deck 5	110.00	11.90	825.00	740.00	1100.00	1015.00
Car deck 6	110.00	14.20	825.00	740.00	1100.00	1015.00
Car deck 7	110.00	16.50	825.00	740.00	1100.00	1015.00
Car deck 8	110.00	18.80	975.00	880.00	1300.00	1210.00
Car deck 9	110.00	21.10	975.00	890.00	1300.00	1210.00
Car deck 10	110.00	23.40	975.00	890.00	1300.00	1215.00
Car deck 11	110.00	25.70	975.00	890.00	1300.00	1215.00
Car deck 12	110.00	28.00	975.00	890.00	1300.00	1215.00
Car deck 13	110.00	30.30	975.00	890.00	1300.00	1215.00
Car deck 14	110.00	32.60	975.00	890.00	1300.00	1215.00
Service req.	115.00	8.00	14200.00	14200.00	14200.00	14200.00
CO_2 storage tank port side	50.00	32.00	0.00	400.00	0.00	400.00
CO_2 storage tank stb. side	50.00	32.00	0.00	400.00	0.00	400.00
Carbon capture system	50.00	32.00	0.00	400.00	0.00	400.00
Total tonnage			53050.00	53050.00	56900.00	56900.00

Note: * "Conv." is for carrying conventionally engined cars; "Conv.+CCS" is for carrying conventionally engined cars with a carbon-captured system ship; "EVs" is for carrying electric vehicles; "EVs+CCS" is for carrying electric vehicles with a carbon-captured system ship.

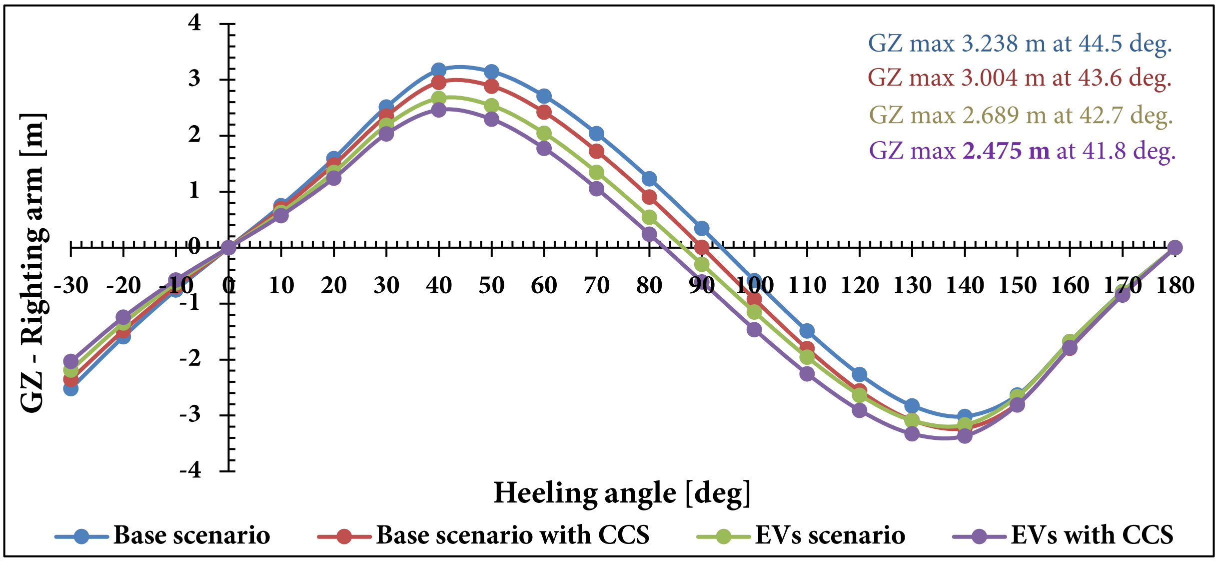


Figure 5. Stability curves for all conditions

A series of calculations must be performed to determine the equilibrium and stability characteristics of a designed ship model. For these calculations, it is necessary to first determine the weight of the ship's hull, machinery, and equipment, the load transported on the decks and holds, the load required for service, and the position of equivalent specialized equipment on the ship's hull. With the data derived from stability calculations and related equilibrium conditions, it is possible to predict the ship's movements in the floating state. Table 6 displays the cargo information for each loading combination of the concept ship. These calculations are also beneficial for developing hull designs.

As depicted in Figure 5, the $GZ - \varphi$ graph must be available to determine if the ship could meet the floating condition at the end of any change caused by internal and external forces acting on the ship; if these forces disappear, the ship can return to its initial equilibrium position. Considering the values obtained for the four distinct loading conditions to be evaluated within the scope of the study, the case where conventional vehicles are carried without CCS has the largest positive stability range and maximum GZ righting arm.

Definition of Resistance-Power Values

The Holtrop-Mennen method was utilized for the resistance calculations of the conceptual ship shape developed. Ship resistance calculations, which are crucial in deciding the main engine type and power during the design phase, are also commonly used to approximately predict the cruising speeds under the decided conditions with the existing main engine. To determine the amount of main engine power that will be needed for propulsion if the propulsion efficiency (η_T) is limited to 40%, and to obtain what speeds the determined form will encounter with what magnitude of resistance, the data in Table 7 can be accessed under two different draft conditions evaluated in the study.

Naturally, increasing the draft, i.e. carrying more cargo, will lead to either a higher main engine power requirement or a slower cruising speed with the same power. So, Figure 6 illustrates the increase in required power as the draft increases for two distinct drafts.

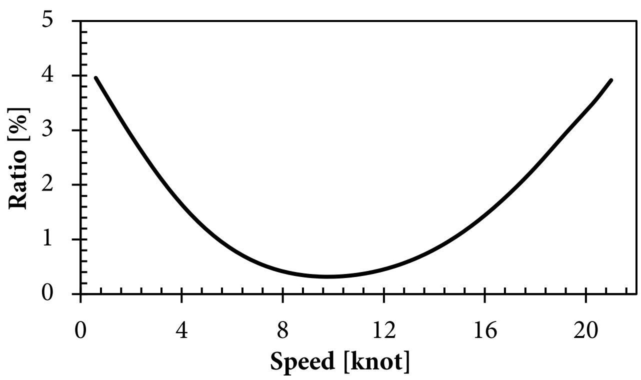


Figure 6. Increase in power by changing speed with the draft from 10.50 to 11.11 m

Table 7. Resistance-Power values for the concept ship at different drafts

Speed (knot)	Draft at 10.50 m		Draft at 11.11 m	
	Resistance (kN)	Power (kW)	Resistance (kN)	Power (kW)
0	--	--	--	--
3.0	28.8	111	29.4	114
6.0	108.7	839	109.6	846
9.0	236.2	2734	237.0	2743
12.0	411.0	6343	412.9	6372
12.6	452.8	7337	455.2	7377
13.2	497.4	8444	500.6	8498
13.8	545.2	9676	549.3	9750
14.4	596.6	11049	602.1	11150
15.0	652.1	12581	659.3	12718
15.6	712.3	14291	721.5	14476
16.2	777.7	16203	789.5	16450
16.8	848.9	18342	863.9	18666
17.4	926.6	20735	945.4	21157
18.0	1011.4	23415	1034.9	23958
18.6	1103.9	26407	1132.9	27102
19.2	1204.3	29737	1239.7	30613
19.8	1313.8	33455	1356.4	34542
20.4	1434.7	37643	1485.8	38983
21.0	1568.4	42360	1629.8	44019

Determination of Carbon Capture and EEDI

The most important factor in carbon capture processes is the choice of solvent to absorb CO_2 emissions. In this study, the MEA solution, which is mostly used in the literature, was used in the system model with 25% MEA and 75% water by weight. In this study, the effect of MEA solution amount on CO_2 reduction performance was investigated under five different engine load exhaust conditions. The effect of MEA at different rates for each load case on the CO_2 reduction performance is given in Figure 7. CCS calculations were made for variable engine loads and corresponding exhaust mass flow rates. The findings show that as the MEA ratio increases, the CO_2 reduction performance increases. However, it was determined that the increased MEA ratio after a certain threshold value did not affect the CO_2 reduction performance. It has been shown that increasing MEA ratio and CO_2 capture performance have the same characteristics for each load condition. In addition, it has been determined that the optimal MEA amount for each load condition is approximately three times the exhaust gas flow rate.

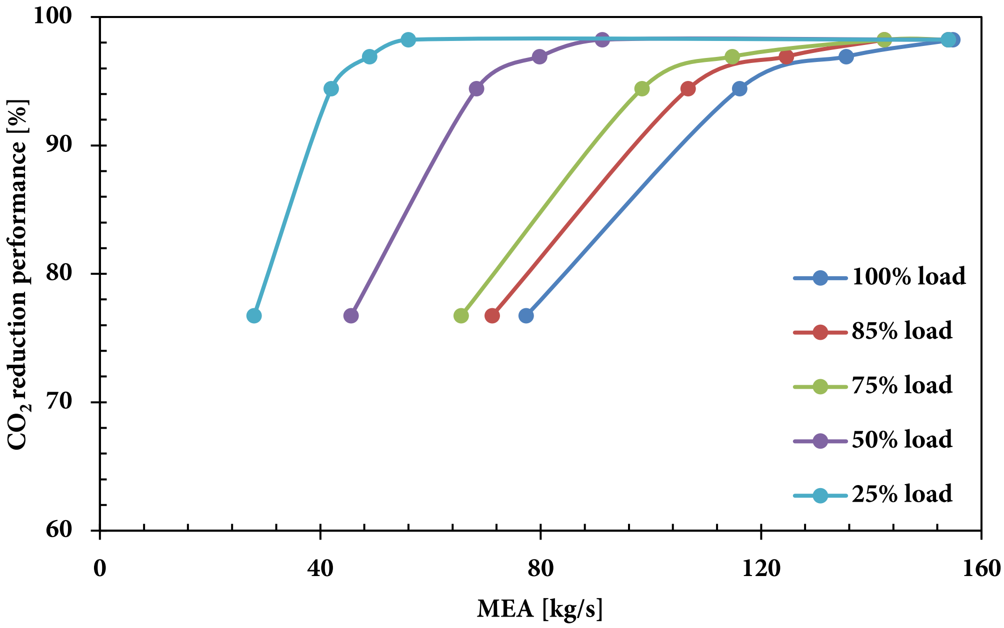


Figure 7. Effect of MEA solution amount on CO_2 reduction performance

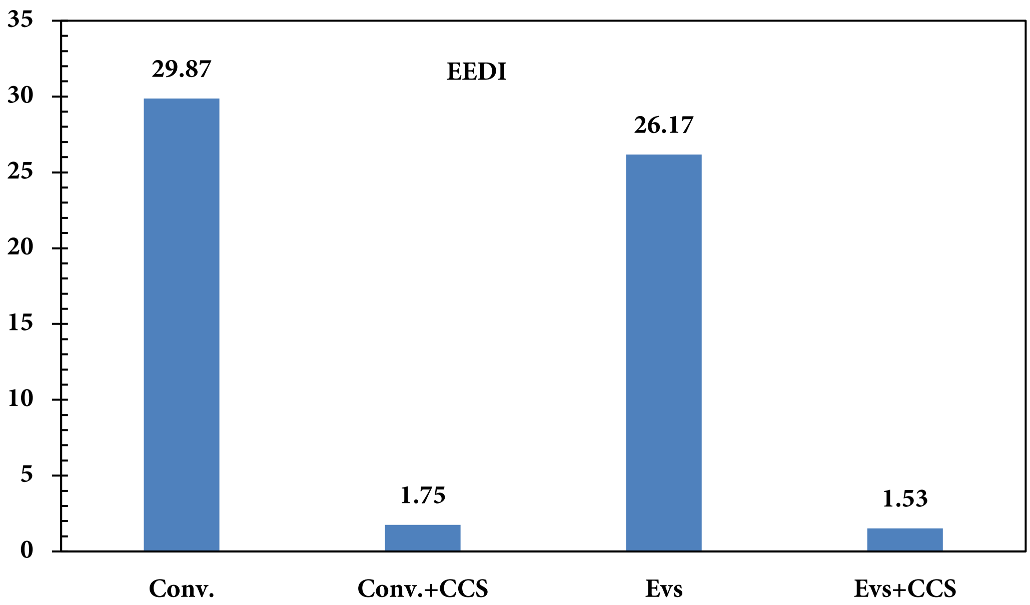


Figure 8. EEDI for variable ship configurations

Table 8. The molar fraction of components in the CCS

Components	Absorber MEA inlet	Absorber Exhaust inlet	Absorber MEA outlet	Absorber Exhaust outlet
H_2O	0.95	0.13	0.9259	0.03
CO_2	0	0.12	0.0288	0.067
N_2	0	0.72	1E-5	0.9245
O_2	0	0.03	7.6E-7	0.0385
MEA	0.048	0	0.0453	0

A CCS absorber is a column with two inputs and two outputs. Marine diesel engines exhaust gas absorber on one side and MEA solution enters the system on the other side. A 20-stage structure has been used throughout the system, and the absorber is based on the process of dissolving CO_2 in the MEA solution by mass transfer. The CO_2 components, which were initially 12% by volume, decreased to approximately 0.67% with a 95% decrease in the absorber output. After mass transfer, the CO_2 in the MEA solution was determined to be approximately 0.0288% by volume. Figure 8 expresses the volumetric ratios of H_2O, CO_2, N_2, O_2, and MEA components in the CCS absorber at the absorber inlet and outlet states.

CO_2 emissions, which cause greenhouse gases on ships, are tried to be reduced with EEDI. There are different options for meeting the IMO's 2050 carbon reduction strategies, these are renewable energy sources, carbon-free fuels, and carbon capture systems. In this study, EEDI calculations were made for four different scenarios. These are configurations that include conventional vehicle-carrying Ro-Ro, electric-vehicle-carrying Ro-Ro, and CCS integration into them. The estimated EEDI for each case is presented in Figure 8. The results show that the use of carbon capture systems on ships can catch up with IMO 2050 strategies. CCS systems reduce the load-carrying capacity of ships and their effects on ship stability are also the main issues to be considered.

The EEDI level of a ship carrying conventional vehicles with CCS was reduced from 29.87 to 1.75, or approximately one-sixteenth. This ratio decreased from 26.17 to 1.53 for electric vehicles and remained approximately the same proportionally.

Conclusion

This study investigated the EEDI effect of stability, hydrostatic, and carbon capture systems installed by IMO by carbon reduction targets for the transport situation of a Ro-Ro ship. According to the ship's design, main engine selection and power requirements were established using appropriate load and resistance calculations. For the chosen equipment and load scenarios, the following results were ultimately obtained.

- According to stability and hydrostatic calculations, the base scenario, which transported conventional vehicles, had the best stability and the scenario involving both EVs and CCS had the lowest stability.
- For both different scenarios, the main engine that can provide the calculations' required power was chosen, and the corresponding speeds for the use of the same engine were established.
- The CO_2 reduction performances of the carbon capture system for Conventional Vehicle transport and EVs transport at different engine loads were evaluated. It was determined that the carbon capture performance increased with increasing MEA solution. It was found that the typical amount of MEA solution to be applied should flow rate around three times that of the exhaust.
- The EEDI value implemented following the IMO carbon reduction targets is highest for conventional vehicles and lowest for EVs with CCS systems. Conclusions reached according to the IMO 2050 objectives; the adoption of CCS reduces CO_2 emissions by almost 95%.

Acknowledgements

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Compliance With Ethical Standards

Authors' Contributions

BG-KB: Designed the study.
BG-KB: Wrote the first draft of the manuscript.
BG-KB: Performed and managed statistical analyses.
Both authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

Ampah, J. D., Yusuf, A. A., Afrane, S., Jin, C., & Liu, H. (2021). Reviewing two decades of cleaner alternative marine fuels: Towards IMO's decarbonization of the maritime transport sector. *Journal of Cleaner Production*, *320*, 128871. https://doi.org/10.1016/j.jclepro.2021.128871

Barrass, B. (2004). *Ship design and performance for masters and mates*. Elsevier.

Bøckmann, E., & Steen, S. (2016). Calculation of EEDI weather for a general cargo vessel. *Ocean Engineering*, *122*, 68-73. https://doi.org/10.1016/j.oceaneng.2016.06.007

Charchalis, A. (2014). Determination of main dimensions and estimation of propulsion power of a ship. *Journal of KONES. Powertrain and Transport*, *21*(2), 39–44. https://doi.org/10.5604/12314005.1133863

Demirel, Y. K., Turan, O., & Incecik, A. (2017). Predicting the effect of biofouling on ship resistance using CFD. *Applied Ocean Research*, *62*, 100–118. https://doi.org/10.1016/j.apor.2016.12.003

Fayaz, H., Saidur, R., Razali, N., Anuar, F. S., Saleman, A. R., & Islam, M. R. (2012). An overview of hydrogen as a vehicle fuel. *Renewable and Sustainable Energy Reviews*, *16*(8), 5511–5528. https://doi.org/https://doi.org/10.1016/j.rser.2012.06.012

Göksu, B., & Bayramoğlu, K. (2021). Control of ship roll and yaw angles during turning motion. *Marine Science and Technology Bulletin*, *10*(4), 340–349. https://doi.org/10.33714/masteb.930338

Grabowska, K., & Szczuko, P. (2015). Ship resistance prediction with Artificial Neural Networks. *2015 Signal Processing: Algorithms, Architectures, Arrangements, and Applications (SPA)*, 168–173. https://doi.org/10.1109/SPA.2015.7365154

Hasan, S. M. R. (2011). *Impact of EEDI on Ship Design and Hydrodynamics: A Study of the Energy Efficiency Design Index and Other Related Emission Control Indexes*. [MSc. Thesis. Chalmers University of Technology].

Holtrop, J., & Mennen, G. G. J. (1982). An approximate power prediction method. *International Shipbuilding Progress*, *29*(335), 166-170.

Ibrahim, R. A., & Grace, I. M. (2010). Modeling of ship roll dynamics and its coupling with heave and pitch. *Mathematical Problems in Engineering*, *2010*, 13–18. https://doi.org/10.1155/2010/934714

Im, N.-K., & Choe, H. (2021). A quantitative methodology for evaluating the ship stability using the index for marine ship intact stability assessment model. *International Journal of Naval Architecture and Ocean Engineering*, *13*, 246–259. https://doi.org/10.1016/j.ijnaoe.2021.01.005

IMO. (2022). Marine Environment Protection Committee (MEPC) – 79th session, 12-16 December 2022.

Irkal, M. A. R., Nallayarasu, S., & Bhattacharyya, S. K. (2016). CFD approach to roll damping of ship with bilge keel with experimental validation. *Applied Ocean Research*, *55*, 1–17. https://doi.org/10.1016/j.apor.2015.11.008

Issa, M., Ilinca, A., & Martini, F. (2022). Ship energy efficiency and maritime sector initiatives to reduce carbon emissions. *Energies*, *15*(21), 7910. https://doi.org/10.3390/en15217910

Jia, J. (2007). Investigations of vehicle securing without lashings for Ro-Ro ships. *Journal of Marine Science and Technology*, *12*(1), 43–57. https://doi.org/10.1007/s00773-006-0240-7

Kafalı, K. (1988). *Gemilerin dizaynı*. İTÜ Baskısı.

Kane, M. (2023). Electric cars from heaviest to lightest. Retrieved on June 5, 2023, from https://insideevs.com/news/527966/electric-cars-from-heaviest-lightest/

Kang, M. H., Choi, H. R., Kim, H. S., & Park, B. J. (2012). Development of a maritime transportation planning support system for car carriers based on genetic algorithm. *Applied Intelligence*, *36*, 585–604. https://doi.org/10.1007/s10489-011-0278-z

Kavli, H. P., Oguz, E., & Tezdogan, T. (2017). A comparative study on the design of an environmentally friendly RoPax ferry using CFD. *Ocean Engineering*, *137*, 22–37. https://doi.org/10.1016/j.oceaneng.2017.03.043

Kennedy, C. (2023). Ro-Ro ferries and the expansion of the PLA's landing ship fleet. Retrieved on June 2, 2023, from https://cimsec.org/ro-ro-ferries-and-the-expansion-of-the-plas-landing-ship-fleet/

Korlak, P. K. (2021). Analysis of operational efficiency of the proposed propulsion systems for selected large ropax vessel. *Nase More*, *68*(3), 199–210. https://doi.org/10.17818/NM/2021/3.7

Kupras, L. K. (1981). Design charts for determining main dimensions, main engine power and building costs of bulkcarriers. *International Shipbuilding Progress*, *28*(322), 136–150.

Kweku, D., Bismark, O., Maxwell, A., Desmond, K., Danso, K., Oti-Mensah, E., Quachie, A., & Adormaa, B. (2017). Greenhouse effect: greenhouse gases and their impact on global warming. *Journal of Scientific Research and Reports*, *17*(6), 1–9. https://doi.org/10.9734/jsrr/2017/39630

Labanti, J., Islam, H., & Guedes Soares, C. (2016). CFD assessment of ropax hull resistance with various initial drafts and trim angles. *Proceedings of 3rd International Conference on Maritime Technology and Engineering, MARTECH 2016*, *1*(October 2017), 325–332. https://doi.org/10.1201/b21890-45

Law, L. C., Othman, M. R., & Mastorakos, E. (2023). Numerical analyses on performance of low carbon containership. *Energy Reports*, *9*, 3440–3457. https://doi.org/10.1016/j.egyr.2023.02.035

Lee, S., Yoo, S., Park, H., Ahn, J., & Chang, D. (2021). Novel methodology for EEDI calculation considering onboard carbon capture and storage system. *International Journal of Greenhouse Gas Control*, *105*, 103241. https://doi.org/10.1016/j.ijggc.2020.103241

Luo, X., & Wang, M. (2017). Study of solvent-based carbon capture for cargo ships through process modelling and simulation. *Applied Energy*, *195*, 402–413. https://doi.org/10.1016/j.apenergy.2017.03.027

MAN. (2014). EEDI energy efficiency design index. Retrieved on October 1, 2014, from https://www.man-es.com/docs/default-source/document-sync-archive/eedi-eng.pdf?sfvrsn=23fbab95_4#:~:text=What%20is%20the%20Energy%20Efficiency,negative%20impact%20on%20the%20environment.

MAN. (2017). Emission project guide. In MAN Energy Solutions. Retrieved on October 1, 2017, from https://man-es.com/applications/projectguides/2stroke/content/special_pg/PG_7020-0145.pdf

Marlantes, K. E., Kim, S. P., & Hurt, L. A. (2022). Implementation of the IMO Second Generation Intact Stability Guidelines. *Journal of Marine Science and Engineering*, *10*, 41. https://doi.org/10.3390/jmse10010041

McClintock, J., Ducklow, H., & Fraser, W. (2008). Ecological responses to climate change on the Antarctic Peninsula. *American Scientist*, *96*(4), 302–310. https://doi.org/10.1511/2008.73.3844

Mihail–Vlad, V. (2018). Advantages and disadvantages of different types of graphs. *Journal of Marine Technology and Environment*, *2*(2), 57.

Mikhaylov, A., Moiseev, N., Aleshin, K., & Burkhardt, T. (2020). Global climate change and greenhouse effect. *Entrepreneurship and Sustainability Issues*, *7*(4), 2897–2913. https://doi.org/10.9770/jesi.2020.7.4(21)

Molland, A. F., Turnock, S. R., & Hudson, D. A. (2017). *Ship resistance and propulsion*. Cambridge University Press.

Mores, P., Rodríguez, N., Scenna, N., & Mussati, S. (2012). CO_2 capture in power plants: Minimization of the investment and operating cost of the post-combustion process using MEA aqueous solution. *International Journal of Greenhouse Gas Control*, *10*, 148–163. https://doi.org/10.1016/j.ijggc.2012.06.002

Mores, P., Scenna, N., & Mussati, S. (2012). A rate based model of a packed column for CO2 absorption using aqueous monoethanolamine solution. *International Journal of Greenhouse Gas Control*, *6*, 21-36. https://doi.org/10.1016/j.ijggc.2011.10.012

Nieuwenhuis, P. (2017). Car Shipping. In A. Beresford & S. Pettit (Eds.), *International Freight Transport: Cases, Structures and Prospects*. Kogan Page.

Niklas, K., & Pruszko, H. (2019). Full-scale CFD simulations for the determination of ship resistance as a rational, alternative method to towing tank experiments. *Ocean Engineering*, *190*, 106435. https://doi.org/10.1016/j.oceaneng.2019.106435

Perissi, I., & Jones, A. (2022). Investigating European Union decarbonization strategies: Evaluating the pathway to carbon neutrality by 2050. *Sustainability*, *14*(8), 4728. https://doi.org/10.3390/su14084728

Perrault, D. (2016). Correlations of GZ curve parameters. *Proceedings of the 15th International Ship Stability Workshop*, Sweden. pp. 1-10.

Polakis, M., Zachariadis, P., & de Kat, J. O. (2019). The energy efficiency design index (EEDI). In Psaraftis, H. (Ed.), *Sustainable shipping*. Springer. https://doi.org/10.1007/978-3-030-04330-8_3

Rutherford, D., Mao, X., & Comer, B. (2020). Potential CO_2 reductions under the Energy Efficiency Existing Ship Index. *International Council on Clean Transportation, Working Paper 2020-27. November 2020*, 1-18.

Sachs, N. M. (2020). The Paris agreement in the 2020s: Breakdown or breakup. *Ecology Law Quarterly*, *46*(3), 865–909. https://doi.org/10.15779/Z38H708140

Salinger, M.J. (2005). Climate variability and change: Past, present and future — an overview. In Salinger, J., Sivakumar, M., & Motha, R. P. (Eds.), *Increasing climate variability and change* (pp. 9-27). Springer. https://doi.org/10.1007/1-4020-4166-7_3

Shakeel, M., Khalid, H., Riaz, Z., Ansari, S. A., & Khan, M. J. (2022). Development of intact stability calculations tool for ships. *Proceedings of 2022 19th International Bhurban Conference on Applied Sciences and Technology*, pp. 858–872. https://doi.org/10.1109/IBCAST54850.2022.9990257

Shepherd, T. A., Zhao, Y., Li, H., Stinn, J. P., Hayes, M. D., & Xin, H. (2015). Environmental assessment of three egg production systems- Part II. Ammonia, greenhouse gas, and particulate matter emissions. *Poultry Science*, *94*(3), 534–543. https://doi.org/10.3382/ps/peu075

Shin, J., & Park, S. (2023). Numerical analysis for optimizing combustion strategy in an ammonia-diesel dual-fuel engine. *Energy Conversion and Management*, *284*, 116980. https://doi.org/10.1016/j.enconman.2023.116980

Simopoulos, G., Konovessis, D., & Vassalos, D. (2008). Sensitivity analysis of the probabilistic damage stability regulations for RoPax vessels. *Journal of Marine Science and Technology*, *13*(2), 164–177. https://doi.org/10.1007/s00773-007-0261-x

Skoupas, S., Zaraphonitis, G., & Papanikolaou, A. (2009). Parametric design and optimization of high-speed, twin-hull roro-passenger vessels. *Proceedings of the 10th International Marine Design Conference*, Norway. pp. 744-760.

Song, L. H., Zhang, Z. G., Wang, X. Z., & Feng, D. K. (2013). Prediction of surface ship's residual resistance coefficient using neural networks. *Advanced Materials Research*, *756–759*, 3141–3144. https://doi.org/10.4028/www.scientific.net/AMR.756-759.3141

Stec, M., Tatarczuk, A., Iluk, T., & Szul, M. (2021). Reducing the energy efficiency design index for ships through a post-combustion carbon capture process. *International Journal of Greenhouse Gas Control*, *108*, 103333. https://doi.org/10.1016/j.ijggc.2021.103333

Sun, X., Wang, S., Wang, Z., Liu, C., & Yin, Y. (2022). A semi-automated approach to stowage planning for Ro-Ro ships. *Ocean Engineering*, *247*, 110648. https://doi.org/10.1016/j.oceaneng.2022.110648

Tadros, M., Ventura, M., & Guedes Soares, C. (2022). Optimization procedures for a twin controllable pitch propeller of a ROPAX ship at minimum fuel consumption. *Journal of Marine Engineering and Technology*, *22*(4), 167-175. https://doi.org/10.1080/20464177.2022.2106623

Thies, F., & Ringsberg, J. W. (2023). Retrofitting WASP to a RoPax vessel—design, performance and uncertainties. *Energies*, *16*(2), 673. https://doi.org/10.3390/en16020673

Tuswan, T., Zubaydi, A., Piscesa, B., Ismail, A., Ariesta, R. C., Ilham, M. F., & Mualim, F. I. (2021). Influence of application of sandwich panel on static and dynamic behaviour of ferry ro-ro ramp door. *Journal of Applied Engineering Science*, *19*(1), 208–216. https://doi.org/10.5937/jaes0-27708

Wang, H., Hou, Y., Xiong, Y., & Liang, X. (2021). Research on multi-interval coupling optimization of ship main dimensions for minimum EEDI. *Ocean Engineering*, *237*, 109588. https://doi.org/10.1016/j.oceaneng.2021.109588

Wang, M., Lawal, A., Stephenson, P., Sidders, J., & Ramshaw, C. (2011). Post-combustion CO_2 capture with chemical absorption: A state-of-the-art review. *Chemical Engineering Research and Design*, *89*(9), 1609–1624. https://doi.org/10.1016/j.cherd.2010.11.005

Xing, H., Spence, S., & Chen, H. (2020). A comprehensive review on countermeasures for CO_2 emissions from ships. *Renewable and Sustainable Energy Reviews*, *134*, 110222. https://doi.org/10.1016/j.rser.2020.110222

Yasukawa, H. (2019). Maneuvering hydrodynamic derivatives and course stability of a ship close to a bank. *Ocean Engineering*, *188*, 106149. https://doi.org/10.1016/j.oceaneng.2019.106149

Zhong, W., & Haigh, J. D. (2013). The greenhouse effect and carbon dioxide. *Weather*, *68*(4), 100–105. https://doi.org/10.1002/wea.2072

Zhou, Y.-M., & Feng, Y.-S. (2014). The strategy and technology selection for non-CO_2 greenhouse gas emission control. *Advances in Climate Change Research*, *5*(1), 28–33. https://doi.org/10.3724/SP.J.1248.2014.028

Mar. Sci. Tech. Bull. (2023) 12(3): 282-311
e–ISSN: 2147–9666
info@masteb.com

dergipark.org.tr/en/pub/masteb
www.masteb.com
DOI: 10.33714/masteb.1224099

Marine Science and Technology Bulletin

PRENSIP
https://prensip.gen.tr/

REVIEW ARTICLE

Optimization for green container shipping: A review and future research directions

Ercan Kurtuluş[1*]

[1] *Karadeniz Technical University, Surmene Faculty of Marine Science, Department of Maritime Business Administration, 61530, Trabzon, Türkiye*

ARTICLE INFO

Article History:
Received: 25.12.2022
Received in revised form: 02.08.2023
Accepted: 13.08.2023
Available online: 28.09.2023

Keywords:
Green container shipping
Environmental optimization
Optimization
Review

ABSTRACT

Maritime freight transportation is one of the least emissions-producing transportation alternatives in terms of transported tonnage per distance. However, it produces a high amount of emissions as around 80% of international freight transportation is conducted through seas and 20% of maritime transportation is conducted through container shipping. This makes it crucial to reduce emissions in container shipping. In this regard, this study reviewed previous studies on the environmental optimization of container shipping and identified various future research directions. The results showed that in the sea segment of environmental optimization of container shipping, decisions which require further attention include resource allocation, emission reduction technology choice, disruption recovery, freight rate optimization, and shipment scheduling. The decisions that require future research in the port segment are related to internal transportation and handing operations in container terminals (i.e., yard crane deployment, yard truck deployment, yard truck scheduling, yard container stack allocation, yard container retrieval), renewable energy source installation, and emission reduction technology choice. Vessel scheduling and speed optimization decisions are the most frequently studied decisions in the sea segment, but they are rarely considered for inland shipping of containers. In the sea-port combined segment of container shipping, future studies are required in quay crane scheduling, vessel scheduling, container route allocation, ship route allocation vessel deployment, and emission reduction technology choice. The least studied decision in the door-to-door segment of container shipping includes hub location-allocation, empty container relocation, ship route allocation, vessel deployment, environmental taxation and subsidy scheme, emissions reduction technology choice, and speed optimization. It was also demonstrated that modeling of future studies should more frequently consider uncertainties and social sustainability parameters.

Please cite this paper as follows:

Kurtuluş, E. (2023). Optimization for green container shipping: A review and future research directions. *Marine Science and Technology Bulletin*, *12*(3), 282-311. https://doi.org/10.33714/masteb.1224099

* Corresponding author
E-mail address: kurtulusercan@gmail.com (E. Kurtuluş)

Introduction

Maritime transportation of freight plays a crucial role in international trade as over 80% of it is carried through seas (UNCTAD, 2021). Means for freight transportation in seas highly depend on the characteristics of the goods to be carried. Therefore, maritime transportation consists of various sub-markets, and container shipping is one of them. Container shipping is conducted by standardized maritime container equipment in which freight is stuffed. That container equipment requires specialized container ships to carry them and specialized container terminals at seaports to transfer them between ships and shore. The adoption of containers in maritime transportation grew fast because of their convenience and efficiency in handling and transferring them between different modes of transport. This growth in container transportation has led container shipping companies to increase their transportation capacity by ordering more and bigger ships. The increased adoption of containerization has brought the environmental impacts of container ships under scrutiny.

Like any other industry, reducing emissions in the maritime transportation sector has become important as the effects of climate change show themselves more and more. Maritime freight transportation is one of the least emissions-producing transportation alternatives in terms of transported tonnage per distance because of its high-capacity transportation capability. Although it produces a low amount of emission per unit transported, it produces a high amount of emission as most of the international trade is conducted by maritime transportation. For this reason, in 2018, IMO member states agreed to reduce the total annual GHG emissions resulting from ships by at least 50% by 2050 compared to 2008. Because around 20% of maritime freight transportation consists of container shipping (UNCTAD, 2021), container shipping must also comply with the emissions target of IMO.

Achieving the emissions target set by IMO requires a holistic approach that includes planning container shipping activities at strategic, tactical, or operational levels in addition to the adaptation of new technologies such as scrubbers, and new propulsion systems working with LNG or ammonia or fuel cells (Lagemann et al., 2022). Planning those activities requires an analytical approach to derive a benefit from it because the application of ad hoc planning might result in financial loss without environmental benefits (Dulebenets et al., 2021). In that manner, optimization modeling is widely used for the environmental planning of container shipping. However, there are still areas that need to be explored to reach the emissions target of the container shipping industry. To determine research gaps and the status of scientific knowledge in the area of environmental optimization in container shipping, there is a need for an in-depth literature review and analysis of future research opportunities. Several previous studies performed reviews in the area of container shipping optimization, but they mostly neglect the environmental aspect. They can be grouped under four headings: the studies that reviewed container shipping optimization studies in the seaborne transportation segment (J. Chen, Ye, Zhuang, et al., 2022; Christiansen et al., 2020; Dulebenets et al., 2021; Mansouri et al., 2015; Meng et al., 2014; Psaraftis & Kontovas, 2013; S. Wang & Meng, 2017; H. Yu et al., 2021); the studies that reviewed container shipping optimization studies in the container terminal segment (Abdelmagid et al., 2022; Yu et al., 2022); the studies that reviewed container shipping optimization studies in the inland transportation segment (R. Chen et al., 2022; Lam & Gu, 2013); the studies that reviewed door-to-door container shipping optimization studies (Caris et al., 2008; Rajkovic et al., 2016). Few of the review studies in the area investigated the environmental optimization of container shipping. Lam & Gu (2013) provided a review of the studies in the area of hinterland container flow optimization with green concerns. Psaraftis & Kontovas (2013) reviewed the studies that modeled speed optimization for energy efficiency in the sea leg of container shipping. In a very similar vein, Yu et al. (2021) investigated the studies that provided voyage optimization modeling to reduce environmental emissions of container shipping. In another study on the sea leg of container shipping optimization, Dulebenets et al. (2021) reviewed studies on the optimization of container liner shipping vessel schedules and distinguished the ones that provide an environmental perspective. The current study differentiates from those studies by providing a comprehensive literature review that considers environmental optimization in every segment of container shipping (i.e., sea, port, and inland). A handful of the previous studies provided optimization modeling that combines two or more segments, for example, some studies combined vessel speed optimization with berth allocation. In this regard, the current study aims to review the studies which focused on environmental optimization in each segment of container shipping by analyzing the status of the scientific contributions and providing insights regarding future research opportunities. The results of the analysis will provide scholars with prominent research directions to investigate the most under-researched research subjects related to the environmental optimization of container shipping.

Material and Method

This study reviewed the scientific studies on the environmental optimization of container shipping. To ensure the research conducted in the studies has a certain level of quality and is peer-reviewed, the review only considered the ones published in Web of Science indexed journals particularly indexed in the core collection: SCI-Expanded, SSCI, and ESCI. A systematic review method was adapted in this study. The systematic review is a literature review approach which has a clear research question and uses a systematic approach for identifying, selecting and analyzing studies (Moher et al., 2009; Snyder, 2019). To be systematic in the search process, we used a combination of three groups of keywords in three orders. The keywords in the first order included three keywords that specified the optimization aspect ("optimize", "optimizing", and "optimization"), and the keywords in the second order also included three keywords that specified the environmental aspect (“green”, “environmental”, and “emissions”), and the keywords in the last order included six keywords that specified the container shipping aspect ("container shipping", "liner shipping", "container terminal", "container port", "container transport", and "container transportation"). For example, one of the searches included a combination of those keywords in the keyword groups as "optimize green container shipping". A total of 54 searches were performed in the keywords, abstract, and title sections of the articles because the total combination of the keywords in the three groups is 54 (3×3×6).

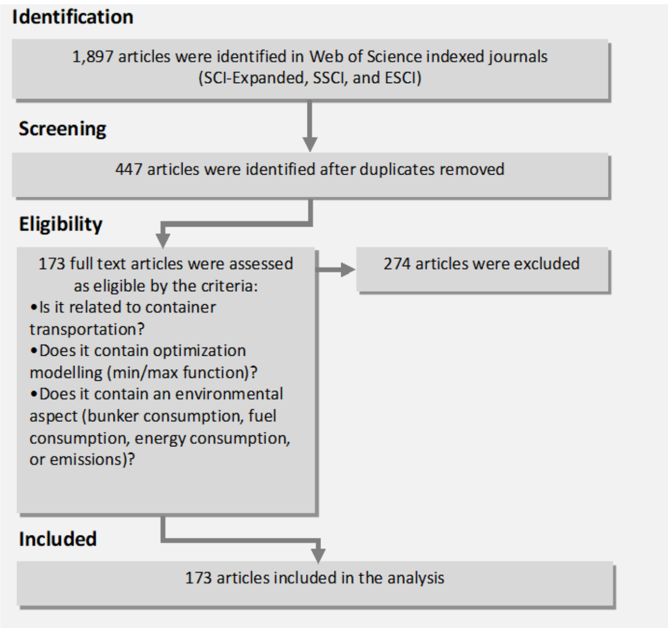


Figure 1. Article inclusion/exclusion process

Article inclusion/exclusion workflow was visualized in Figure 1. The workflow process visualization was done according to Moher et al. (2009). The search results included 1,897 items including duplicates. After the duplicates in the results were removed, 447 scientific articles remained. However, there were still unrelated articles present in the results. Therefore, each paper was further evaluated considering if it is in the area of container shipping and if it performed an optimization modelling (has a max/min function), and if it includes environmental optimization (bunker consumption, fuel consumption, energy consumption, or emissions) in its objective function or its constraints. The oldest research article dated back to 2009. Because the oldest article which satisfies the incision criteria is only 14 years old, a year limit was not included. After the elimination of the articles that do not satisfy those criteria, 173 articles were finally included in for the analysis.

The articles were grouped under the segments of container shipping they considered. The research in some of the articles considered more than one segment. Five groups of articles were constructed according to the container shipping segment considered in their research: environmental optimization in the sea segment of container shipping; environmental optimization in the port segment of container shipping; environmental optimization in the inland segment of container shipping; environmental optimization in the sea-port (includes combination both sea and port) segment of container shipping; and environmental optimization in door-to-door (includes sea, port, and inland) container shipping. Decisions considered by each included research article was identified along with other aspects. Some terms used in those decisions were kept general. For example, quay crane includes mobile harbor crane and gantry crane and yard truck includes terminal truck, automated guided vehicles and straddle carriers (straddle carriers can transport containers in a container terminal and stuck them at a container yard). Under these five groups, the following sections will evaluate the current status of the scientific contribution and future research directions.

Results and Discussion

Environmental Optimization in the Sea Segment of Container Shipping

Table 1 summarizes the environmental optimization studies related to the sea segment of container shipping. The studies evaluated five aspects: the decisions considered in their research, the type of uncertainty if their research includes stochasticity, the modeling approach, decision level, and parameters considered in their objective functions. Before further elaboration, it needs to be clarified that in the context of this study vessel scheduling decisions include the determination of arrival times and departure times of vessels and service frequency on liner services, on the other hand, vessel deployment decisions include the determination of the number of vessels should be allocated to liner services.

Table 1 shows that 74 studies focused on the sea segment of container shipping. It is more than one-third of the total 173. This indicates that environmental optimization studies on container shipping mostly consider the sea segment. As it comes to the decisions considered in those studies, speed optimization is the most studied decision after vessel deployment and vessel scheduling decisions are the ones that were studied most.

As it is shown in Table 1, several of the articles considered single decisions. X. Li et al. (2022), Lu et al. (2023), X. Li et al. (2020), Y. Zhao et al. (2020), Lee et al. (2018), and Wong et al. (2015) included speed optimization as a single decision. X. Li et al. (2022) minimized fuel consumption. Y. Zhao et al. (2020), Lee et al. (2018), and Wong et al. (2015) minimized fuel consumption and time while X. Li et al. (2020) and Lu et al. (2023) minimized fuel consumption and other costs. None of them considered uncertainties. L. Chen et al. (2018) and Du et al. (2015) studied ship route allocation as a single decision. L. Chen et al. (2018) optimized fuel consumption, costs, and time without considering uncertainties. Du et al. (2015) only optimized fuel consumption and considered the fuel consumption of ships as an uncertain input. M. Liu et al. (2022) and Trapp et al. (2020) optimized container route allocation. M. Liu et al. (2022) minimized emissions and costs while considering transportation demand as an uncertain input. Trapp et al. (2020) minimized emissions, costs, and transit time without including stochasticity. Zhen et al. (2017) considered the bunkering decision as a single decision to optimize fuel consumption. They included ship fuel consumption and fuel price as uncertain inputs. M.-M. Yu & Chen (2016) evaluated resource allocation decisions while optimizing efficiency and they considered emission production as one of their constraints.

Several of the studies shown in Table 1 included a combination of two decisions. Zacharioudakis et al. (2011), S. Wang (2016), S. Wang & Wang (2016), and Xing et al. (2019) considered speed optimization and vessel deployment decisions together. Xing et al. (2019) optimized fuel consumption and other costs while Zacharioudakis et al. (2011), S. Wang (2016), S. Wang & Wang (2016) optimized ship time in addition to fuel consumption and costs. None of those studies included stochasticity. Zhen, Hu, et al. (2020) and W. Zhao et al. (2021) considered ship route allocation and speed optimization together. Zhen, Hu, et al. (2020) optimized only fuel consumption, on the other hand, W. Zhao et al. (2021) minimized the time and navigational risks. Both of them neglected uncertainty. C. Li et al. (2015) and Y. Liu et al. (2022) studied disruption recovery and speed optimization together while overlooking uncertainties. C. Li et al. (2015) minimized fuel consumption and time. Y. Liu et al. (2022) minimized costs in addition to those parameters. Qi & Song (2012), S. Wang et al. (2015), and Reinhardt et al. (2020) studied vessel scheduling and speed optimization together. Reinhardt et al. (2020) optimized only fuel consumption. Qi & Song (2012) and S. Wang et al. (2015) minimized the shipping time in addition to fuel consumption. Qi & Song (2012) included port times as uncertain inputs for their model. Y. Liu et al. (2021) studied speed optimization and container route allocation together and minimized emissions and costs. Dong & Tae-Woo Lee (2020) considered speed optimization together with freight rate optimization while minimizing fuel consumption, costs, and shipping time. R. Tan et al. (2020) integrated speed optimization with bunkering and minimized bunker consumption and costs. J. Chen, Ye, Liu, et al. (2022) studied emission reduction strategy choice and ship route allocation and optimized emission production and costs. Their study considered uncertain transportation demand. X. Zhang et al. (2020) studied shipment scheduling and container route optimization to minimize both emissions and costs. M. Zhu et al. (2018) studied ship route allocation and vessel deployment together while considering carbon tax as an uncertain input, they optimized both emissions and costs. Matsukura et al. (2010) considered ship route allocation and container route allocation together to optimize emission production. Wu et al. (2023) and R. Tan et al. (2022) integrated emission reduction technology choice and speed optimization by optimizing emissions and other costs.

Table 1 shows that several studies included a combination of three decisions. A handful of them considered vessel scheduling, vessel deployment, and speed optimization decisions together (Dulebenets & Ozguven, 2017; Giovannini & Psaraftis, 2019; Song et al., 2015; S. Wang et al., 2014; W. Ma et al., 2022; Sun et al., 2022). Dulebenets (2022), Jiang et al. (2020), Dulebenets (2018a), Dulebenets (2018b), Dulebenets & Ozguven (2017), Dulebenets, Golias, et al. (2017), Dulebenets

(2016), Giovannini & Psaraftis (2019), and S. Wang et al. (2014) optimized fuel consumption, costs and time while Song et al. (2015) optimized fuel consumption, cost and time reliability and Alharbi et al. (2015), W. Ma et al. (2022) and Sun et al. (2022) only optimized fuel consumption and other costs. None of those studies included uncertain inputs in their modeling. A few studies considered speed optimization, bunkering and vessel deployment decisions (S. Wang & Meng, 2015; M. Liu et al., 2020; Y. Wang et al., 2018; Wu et al., 2022a). M. Liu et al. (2020) and S. Wang & Meng (2015) optimized fuel consumption, costs, and time, on the other hand, Y. Wang et al. (2018) and Wu et al., (2022a) only optimized fuel consumption and other costs. Except Wu et al., (2022a), all of them included uncertainty in their modeling. M. Liu et al. (2020) considered uncertain transportation demand, Y. Wang et al. (2018) considered fuel price as uncertain and S. Wang & Meng (2015) considered the speed of ships as uncertain input to their modeling. Cheaitou & Cariou (2019) and S. Wang & Meng (2012) studied speed optimization, vessel deployment, and container route allocation decisions altogether. While Cheaitou & Cariou (2019) optimized fuel consumption, costs, and time, S. Wang & Meng (2012) only optimized fuel consumption and costs. Both of the studies did not consider uncertainty in their modeling. Y. Zhao et al. (2021) also considered vessel deployment and ship route allocation together but they included emission reduction technology choice to optimize emissions and costs. Their model considered several uncertainties i.e., transportation demand, charter rate, fuel price, and ship technology renewal time for emission reduction. C. Wang et al. (2022) considered vessel deployment, ship route allocation, and vessel scheduling together. They optimized fuel consumption, costs, and shipping time. Wu et al. (2022b), Lan, Zuo, et al. (2023), and Zhuge et al. (2021) studied vessel deployment and ship route allocation together in the context of speed optimization by minimizing fuel consumption and other costs. Y. Yu et al. (2021) studied container route allocation, and ship route allocation with speed optimization by optimizing fuel consumption and costs. S. Li, Tang, et al. (2023) and Abioye et al. (2019) studied disruption recovery in vessel scheduling by optimizing ship speed. S. Li, Tang, et al. (2023) optimized fuel consumption and other costs and Abioye et al. (2019) optimized fuel consumption, other costs, and shipping time. S. Zhao et al. (2022) and Aydin et al. (2017) studied ship bunkering by considering vessel scheduling and speed optimization. S. Zhao et al. (2022) optimized emissions and other costs. Aydin et al. (2017) optimized fuel consumption and ship time while considering port time as an uncertain input. Y. Zhao et al. (2023) integrated vessel deployment, emission reduction technology choice, and speed optimization while minimizing fuel consumption and other costs.

Some of the studies shown in Table 1 simultaneously consider four decisions. Lan, Tao, et al. (2023), Gao & Hu (2021), and Cariou et al. (2018) studied container route allocation, ship route allocation, vessel deployment, and speed optimization decisions simultaneously. Lan, Tao, et al. (2023) and Gao & Hu (2021) optimized fuel consumption with other costs. Cariou et al. (2018) minimized shipping time as well as fuel consumption and costs. Wen et al. (2022) studied disruption recovery, vessel deployment, vessel scheduling, and speed optimization simultaneously by optimizing fuel consumption, costs, and time reliability. De et al. (2021) studied ship bunkering together with vessel scheduling, disruption recovery, and speed optimization and their objective function included the minimization of fuel consumption and costs. W. Ma et al., (2021) also studied ship bunkering, vessel scheduling, and speed optimization but with ship route allocation. They optimized fuel consumption, costs, and shipping time. Two other studies related to the shipping bunkering decision was provided by C. Wang & Chen (2017) and Lin & Leong (2022). Their studies integrated vessel scheduling, vessel deployment, and speed optimization in bunkering. C. Wang & Chen (2017) optimized fuel consumption, other costs, and ship time. Lin & Leong (2022) optimized fuel consumption and other costs by considering uncertain fuel consumption. S. Wang et al. (2021) studied ship route allocation, vessel deployment, and speed optimization for emission reduction technology choice for the deployed container ships. Their model optimized emissions and costs. S. Wang et al. (2013) integrated vessel scheduling, vessel deployment, speed optimization, and shipment scheduling to optimize fuel consumption and costs. Pasha et al. (2021) studied ship route allocation, vessel scheduling, vessel deployment, and speed optimization by optimizing fuel consumption, other costs, and ship time.

Environmental Optimization in the Port Segment of Container Shipping

Table 2 summarized the environmental optimization studies related to the port segment of container shipping. The most studied decisions are berth allocation, scheduling, and deployment of quay and yard cranes. In the context of this study, scheduling decisions involve time factors and deployment decisions include the quantity of the deployed entity. As can be seen in Table 2 the majority of the studies considered a combination of two or more decisions.

Table 1: Studies on environmental optimization in sea segment of container shipping

Reference	Uncertainty									Decision										Modelling			Level			Objective					
	Transportation Demand	*Charter Rate*	*Fuel Consumption*	*Fuel Price*	*Carbon Tax*	*Renewal Time*	*Ship Speed*	*Port/Handling Time*	*Resource Allocation*	*Bunkering*	*Vessel Scheduling*	*Container Route Allocation*	*Ship Route Allocation*	*Vessel Deployment*	*Disruption Recovery*	*Emission Reduction Technology Choice*	*Speed Optimization*	*Freight Rate Optimization*	*Shipment Scheduling*	*Non-Linear*	*Linearized*	*Linear*	*Strategic*	*Tactical*	*Operational*	*Emissions/Energy/Fuel*	*Costs (Operational Costs, Handling Costs, Fixed Costs, etc.)*	*Time*	*Time Reliability*	*Navigational Risk*	*Efficiency*
S. Li, Tang, et al. (2023)											√				√		√				√			√	√	√	√				
Lu et al. (2023)																	√			√					√	√	√				
Y. Zhao et al. (2023)														√		√	√				√		√	√	√	√	√				
Lan, Tao, et al. (2023)												√	√	√			√					√		√	√	√	√				
Wu et al. (2023)																√	√				√		√		√	√	√				
Lan, Zuo, et al. (2023)													√	√			√			√				√	√	√	√				
S. Zhao et al. (2022)										√	√						√				√			√	√	√	√				
R. Tan et al. (2022)																√	√				√		√		√	√	√				
X. Li et al. (2022)																	√				√				√	√					
Wu et al. (2022b)													√	√			√			√				√	√	√	√				
Wu et al. (2022a)										√				√			√				√			√	√	√	√				
Sun et al. (2022)											√			√			√					√		√	√	√	√				
Lin & Leong (2022)			√							√	√			√			√				√			√	√	√	√				
W. Ma et al. (2022)											√			√			√			√				√	√	√	√	√			
J. Chen, Ye, Liu, et al. (2022)	√												√			√				√			√	√		√	√				
C. Wang et al. (2022)											√		√	√						√				√		√	√	√			
Dulebenets (2022)											√			√			√				√			√	√	√	√	√			
M. Liu et al. (2022)	√											√									√				√	√	√				
Y. Liu et al. (2022)															√		√			√					√	√	√	√			
Wen et al. (2022)											√			√	√		√			√				√	√	√	√		√		
Gao & Hu (2021)												√	√	√			√				√			√	√	√	√				
Y. Liu et al. (2021)												√					√				√			√	√	√	√				
Pasha et al. (2021)											√		√	√			√				√		√	√	√	√	√	√			
De et al. (2021)										√	√				√		√			√					√	√	√				
Y. Zhao et al. (2021)	√	√		√		√							√	√		√					√		√	√		√	√				
Zhuge et al. (2021)													√	√			√			√			√	√	√	√	√				
W. Ma et al., (2021)										√	√		√				√			√				√	√	√	√	√			
Y. Yu et al. (2021)												√	√				√			√				√	√	√	√				
S. Wang et al. (2021)													√	√		√	√				√		√	√	√	√	√				
W. Zhao et al. (2021)													√				√			√					√	√		√		√	
X. Li et al. (2020)																	√				√				√	√	√				
Zhen, Hu, et al. (2020)													√				√								√	√					
Reinhardt et al. (2020)											√						√				√			√	√	√					
Trapp et al. (2020)												√										√			√	√	√	√			
Dong & Tae-Woo Lee (2020)																	√	√		√					√	√	√	√			
M. Liu et al. (2020)	√									√				√			√				√		√	√	√	√	√	√			
X. Zhang et al. (2020)												√							√		√			√	√	√	√				
Jiang et al. (2020)											√			√			√				√		√	√	√	√	√	√			
R. Tan et al. (2020)										√							√					√			√	√	√				
Y. Zhao et al. (2020)																	√			√					√	√		√			
J. Yu et al. (2019)																√						√	√			√	√				
Xing et al. (2019)														√			√				√			√	√	√	√				
Giovannini & Psaraftis (2019)											√			√			√				√		√	√	√	√	√	√			
Cheaitou & Cariou (2019)												√		√			√			√			√		√	√	√				
Abioye et al. (2019)											√				√		√				√				√	√	√	√			
M. Zhu et al. (2018)					√								√	√								√	√			√	√				
Y. Wang et al. (2018)				√						√				√			√			√				√	√	√	√				
Lee et al. (2018)																	√			√					√	√		√			
Dulebenets (2018a)											√			√			√				√			√	√	√	√				
Dulebenets (2018b)											√			√			√				√			√	√	√	√				
L. Chen et al. (2018)													√									√			√	√	√	√			
Cariou et al. (2018)												√	√	√			√				√		√	√	√	√	√	√			
Zhen et al. (2017)			√	√						√										√					√	√					
C. Wang & Chen (2017)										√	√			√			√			√			√		√	√	√	√			

Table 1 (continued)

Reference	Uncertainty									Decision										Modelling			Level			Objective					
	Transportation Demand	*Charter Rate*	*Fuel Consumption*	*Fuel Price*	*Carbon Tax*	*Renewal Time*	*Ship Speed*	*Port/Handling Time*	*Resource Allocation*	*Bunkering*	*Vessel Scheduling*	*Container Route Allocation*	*Ship Route Allocation*	*Vessel Deployment*	*Disruption Recovery*	*Emission Reduction Technology Choice*	*Speed Optimization*	*Freight Rate Optimization*	*Shipment Scheduling*	*Non-Linear*	*Linearized*	*Linear*	*Strategic*	*Tactical*	*Operational*	*Emissions/Energy/Fuel*	*Costs (Operational Costs, Handling Costs, Fixed Costs, etc.)*	*Time*	*Time Reliability*	*Navigational Risk*	*Efficiency*
Dulebenets & Ozguven (2017)											√			√			√				√			√	√	√	√	√			
Dulebenets, Golias, et al. (2017)											√			√			√							√	√	√	√	√			
Aydin et al. (2017)								√		√	√						√			√					√	√		√			
M.-M. Yu & Chen (2016)									√													√		√							√
S. Wang & Wang (2016)														√			√			√				√	√	√	√	√			
S. Wang (2016)														√			√			√				√	√	√	√	√			
Dulebenets (2016)											√			√			√				√		√	√	√	√	√	√			
Wong et al. (2015)																	√			√					√	√		√			
S. Wang et al. (2015)											√						√					√			√	√		√			
S. Wang & Meng (2015)							√			√				√			√				√		√		√	√	√	√			
Song et al. (2015)								√			√			√			√			√			√		√	√	√		√		
C. Li et al. (2015)															√		√			√					√	√		√			
Du et al. (2015)			√										√								√			√		√					
Alharbi et al. (2015)											√			√			√				√			√	√	√	√				
S. Wang et al. (2014)											√			√			√				√			√	√	√	√	√			
S. Wang et al. (2013)											√			√			√		√	√				√	√	√	√				
S. Wang & Meng (2012)												√		√			√				√			√	√	√	√				
Qi & Song (2012)								√			√						√			√					√	√		√			
Zacharioudakis et al. (2011)														√			√			√				√	√	√	√	√			
Matsukura et al. (2010)												√	√									√		√	√	√					

Several of them considered a single decision. Nadi et al. (2022), Xu et al. (2022), Caballini et al. (2020), Fan et al. (2019), Do et al. (2016), and G. Chen et al. (2013) studied inland truck appointments systems as a single decision in seaport container terminals. Xu et al. (2022) and Fan et al. (2019) optimized emissions, costs, and truck times. Xu et al. (2022) included uncertain truck arrival times in their modeling. Nadi et al. (2022) and G. Chen et al. (2013) optimized only truck times while Caballini et al. (2020) optimized time and time reliability. Do et al. (2016) optimized only emissions while considering uncertainty in truck arrival times. Dulebenets, Moses, et al. (2017), Zhen et al. (2016), and Golias et al. (2009) studied berth allocation in seaport container terminals as a single environmental optimization decision. Dulebenets, Moses, et al. (2017) and Zhen et al. (2016) optimized emissions, costs, and ship time while Golias et al. (2009) optimized only emissions and time and none of them considered uncertainty. S. Chen & Zeng (2021) and J. He, Huang, & Yan (2015) studied yard crane scheduling as a single optimization decision by optimizing emissions and crane time. Kanellos (2019) studied electricity grid allocation in seaport container terminals as a single decision by optimizing emissions and costs and considering electricity price as an uncertain input parameter. D. Liu & Ge (2018) studied crane deployment in seaport container terminals and optimized costs considering emissions as a constraint. L. Li et al. (2018) studied renewable electricity source installation considering uncertain electricity supply and minimized installation costs. H. Li & Li (2022) studied quay crane scheduling optimizing energy usage. Duran et al. (2022) and Abu Aisha et al. (2020) optimized container terminal yard layouts. Duran et al. (2022) minimized emissions while Abu Aisha et al. (2020) optimized emissions and the monetary costs. Tao et al. (2023) studied optimum yard container stack allocation by minimizing travelled distances.

A great deal of the studies on environmental optimization in the port segment of container shipping considered a combination of two decisions.

Table 2. Studies on environmental optimization in port segment of container shipping

Reference	**Uncertainty**								**Decision**															**Modeling Level**						**Objective**						
	Counts of Handled Containers	*Ship Arrival Time*	*Truck Arrival Time*	*Electricity Supply*	*Electricity Demand*	*Workload*	*Electricity Price*	*Port/Handling Time*	*Berth Allocation*	*Quay Crane Deployment*	*Quay Crane Scheduling*	*Yard Layout Optimization*	*Yard Crane Scheduling*	*Yard Crane Deployment*	*Yard Truck Deployment*	*Yard Truck Retrofitting for Emission Reduction*	*Yard Truck Scheduling*	*Yard Container Stack Allocation*	*Yard Container Retrieval*	*Electricity Grid Allocation*	*Renewable Electricity Source Installation*	*Inland Truck Scheduling*	*Emission Reduction Technology Choice*	*Non-Linear*	*Linearized*	*Linear*	*Strategic*	*Tactical*	*Operational*	*Emissions/Energy/Fuel*	*Costs (Operational Costs, Handling Costs, Fixed Costs, etc.)*	*Time*	*Time Reliability*	*Workload*	*Distance*	*Container Throughput*
Duan et al. (2023)													√				√									√			√	√						
Zheng et al. (2023)											√		√				√									√			√	√						
Tao et al. (2023)																		√							√				√	√						
Duran et al. (2022)												√												√				√		√						
Niu et al. (2022)													√				√					√				√			√	√						
H. Li & Li (2022)											√															√			√	√						
H. Yu, Huang, et al. (2022)											√		√					√								√			√					√	√	
Zhen, Lin, et al. (2022)				√							√		√				√			√					√				√							√
Y. Zhang, Liang, et al. (2022)				√	√				√		√		√							√					√				√	√		√				
J. Yu et al. (2022)									√	√	√									√						√			√	√	√	√				
Q. Zhang et al. (2022)						√									√	√										√	√		√	√	√	√				
Zhen, Jin, et al. (2022)	√														√	√										√	√		√	√	√	√				
Nadi et al. (2022)																						√		√					√			√				
Xu et al. (2022)			√																			√		√					√	√	√	√				
Duan et al. (2021)									√		√													√					√	√	√	√				
S. Chen & Zeng (2021)													√													√			√	√		√				
Zhen et al. (2021)		√				√			√		√														√				√	√	√	√				
Karakas et al. (2021)															√			√								√			√	√		√				
Zhong et al. (2020)											√						√									√			√			√				
Abu Aisha et al. (2020)												√													√				√	√	√					
Feng et al. (2020)			√																√			√				√			√	√		√				
Caballini et al. (2020)																						√				√			√			√	√			
D. Yu et al. (2019)						√							√	√										√			√		√	√		√				
Y. Yang et al. (2019)													√				√	√								√			√	√		√				
W. Wang et al. (2019)				√	√															√	√					√	√		√		√					
Peng et al. (2019)		√							√											√						√			√	√	√					
M. Ma et al. (2019)													√									√		√					√	√		√				
X. Li, Peng, et al. (2019)					√															√	√			√			√		√		√					
Kanellos (2019)							√													√						√			√	√	√					
Fan et al. (2019)																						√				√			√	√	√	√				
T. Wang et al. (2018)									√	√	√														√		√		√	√	√	√				
D. Liu & Ge (2018)										√														√			√			√						
L. Li et al. (2018)				√																	√			√			√				√					
H. Yu et al. (2017)															√		√									√									√	
Dulebenets, Moses, et al. (2017)									√																	√			√	√	√	√				
Zhen et al. (2016)									√																√				√	√	√	√				
Peng et al. (2016)		√	√					√						√									√	√			√			√						
He (2016)									√	√	√															√	√		√	√		√				
Do et al. (2016)			√																			√				√			√	√						
Schmidt et al. (2015)					√															√			√							√						
J. He, Huang, & Yan (2015)													√												√				√	√		√				
J. He, Huang, Yan, et al. (2015)											√		√				√								√				√	√		√				
Q.-M. Hu et al. (2014)									√	√	√													√					√	√	√	√				
G. Chen et al. (2013)																						√		√					√	√		√				
Golias et al. (2009)									√																	√			√	√		√				

Niu et al. (2022) and Duan et al. (2023) integrated yard crane scheduling and yard truck scheduling decisions by optimizing energy consumption. Q. Zhang et al. (2022) and Zhen, Jin, et al. (2022) studied yard truck deployment problem for yard truck retrofitting with low-emission technologies by optimizing emission, costs, and truck times. They both considered uncertainty in their input parameters. Q. Zhang et al. (2022) included workload Zhen, Jin, et al. (2022) included transportation demand as an uncertain parameter. Duan et al. (2021) and Zhen et al. (2021) studied berth allocation and quay crane scheduling simultaneously by optimizing emissions, costs, and crane times. Only Zhen et al. (2021) included uncertain parameters, i.e., ship arrival time and workload, in their modeling. W. Wang et al. (2019) and X. Li, Peng, et al. (2019) studied renewable electricity source installation and electricity grid allocation in container terminals by optimizing costs and they both considered uncertainty. W. Wang et al. (2019) included electricity demand and supply uncertainty while X. Li, Peng, et al. (2019) only included electricity demand uncertainty in their modeling. Karakas et al. (2021) integrated the yard truck deployment problem and yard container stack allocation and optimized emissions and time. Zhong et al. (2020) studied quay crane scheduling and yard truck scheduling together by optimizing their operation time. Feng et al. (2020) integrated the problem of yard container retrieval from the container stack into inland truck scheduling considering truck arrival time uncertainty. They optimized both emission and total time. D. Yu et al. (2019) integrated yard crane deployment problem and yard crane scheduling problem. They optimized time and emissions by considering uncertainty in crane workloads. Peng et al. (2019) studied berth allocation and electricity grid allocation for cold ironing. They optimized emissions and costs by considering ship arrival time uncertainty. M. Ma et al. (2019) integrated the modeling of yard crane scheduling into inland truck scheduling to optimize emissions and times. H. Yu et al. (2017) studied yard truck deployment and yard truck scheduling by optimizing the traveled distances of trucks. Peng et al. (2016) integrated yard crane deployment and emission reduction strategy choice modeling to optimize emissions. Their modeling considered uncertainties in ship arrival times, truck arrival times, and handling times. Schmidt et al. (2015) also studied emission reduction strategy choice but they integrated it with electricity grid allocation. They optimized emission production by considering uncertainties in electricity demand.

Some of the studies shown in Table 2 integrated three decisions in their modeling. T. Wang et al. (2018), He (2016), and Q.-M. Hu et al. (2014) studied the integration of berth allocation, quay crane deployment, and quay crane scheduling. Q.-M. Hu et al. (2014) and T. Wang et al. (2018) optimized emissions, costs, and time while He (2016) optimized emissions and time. None of them considered uncertainties. Modeling of H. Yu, Huang, et al. (2022) included quay crane scheduling, yard crane scheduling, and yard container stack allocation simultaneously. They optimized traveled distances and workload allocated to each crane. Y. Yang et al. (2019) modeled yard crane scheduling, yard truck scheduling, and yard container stack allocation to optimize time and emissions. The model proposed by J. He, Huang, Yan, et al. (2015) and Zheng et al. (2023) integrated quay crane scheduling, yard crane scheduling, and yard truck scheduling. J. He, Huang, Yan, et al. (2015) optimized energy consumption and time, while Zheng et al. (2023) optimized only energy consumption.

Table 2 shows that few of the studies integrated four decisions in their modeling. Zhen, Lin, et al. (2022) simultaneously modeled quay crane scheduling, yard crane scheduling, and electricity grid allocation with yard truck scheduling to maximize the container throughput of the container terminal by considering emissions as constraints. Their model included uncertainties in electric supply. Y. Zhang, Liang, et al. (2022) also modeled quay crane scheduling, yard crane scheduling, and electricity grid allocation but integrated them into berth allocation. They optimized time and emissions by considering uncertainties in electricity supply and demand. The model proposed by J. Yu et al. (2022) integrated quay crane scheduling, quay crane deployment, and electricity grid allocation with berth allocation to optimize emissions, costs, and time without considering uncertainties.

Environmental Optimization in the Inland Segment of Container Shipping

Table 3 demonstrates summaries of the environmental optimization studies related to the inland segment of container shipping. The table shows that hub location-allocation and container route allocation are the most studied decisions. Similar to the previously evaluated container shipping segments, the environmental optimization studies in the inland segment mostly integrates two and more decision. However, some of the studies considered single decisions. Digiesi et al. (2019), Tsao & Linh (2018), Y. Chen et al. (2018), Maia & Couto (2013), Sun (2020), and Dai & Yang (2020) studied hub location allocation as a single decision in inland container shipping. Digiesi et al. (2019) and Dai & Yang (2020) only optimized emissions and costs while Y. Chen et al. (2018) and Maia & Couto (2013) optimized time as well as emissions and costs. On the other hand, Sun (2020) optimized time reliability in addition to emissions and costs. Tsao & Linh (2018) included social sustainability variables i.e., noise and accidents in addition to emissions, costs, and time. Only two of them included uncertainty in their modeling. Sun (2020) included uncertainties in transportation time and handling time while Dai & Yang (2020) included transportation demand uncertainty in their modeling. W. He et al. (2021), Shiri & Huynh (2018), Schulte et al. (2017), and Heilig et al. (2017) modeled inland truck scheduling in their studies. Shiri & Huynh (2018) optimized only time considering emissions as a constraint while Schulte et al. (2017) optimized emissions and time. W. He et al. (2021) and Heilig et al. (2017) optimized emissions, costs, and time simultaneously. None of them considered uncertainty in their modeling. S. Zhu et al. (2021) modeled tug scheduling for container barges as a single decision in inland shipping to optimize emissions. S. Li, Wu, et al. (2023) studied optimum emission reduction technology choice by optimizing fuel consumption and the other costs while considering the uncertainties in emission production, transportation demand and transportation capacities.

Table 3. Studies on environmental optimization in inland segment of container shipping

Reference	Uncertainty							Decision									Modeling			Level			Objective									
	Emissions	*Transportation Demand*	*Number of Available Vehicles*	*Costs*	*Capacity*	*Transportation Time*	*Port/Handling Time*	*Hub Location Allocation*	*Vessel Scheduling*	*Barge Tug Scheduling*	*Empty Container Relocation*	*Container Route Allocation*	*Inland Truck Scheduling*	*Emission Reduction Technology Choice*	*Speed Optimization*	*Shipment Scheduling*	*Non-Linear*	*Linearized*	*Linear*	*Strategic*	*Tactical*	*Operational*	*Emissions/Energy/Fuel*	*Costs (Operational Costs, Handling Costs, Fixed Costs, etc.)*	*Time*	*Time Reliability*	*Noise*	*Accidents*	*Infrastructure Deterioration*	*Trucker Rest Time*	*Unemployment*	*Immigration*
J. Ma et al. (2023)		√						√				√							√	√			√	√								
Omran et al. (2023)		√						√				√							√	√			√	√								
S. Li, Wu, et al. (2023)	√	√			√									√					√	√			√	√								
Pourmohammad-Zia et al. (2023)			√									√	√						√			√	√	√	√							
Z. Tan et al. (2022)														√	√		√			√		√	√	√								
Kurtuluş (2022)								√				√						√		√		√	√	√								
S. Zhu et al. (2021)										√									√			√	√									
Ambrosino & Sciomachen (2021)								√				√							√	√		√	√	√	√		√	√	√			
W. He et al. (2021)													√						√			√	√	√	√							
Pian et al. (2021)								√				√							√	√		√	√	√	√							
Sun (2020)						√	√					√						√				√	√	√		√						
Wong et al. (2020)								√			√	√							√	√		√	√	√	√							
Dai & Yang (2020)		√										√							√			√	√	√								
Tsao & Thanh (2019)		√		√	√			√				√							√	√		√	√	√	√						√	√
Digiesi et al. (2019)												√					√		√			√	√	√								
Tsao & Linh (2018)												√					√					√	√	√	√		√	√				
Z. Tan et al. (2018)						√	√		√						√		√				√	√	√		√							
Sun et al. (2018)					√							√				√		√				√	√	√	√							
Shiri & Huynh (2018)													√				√					√			√							
Irannezhad et al. (2018)											√	√							√			√	√	√								
Y. Chen et al. (2018)												√							√				√	√	√							
Schulte et al. (2017)													√									√	√	√								
Heilig et al. (2017)													√				√					√	√	√	√							
Fazili et al. (2017)												√	√			√			√			√	√	√						√		
Shi et al. (2016)												√		√				√		√		√	√	√								
Palacio et al. (2016)								√				√							√	√		√	√	√								
Sun & Lang (2015)												√				√		√				√	√	√	√							
Palacio et al. (2015)					√			√				√							√	√		√	√	√								
Maia & Couto (2013)												√							√	√		√	√	√	√							
Kim et al. (2013)								√				√					√			√		√	√	√	√							

Environmental optimization studies in the inland segment of container shipping mostly combine two decisions in their modeling. The modeling approach of J. Ma et al. (2023), Omran et al. (2023), Kurtuluş (2022), Ambrosino & Sciomachen (2021), Pian et al. (2021), Tsao & Thanh (2019), Palacio et al. (2016), Palacio et al. (2015), and Kim et al. (2013) integrated container route allocation into inland container hub location-allocation. Kurtuluş (2022), Palacio et al. (2016), and Palacio et al. (2015) optimized emissions and costs while Pian et al. (2021) and Kim et al. (2013) optimized time in addition to emissions and other costs. J. Ma et al. (2023) and Omran et al. (2023) also optimized emission and the other costs while considering the uncertainty in transportation demand. Tsao & Thanh (2019) and Ambrosino & Sciomachen (2021) optimized social sustainability parameters i.e., noise, accidents, infrastructure deterioration, unemployment, and immigration in addition to emissions, costs, and time. Only two of those studies considered uncertainties: Palacio et al. (2015) considered capacity uncertainty while Tsao & Thanh (2019) considered uncertainties in transportation demand, costs, and capacities. Sun et al. (2018) and Sun & Lang (2015) combined shipment scheduling and container route allocation in inland container transportation to optimize emissions, costs, and time. Sun et al. (2018) also considered uncertainties in capacities. Z. Tan et al. (2022) combined emission reduction strategy choice and speed optimization in inland container shipping to optimize emissions and costs. Z. Tan et al. (2018) integrated vessel scheduling and speed optimization in inland container shipping. They optimized emissions and time while considering uncertainties in transportation times and port times. Irannezhad et al. (2018) integrated empty container relocation in container route allocation to optimize emissions and costs in inland container transportation. Shi et al. (2016) modeled container route allocation and emission reduction strategy choice to optimize emission production and costs. Pourmohammad-Zia et al. (2023) integrated container route allocation and inland truck scheduling while considering the uncertainties in available number of trucks. They optimized emissions, other costs and transportation time.

Only two studies in environmental optimization combined three decisions. Wong et al. (2020) integrated hub location allocation, empty container relocation, and container route allocation to optimize emissions, costs, and time. Fazili et al. (2017) combined shipment scheduling, container route allocation, and inland truck scheduling to optimize emissions, costs, and trucker rest times. They provided the only research in this review that considers trucker rest time as a parameter in their modeling.

Environmental Optimization in Sea-Port Segment of Container Shipping

Table 4 summarizes the environmental optimization studies that integrated both the sea and port segments of container shipping. It is illustrated in the table that most of the studies considered berth allocation and speed optimization simultaneously while two of them included additional decisions in their modeling. Z.-H. Hu (2020), Venturini et al. (2017), and Du et al. (2011) included only berth allocation and speed optimization decisions. Z.-H. Hu (2020) and Du et al. (2011) optimized emissions and time while Venturini et al. (2017) optimized costs as well as emissions and time. Alvarez et al. (2010) included vessel scheduling decisions to berth allocation and speed optimization decisions. They optimized emissions, costs, and time while considering uncertainties in truck arrival times. Zhen, Wu, et al. (2020) integrated five more decisions i.e., vessel scheduling, container route allocation, ship route allocation, vessel deployment, and emission reduction strategy choice to berth allocation and speed optimization decisions. They optimized emissions, costs, and time. J. Qi & Wang (2023) integrated bunkering, bunkering hub location, emission reduction technology choice and speed optimization decisions while optimizing fuel consumption and the other costs.

Environmental Optimization in Door-to-Door (Sea-Port-Inland) Container Shipping

Studies related to environmental optimization in door-to-door container shipping were summarized in table 5. The table shows that the most studied decision is the container route allocation decision. Similar to the studies in the other segments, the environmental optimization studies in this segment of container shipping mostly consider two or more decisions. On the other hand, some of the studies consider only a single decision. S. Liu (2023), M. Li & Sun (2022), Z. Yang et al. (2021), X. Li, Kuang, et al. (2019), Q. Ma et al. (2018), Martínez-López et al. (2016), and Chang et al. (2010) studied container route allocation as a single decision in door-to-door container shipping. S. Liu (2023) optimized emissions, the costs, transportation time, and quality. M. Li & Sun (2022) optimized emissions, the costs, and transportation time while considering the uncertainties in transportation demand and emission costs. Z. Yang et al. (2021) and X. Li, Kuang, et al. (2019) optimized emissions and costs while Q. Ma et al. (2018) optimized costs and quality by considering emissions as constraints. On the other hand, Martínez-López et al. (2016) and Chang et al. (2010) optimized time in addition to emissions and costs. Q. Hu et al. (2022) studied the environmental subsidy scheme as a single decision to optimize emissions. Sáinz Bernat et al. (2016) studied empty container relocation as a single decision in door-to-door container shipping considering uncertainties in transportation demand and empty container supply to optimize emissions, costs, and time.

Table 4. Studies on environmental optimization in sea-port segment of container shipping

Reference	**Uncertainty**	**Decision**									**Modeling**			**Level**			**Objective**		
	Truck Arrival Time	*Bunkering*	*Bunkering Hub Allocation*	*Berth Allocation*	*Quay crane Scheduling*	*Vessel Scheduling*	*Container Route Allocation*	*Ship Route Allocation*	*Vessel Deployment*	*Emission Reduction Technology Choice*	*Speed Optimization*	*Non-Linear*	*Linearized*	*Linear*	*Strategic*	*Tactical*	*Operational*	*Emissions/Energy/Fuel*	*Costs (Operational Costs, Handling Costs, Fixed Costs, etc.)*	*Time*
J. Qi & Wang (2023)		√	√							√	√		√		√		√	√	√	
Z.-H. Hu (2020)				√							√	√					√	√		√
Zhen, Wu, et al. (2020)				√		√	√	√	√	√	√		√		√	√	√	√	√	√
Venturini et al. (2017)				√							√			√			√	√	√	√
Du et al. (2011)				√							√	√					√	√		√
Alvarez et al. (2010)	√			√	√						√			√			√	√	√	√

Table 5. Studies on environmental optimization in door-to-door container shipping

Reference	**Uncertainty**			**Decision**										**Modeling**			**Level**			**Objective**			
	Emissions cost	*Transportation Demand*	*Empty Container Supply*	*Hub Location Allocation*	*Empty Container Relocation*	*Container Route Allocation*	*Ship Route Allocation*	*Vessel Deployment*	*Environmental Taxation Scheme*	*Environmental Subsidy Scheme*	*Emission Reduction Technology*	*Speed Optimization*	*Shipment Scheduling*	*Non-Linear*	*Linearized*	*Linear*	*Strategic*	*Tactical*	*Operational*	*Emissions/Energy/Fuel*	*Costs (Operational Costs, Handling Costs, Fixed Costs, etc.)*	*Time*	*Quality*
(S. Liu, 2023)						√										√			√	√	√	√	√
(M. Li & Sun, 2022)	√	√				√										√			√	√	√	√	
Q. Hu et al. (2022)										√					√		√			√			
Y. Zhang, Atasoy, et al. (2022)						√							√			√			√	√	√	√	
Martínez-López (2021)						√	√	√						√			√			√	√	√	
Z. Yang et al. (2021)						√								√			√			√	√		
K. Chen et al. (2020)						√			√	√				√			√		√	√	√		
Martínez-López & Chica (2020)						√	√	√				√		√			√	√	√	√	√	√	
Martínez-López et al. (2019)						√					√			√			√		√	√	√	√	
X. Li, Kuang, et al. (2019)						√										√			√	√	√		
Martínez-López et al. (2018)						√					√			√			√		√	√	√	√	
Q. Ma et al. (2018)						√										√			√		√		√
Tran et al. (2017)						√	√									√			√	√	√	√	
Sáinz Bernat et al. (2016)		√	√		√									√					√	√	√	√	
Martínez-López et al. (2016)						√								√			√		√	√	√	√	
Lam & Gu (2016)					√	√										√	√		√	√	√	√	
M. Zhang et al. (2013)				√		√										√	√		√	√	√		
Chang et al. (2010)						√										√			√	√	√	√	

Table 5 shows that several of the environmental optimization studies in door-to-door container shipping combined two decisions. Martínez-López et al. (2019) and Martínez-López et al. (2018) integrated container route allocation and emission reduction strategy choice for container ships in door-to-door container shipping to optimize emissions, costs, and time. Y. Zhang, Atasoy, et al. (2022) combined container route allocation and shipment scheduling to optimize emissions, costs, and time. Tran et al. (2017) integrated container route allocation and container ship route allocation and optimized emissions, costs, and time. Lam & Gu (2016) integrated empty container relocation in container route allocation and optimized emissions, costs, and time. M. Zhang et al. (2013) studied inland container hub allocation and container route allocation to optimize emissions and costs.

Table 5 demonstrates that only two of the studies combined three decisions. Martínez-López (2021) combined container route allocation, container ship route allocation, and vessel deployment to optimize emissions, costs, and time. On the other hand, K. Chen et al. (2020) integrated environmental taxation and subsidy scheme in container route allocation and optimized emissions and costs.

As illustrated in Table 5, only Martínez-López & Chica (2020) combined four decisions. They integrated ship route allocation, vessel deployment, and speed optimization in container route allocation and optimized emissions, costs, and time.

Research Directions Through Years

Figure 2 show the change in research direction trough years. It can be seen in the first graph in the figure that the number of research articles in the environmental optimization of sea segment of container shipping has been consistently increased in the later years. Lately, vessel speed optimization, vessel deployment and vessel scheduling decisions took increased attention of the scholars in the area. This is understandable considering the increased environmental concerns in the shipping industry because those decisions can have a big impact on environmental performance of container shipping. By optimizing the speed of container vessels, bunker consumption can be reduced thus the amount of emission production. Vessel scheduling and number of the vessels deployed can also have a big impact on vessel speed and bunker consumption. Emission production can be high in a container service with a tight schedule and few container vessels because vessels must speed up to catch up with the schedule.

The second graph in Figure 2 show the yearly change in research direction in port segment in the research area. Similar to the sea segment, number of research in the port segment has been increased in the later years. Researchers mostly focused on quay crane scheduling and yard crane scheduling in the recent years. By optimizing quay crane and yard crane scheduling, energy consumption of those equipment per handled container as well as yard truck and inland truck waiting times can be improved thus emission production can be reduced. The third graph in Figure 2 shows the development of research through the years in inland segment of the research area. The graph show that number of research articles has not been increased in the recent years. It was consistent throughout the years. In the recent years, researchers focused on hub location allocation and container route allocation decisions. Locations of inland container hubs can have a significant impact of emission production because by selecting optimum locations, total travelled distances can be reduced. Additionally, container route allocation include transportation mode choice and emission production can be reduced by using environmentally friendly alternatives to road transportation of inland containers.

Fourth graph in figure 2 shows the yearly change in research direction in the research articles which considered both sea and port segment of container shipping. Even though there are few research articles that consider both sea and port segment, the number of articles has been increased in the recent years. The recent articles mostly focused on berth allocation and speed optimization decisions. Those two decisions are closely related because with optimum berth allocation, waiting times of container vessels can be minimized therefore excess time can be used to reduce optimum speeds of container vessels. The last graph in figure 2 illustrates the yearly change in the number of research articles according to considered decisions on the door-to-door segment of container shipping. The graph shows that there is not much increase in the number of research articles in the area. The number of research articles are fairly consisted throughout the years. Most studied optimization decision in the recent years shown in the graph is container route allocation. The container route allocation decisions in the door-to-door container shipping include selection of transportation modes thorough different routes. It is understandable that this decision become popular among researchers in the area of environmental optimization in container shipping because choice of a low emission producing transportation alternative can increase the environmental performance of container shipping.

Figure 2. Change in research directions through years

Future Research Directions

Even though environmental optimization in container shipping widely researched area, there is still a need for further research. Expanding the research in environmental optimization of container shipping to reduce emissions has become more important as the negative effects of climate change are more frequently seen. In this regard, this study identified various future research directions in the area. Table 6 shows the decisions considered by each segment of environmental optimization studies in the research area. The future research directions were identified in terms of the number of research articles focused on each identified optimization decisions, uncertainty modelling and objective function. The number of research articles on the considered decisions were illustrated in Table 6 according to the container shipping segment. As it can be seen in the table that some decisions were well studies in one or more segment but not in the other segments.

Table 6. Number of research articles on the considered decisions

	Sea	Port	Inland	Sea-Port	Door-to-Door
Barge Tug Scheduling			1 (%2)		
Berth Allocation		11 (%13)		5 (%25)	
Bunkering	12 (%6)			1 (%5)	
Bunkering Hub Allocation				1 (%5)	
Container Route Allocation	11 (%6)		22 (%44)	1 (%5)	16 (%52)
Disruption Recovery	6 (%3)				
Electricity Grid Allocation		8 (%9)			
Emission Reduction Technology Choice	7 (%4)	2 (%2)	3 (%6)	2 (%10)	2 (%6)
Empty Container Relocation			2 (%4)		2 (%6)
Environmental Subsidy Scheme					2 (%6)
Environmental Taxation Scheme					1 (%3)
Freight Rate Optimization	1 (%1)				
Hub Location Allocation			10 (%20)		1 (%3)
Inland Truck Scheduling		9 (%10)	6 (%12)		
Quay Crane Deployment		5 (%6)			
Quay Crane Scheduling		13 (%15)		1 (%5)	
Renewable Electricity Source Installation		3 (%3)			
Ship Route Allocation	19 (%10)			1 (%5)	3 (%10)
Shipment Scheduling	2 (%1)		3 (%6)		1 (%3)
Speed Optimization	61 (%33)		2 (%4)	6 (%30)	1 (%3)
Vessel Deployment	39 (%21)			1 (%5)	2 (%6)
Vessel Scheduling	28 (%15)		1 (%2)	1 (%5)	
Yard Container Retrieval		1 (%1)			
Yard Container Stack Allocation		4 (%5)			
Yard Crane Deployment		2 (%2)			
Yard Crane Scheduling		12 (%14)			
Yard Layout Optimization		2 (%2)			
Yard Truck Deployment		4 (%5)			
Yard Truck Retrofitting for Emission Reduction		2 (%2)			
Yard Truck Scheduling		8 (%9)			
Total	186 (%100)	86 (%100)	50 (%100)	20 (%100)	31 (%100)

Research Direction Towards Uncertainty Modelling

Uncertainty is the often-neglected aspect of environmental optimization studies in container shipping. Compared to different segments, uncertainty is more frequently included in the models of the studies in the port segment of container shipping but still over half of the reviewed studies on port segment neglected uncertainties as illustrated in Table 1-5. Future studies in different segments can include different uncertain inputs in their modeling.

Future studies related to environmental optimization in the sea segment of container shipping can include uncertainties in sailing times, port times, and fuel/energy consumption. Uncertainties in those parameters were rarely considered by previous studies although they can be highly volatile caused of various factors such as weather conditions, sea currents, worker strikes, and oil prices.

Future studies on environmental optimization in the port segment of container shipping can also include various neglected uncertain parameters i.e., count of containers handled, electricity supply, and demand. Transportation demand depends on economic conditions and can be highly volatile. Strategic environmental optimization decisions with high fixed costs in the port segment of container shipping must consider uncertainties in the number of containers handled to avoid big financial losses. Uncertainties in electricity supply and demand are important aspects for future studies on cold ironing and electrification of container handling equipment to reduce emissions of container terminals. Additionally, the studies related the renewable energy source installation in ports must consider those uncertainties in their modeling to ensure reliable energy supply and effective usage of financial resources.

Uncertainty was seldom considered by the environmental optimization studies in the inland segment of container shipping. Future studies can include uncertainties in transportation demand and transportation times. Considering uncertainties in transportation demand for inland container shipping is critical for studies that evaluate expensive infrastructure installment in hinterlands of ports. Additionally, considering uncertainties in transportation time is critical for accurate emission calculation and calculation of external social costs because congestion in inland transportation networks is a frequently occurring phenomenon that needs to be dealt with.

In the sea-port combined segment of container shipping, only one study included uncertainty in its research. Future studies that will focus on environmental optimization in the sea-port integrated segment of container shipping can include uncertainties in ship arrival times, inland truck arrival times, and workloads because volatilities in those parameters can highly impact costs and emission production.

Similar to the sea-port segment, only one study in environmental optimization of the door-to-door container shipping segment considered uncertainty in their modeling. In door-to-door container shipping, uncertainties in transit times in different segments (i.e., sea, port, and inland) can have a huge impact on the container route selection and hub location-allocation. Therefore, they can affect emission production and total costs. In addition to uncertainties in transit times, uncertainties in transportation demand also affect container route allocation and hub location allocation because high demand means lower unit transportation costs and lower emissions per unit of containerized freight transported.

Research Directions for Sea Segment of Container Shipping

The most under-researched decisions in environmental optimization models in the sea segment of container shipping include resource allocation, emission reduction technology choice, disruption recovery, freight rate optimization, and shipment scheduling. Future studies can integrate those decisions in their modeling to expand the research in the area. Resource allocation in the sea segment can be combined with research allocation in inland container shipping networks and resources of the container shipping companies can be allocated to reduce emissions in the whole door-to-door container shipping chain. Consideration of emission reduction strategy choice for future studies on environmental optimization is crucial because the adaptation of an analytical approach for investing and application to an emission reduction strategy can deliver more effective results. Those emission reduction technologies can include but are not limited to scrubber installation, retrofitting ship engines for alternative low-emission fuels (ammonia, LNG, and hydrogen fuel cells, etc.), an adaptation of wind-assisted sailing systems, or wave-assisted sailing systems. Disruption recovery is another decision that is under-researched for environmental optimization. Measures for recovering disruptions such as increasing ship speed can produce high emissions. Therefore, future studies can focus on environmental optimization in disruption recovery to minimize emissions resulting from container ship operations. Future studies on freight rate optimization can be helpful for the determination of environmental tax caps in container shipping because shipping companies eventually will reflect environmental taxes to their customers inside their freight rates. Shipment scheduling decisions are another important area for future research in environmental optimization. Shipment scheduling decisions including the determination of timing and frequency of containerized freight shipments can have a huge impact on companies' carbon footprint since bigger shipments mean less emission per ton of shipped containerized freight.

Research Directions for Port Segment of Container Shipping

The evaluation of previous environmental optimization of the port segment of container shipping revealed the least researched areas as decisions related to internal transportation and handing operations in container terminals (i.e., yard crane deployment, yard truck deployment, yard truck scheduling, yard container stack allocation, yard container retrieval), renewable energy source installation, and emission reduction technology choice. Optimization of internal transportation and handling operations can have a big impact on energy consumption thus emission production in container terminals. Future studies can focus on this area by providing environmental optimization models for internal transportation and handling operations of container terminals. The problem of renewable energy source installation in the seaport areas lately gained importance because ports can require a high amount of energy for their operations and there are usually industrial clusters located around ports that require a high amount of energy for their operations. Therefore, ports can be established as focal energy production and distribution points for the industry by investing and establishing renewable energy production infrastructures such as wind tribunes, wave tribunes, or facilities that produce electricity from organic waste. Future studies related to environmental optimization can model decisions related to the number, location, and energy distribution of renewable energy source installations in ports. Another under-researched area for environmental optimization related to container terminals is the emission reduction strategy choice. From a financial point of view, the selection of emission reduction technology can have a big importance and must not be decided in an ad hoc manner. For example, what kind of zero-emission technology should a container terminal invest in such as retrofitting internal transportation and handling equipment for electrification, battery usage, fuel cell usage, or alternative fuel usage e.g., ammonia or LNG usage for hydrogen production with a carbon capture technology.

Research Directions for Inland Segment of Container Shipping

The review of this study showed the decisions seldom considered by previous environmental optimization studies in the inland segment of container shipping include vessel scheduling, barge tug scheduling, empty container relocation, emission reduction strategy choice, speed optimization, and shipment scheduling. Vessel scheduling and speed optimization decisions are the most frequently studied decisions in the sea segment, but they are rarely considered for inland shipping of containers. Because inland shipping is performed in inland waterways and rivers, it has different operational dynamics than seaborne container shipping. For example, inland navigation can be affected by such factors as river currents, draft, and air draft limitations, dam crossings, etc. For this reason, future studies can model vessel scheduling and speed optimization in inland container shipping for optimizing emission production. Barge tug scheduling is also an under-researched decision. Inland container shipping through barges is common practice in Europe and China. Therefore, there is a need for future studies on environmental optimization in the area. Empty container relocation is well studies area in general, but studies mostly focused on the sea segment and often neglected empty container relocation in inland container transportation. Empty containers for inland container transportation are stored in inland hubs and the demand and supply of empty containers highly depend on the demand for export and import containerized freight transport. In this regard, future studies can provide a modeling perspective for empty container relocation in inland container transportation, especially in combination with inland container route allocation and inland container hub location. The emission reduction strategy choice in the inland segment of container shipping is another decision that requires more future research for environmental optimization. The emission reductions strategies for inland container transportation can include but are not limited to the adaptation of emission reduction technologies by inland container ships and container barge tugs such as scrubbers, fuel cells, batteries, or zero emission propulsion technologies as well as electrification of rail lines or retrofitting inland transportation trucks with zero-emission technologies. An ad hoc decision approach to the adoption of those technologies can result in inefficiencies in the usage of financial resources, therefore, there is a need for future studies on optimization modeling in the area. Shipment scheduling for environmental optimization in the inland segment of container shipping also requires further research. Shipment scheduling includes deciding on the timing and frequency of containerized freight shipments. Shipments with low frequency and bigger baches produce less emission as per tonnage transported but increase inventory holding cost. Future studies on optimization modeling for shipment scheduling can provide help for trade-offs between costs and emissions.

Research Directions for Sea-Port Segment of Container Shipping

The decisions that require further research in the sea-port segment of container shipping include quay crane scheduling, vessel scheduling, container route allocation, ship route allocation vessel deployment, and emission reduction technology choice. Most of those decisions are well-researched in the other segments but all the studies in the sea-port combined segment of container shipping only included berth allocation and speed optimization decisions. Consideration of quay crane scheduling can have a big impact on berth allocation decisions and speed optimization is highly affected by vessel scheduling and vessel deployment decisions. Future environmental optimization studies in the sea-port segment of container shipping can integrate those decisions to provide more accurate and comprehensive modeling perspectives. Container route allocation and container ship route allocation decisions are highly related since containers allocated to a shipping route require the allocation of container ships in the services of the container lines. And ship route allocation decisions impact vessel scheduling and vessel deployment decisions. Therefore, future environmental optimization studies in the sea-port segment must also integrate container route and ship route allocation decisions into their models. As in the other segments, emission reduction technology choice is seldom considered in the sea-port segment. Future studies on emission reduction technology choice in the sea-port segment can integrate decisions on emission reduction technologies in the sea segment (e.g., scrubber installation, retrofitting ship engines for alternative zero-emission fuels, wind-assisted sailing systems, or wave-assisted sailing systems) to decisions on emission reduction technologies in the port segment (e.g., retrofitting internal transportation and handling equipment for electrification, battery usage, fuel cell usage or alternative fuel usage).

Research Directions for Door-to-Door Segment of Container Shipping

Almost all the research in environmental optimization in the door-to-door segment of container shipping considered container route allocation decisions. There is a need for further research that includes other decisions i.e., hub location-allocation, empty container relocation, ship route allocation, vessel deployment, environmental taxation and subsidy scheme, emissions reduction strategy choice, and speed optimization. Two of the least studied decisions, i.e., hub location-allocation and vessel deployment, in the door-to-door segment are well-studied in other segments. However, they should be considered by environmental optimization studies in the door-to-door segment. Hub locations can impact transportation costs and choice of transportation modes as well as emission production. Vessel deployment is rarely explicitly considered by the models in the door-to-door segment since consideration of vessel deployment can highly increase model complexity and solvability. However, vessel deployment decisions can have a big impact on the amount of emission production. Emission reduction strategy choice is another area in the door-to-door segment that needs further research. Emission reduction technology choice in the sea segment is highly related to vessel deployment decisions. The choice of emission reduction technologies in the sea, port, and inland segments of container shipping can be integrated with the models of the door-to-door segment. Empty container relocation and ship route allocation decisions in the door-to-door segment also require more research. The two decisions are very related and can be integrated into container route allocation for environmental optimization in door-to-door container shipping. Future studies can also consider modeling environmental taxation and subsidy provision since the determination of environmental taxation and subsidies by optimization modeling can ensure policy effectiveness. Speed optimizations is another under-researched decision in the door-to-door segment however it is well studied in the sea segment. Speed optimization in the door-to-door segment requires a different perspective than speed optimization in the sea segment because in door-to-door segments it is highly integrated with transportation mode choice and shipment scheduling. Therefore, future environmental optimization studies that consider speed optimization in door-to-door container shipping should integrate mode choice decisions and shipment scheduling in their modeling.

Research Directions towards Combination of Environmental and Social Sustainability

The result of this review reveals that objective functions of the previous study in the environmental optimization of container shipping mostly included parameters related to fuel/energy consumption, emissions, costs, and time. Those parameters are related to economic and environmental sustainability. Future studies can quantify and include social sustainability parameters such as noise production, accidents, quality, immigration, employment, and personnel rest times. One of the interesting and very important social sustainability parameters considered in one of the previous studies was the trucker rest times (Fazili et al., 2017) which is crucial for the safety and health of the truckers. For example, future studies in the sea or port segment can integrate similar parameters in their studies because working conditions and overworking of port and ship personnel were one of the most criticized realities in the shipping sector and it got worse and under scrutiny during the Covid-19 pandemic.

Conclusion

Around 80% of international freight transportation is conducted through seas and 20% of maritime transportation is conducted through container shipping (UNCTAD, 2021). Therefore, total emissions produced by container shipping constitute a high share of total industrial emission production. This makes it crucial to expand the research to reduce emissions in container shipping. In this regard, this study provided a review of previous studies on the environmental optimization of container shipping and identified various future research directions. The review grouped the environmental optimization studies under five segments: sea, port, inland, sea-port combined, and door-to-door container shipping.

Under each segment of container shipping, the decisions that require future research on environmental optimization were revealed. In the sea segment of environmental optimization of container shipping, decisions which require further attention include resource allocation, emission reduction technology choice, disruption recovery, freight rate optimization, and shipment scheduling. The decisions that require future research in the port segment are related to internal transportation and handing operations in container terminals (i.e., yard crane deployment, yard truck deployment, yard truck scheduling, yard container stack allocation, yard container retrieval), renewable energy source installation, and emission reduction technology choice. Vessel scheduling and speed optimization decisions are the most frequently studied decisions in the sea segment, but they are rarely considered for inland shipping of containers. In the sea-port combined segment of container shipping future studies required in quay crane scheduling, vessel scheduling, container route allocation, ship route allocation vessel deployment, and emission reduction technology choice, although they were well-researched in the other segments. The least studied decision in the door-to-door segment of container shipping includes hub location-allocation, empty container relocation, ship route allocation, vessel deployment, environmental taxation and subsidy scheme, emissions reduction technology choice, and speed optimization. The hub location-allocation and vessel deployment are well-studied in other segments.

Additionally, the review showed that uncertainties in modeling approaches and objective function parameters related to social sustainability require the attention of scholars in the area. The analysis provided in previous studies in this review demonstrated the level of scientific rigor regarding environmental optimization of container shipping to the scholars that plan to provide research in the area. The future research directions on environmental optimization in container shipping revealed in this study will provide a guide for scholars in the area to investigate the most under-researched subjects.

Compliance With Ethical Standards

Conflict of Interest

The author declares that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

References

Abdelmagid, A. M., Gheith, M. S., & Eltawil, A. B. (2022). A comprehensive review of the truck appointment scheduling models and directions for future research. *Transport Reviews*, *42*(1), 102–126. https://doi.org/10.1080/01441647.2021.1955034

Abioye, O. F., Dulebenets, M. A., Pasha, J., & Kavoosi, M. (2019). A Vessel Schedule Recovery Problem at the Liner Shipping Route with Emission Control Areas. *Energies*, *12*(12), 2380. https://doi.org/10.3390/en12122380

Abu Aisha, T., Ouhimmou, M., & Paquet, M. (2020). Optimization of Container Terminal Layouts in the Seaport—Case of Port of Montreal. *Sustainability*, *12*(3), 1165–1165. https://doi.org/10.3390/su12031165

Alharbi, A., Wang, S., & Davy, P. (2015). Schedule design for sustainable container supply chain networks with port time windows. *Advanced Engineering Informatics*, *29*(3), 322–331. https://doi.org/10.1016/j.aei.2014.12.001

Alvarez, J. F., Longva, T., & Engebrethsen, E. S. (2010). A methodology to assess vessel berthing and speed optimization policies. *Maritime Economics & Logistics*, *12*(4), 327–346. https://doi.org/10.1057/mel.2010.11

Ambrosino, D., & Sciomachen, A. (2021). Impact of Externalities on the Design and Management of Multimodal Logistic Networks. *Sustainability*, *13*(9). https://doi.org/10.3390/su13095080

Aydin, N., Lee, H., & Mansouri, S. A. (2017). Speed optimization and bunkering in liner shipping in the presence of uncertain service times and time windows at ports. *European Journal of Operational Research*, *259*(1), 143–154. https://doi.org/10.1016/j.ejor.2016.10.002

Caballini, C., Gracia, M. D., Mar-Ortiz, J., & Sacone, S. (2020). A combined data mining – optimization approach to manage trucks operations in container terminals with the use of a TAS: Application to an Italian and a Mexican port. *Transportation Research Part E: Logistics and Transportation Review*, *142*, 102054–102054. https://doi.org/10.1016/j.tre.2020.102054

Cariou, P., Cheaitou, A., Larbi, R., & Hamdan, S. (2018). Liner shipping network design with emission control areas: A genetic algorithm-based approach. *Transportation Research Part D: Transport and Environment*, *63*, 604–621. https://doi.org/10.1016/j.trd.2018.06.020

Caris, A., Macharis, C., & Janssens, G. K. (2008). Planning problems in intermodal freight transport: accomplishments and prospects. *Transportation Planning and Technology*, *31*(3), 277–302. https://doi.org/10.1080/03081060802086397

Chang, Y.-T., Lee, P. T.-W., Kim, H.-J., & Shin, S.-H. (2010). Optimization model for transportation of container cargoes considering short sea shipping and external cost. *Transportation Research Record: Journal of the Transportation Research Board*, *2166*(1), 99–108. https://doi.org/10.3141/2166-12

Cheaitou, A., & Cariou, P. (2019). Greening of maritime transportation: A multi-objective optimization approach. *Annals of Operations Research*, *273*(1–2), 501–525. https://doi.org/10.1007/s10479-018-2786-2

Chen, G., Govindan, K., & Golias, M. M. (2013). Reducing truck emissions at container terminals in a low carbon economy: Proposal of a queueing-based bi-objective model for optimizing truck arrival pattern. *Transportation Research Part E: Logistics and Transportation Review*, *55*, 3–22. https://doi.org/10.1016/j.tre.2013.03.008

Chen, J., Ye, J., Liu, A., Fei, Y., Wan, Z., & Huang, X. (2022). Robust optimization of liner shipping alliance fleet scheduling with consideration of sulfur emission restrictions and slot exchange. *Annals of Operations Research*. https://doi.org/10.1007/s10479-022-04590-x

Chen, J., Ye, J., Zhuang, C., Qin, Q., & Shu, Y. (2022). Liner shipping alliance management: Overview and future research directions. *Ocean & Coastal Management*, *219*, 106039–106039. https://doi.org/10.1016/j.ocecoaman.2022.106039

Chen, K., Xin, X., Niu, X., & Zeng, Q. (2020). Coastal transportation system joint taxation-subsidy emission reduction policy optimization problem. *Journal of Cleaner Production*, *247*, 119096–119096. https://doi.org/10.1016/j.jclepro.2019.119096

Chen, L., Yip, T. L., & Mou, J. (2018). Provision of Emission Control Area and the impact on shipping route choice and ship emissions. *Transportation Research Part D: Transport and Environment*, *58*, 280–291. https://doi.org/10.1016/j.trd.2017.07.003

Chen, R., Meng, Q., & Jia, P. (2022). Container port drayage operations and management: Past and future. *Transportation Research Part E: Logistics and Transportation Review*, *159*, 102633–102633. https://doi.org/10.1016/j.tre.2022.102633

Chen, S., & Zeng, Q. (2021). Carbon-efficient scheduling problem of electric rubber-tyred gantry cranes in a container terminal. *Engineering Optimization*, 1–19. https://doi.org/10.1080/0305215X.2021.1972293

Chen, Y., Guo, D., Chen, Z., Fan, Y., & Li, X. (2018). Using a multi-objective programming model to validate feasibility of an underground freight transportation system for the Yangshan port in Shanghai. *Tunnelling and Underground Space Technology*, *81*, 463–471. https://doi.org/10.1016/j.tust.2018.07.012

Christiansen, M., Hellsten, E., Pisinger, D., Sacramento, D., & Vilhelmsen, C. (2020). Liner shipping network design. *European Journal of Operational Research*, *286*(1), 1–20. https://doi.org/10.1016/j.ejor.2019.09.057

Dai, Q., & Yang, J. (2020). A distributionally robust chance-constrained approach for modeling demand uncertainty in green port-hinterland transportation network optimization. *Symmetry*, *12*(9). https://doi.org/10.3390/sym12091492

De, A., Wang, J., & Tiwari, M. K. (2021). Fuel bunker management strategies within sustainable container shipping operation considering disruption and recovery policies. *IEEE Transactions on Engineering Management*, *68*(4), 1089–1111. https://doi.org/10.1109/TEM.2019.2923342

Digiesi, S., Facchini, F., & Mummolo, G. (2019). Dry port as a lean and green strategy in a container terminal hub: A mathematical programming model. *Management and Production Engineering Review*, *10*(1), 14–28. https://doi.org/10.24425/mper.2019.128240

Do, N. A. D., Nielsen, I. E., Chen, G., & Nielsen, P. (2016). A simulation-based genetic algorithm approach for reducing emissions from import container pick-up operation at container terminal. *Annals of Operations Research*, *242*(2), 285–301. https://doi.org/10.1007/s10479-014-1636-0

Dong, G., & Tae-Woo Lee, P. (2020). Environmental effects of emission control areas and reduced speed zones on container ship operation. *Journal of Cleaner Production*, *274*, 122582–122582. https://doi.org/10.1016/j.jclepro.2020.122582

Du, Y., Chen, Q., Quan, X., Long, L., & Fung, R. Y. K. (2011). Berth allocation considering fuel consumption and vessel emissions. *Transportation Research Part E: Logistics and Transportation Review*, *47*(6), 1021–1037. https://doi.org/10.1016/j.tre.2011.05.011

Du, Y., Meng, Q., & Wang, Y. (2015). Budgeting fuel consumption of container ship over round-trip voyage through robust optimization. *Transportation Research Record: Journal of the Transportation Research Board*, *2477*(1), 68–75. https://doi.org/10.3141/2477-08

Duan, J., Li, L., Zhang, Q., Qin, J., & Zhou, Y. (2023). Integrated scheduling of automatic guided vehicles and automatic stacking cranes in automated container terminals considering landside buffer zone. *Transportation Research Record. In Press.* https://doi.org/10.1177/03611981231168862

Duan, J., Liu, Y., Zhang, Q., & Qin, J. (2021). Combined Configuration of Container Terminal Berth and Quay Crane considering Carbon Cost. *Mathematical Problems in Engineering*, *2021*, 1–16. https://doi.org/10.1155/2021/6043846

Dulebenets, M. A. (2016). Advantages and disadvantages from enforcing emission restrictions within emission control areas. *Maritime Business Review*, *1*(2), 107–132. https://doi.org/10.1108/MABR-05-2016-0011

Dulebenets, M. A. (2018a). A comprehensive multi-objective optimization model for the vessel scheduling problem in liner shipping. *International Journal of Production Economics*, *196*, 293–318. https://doi.org/10.1016/j.ijpe.2017.10.027

Dulebenets, M. A. (2018b). The green vessel scheduling problem with transit time requirements in a liner shipping route with Emission Control Areas. *Alexandria Engineering Journal*, *57*(1), 331–342. https://doi.org/10.1016/j.aej.2016.11.008

Dulebenets, M. A. (2022). Multi-objective collaborative agreements amongst shipping lines and marine terminal operators for sustainable and environmental-friendly ship schedule design. *Journal of Cleaner Production*, *342*, 130897. https://doi.org/10.1016/j.jclepro.2022.130897

Dulebenets, M. A., Golias, M. M., & Mishra, S. (2017). The green vessel schedule design problem: Consideration of emissions constraints. *Energy Systems*, *8*(4), 761–783. https://doi.org/10.1007/s12667-015-0183-3

Dulebenets, M. A., Moses, R., Ozguven, E. E., & Vanli, A. (2017). Minimizing carbon dioxide emissions due to container handling at marine container terminals via hybrid evolutionary algorithms. *IEEE Access*, *5*, 8131–8147. https://doi.org/10.1109/ACCESS.2017.2693030

Dulebenets, M. A., & Ozguven, E. E. (2017). Vessel scheduling in liner shipping: Modeling transport of perishable assets. *International Journal of Production Economics*, *184*, 141–156. https://doi.org/10.1016/j.ijpe.2016.11.011

Dulebenets, M. A., Pasha, J., Abioye, O. F., & Kavoosi, M. (2021). Vessel scheduling in liner shipping: A critical literature review and future research needs. *33*(1), 106. https://doi.org/10.1007/s10696-019-09367-2

Duran, C., Derpich, I., & Carrasco, R. (2022). Optimization of port layout to determine greenhouse gas emission gaps. *Sustainability*, *14*(20), 13517. https://doi.org/10.3390/su142013517

Fan, Ren, Guo, & Li. (2019). Truck scheduling problem considering carbon emissions under truck appointment system. *Sustainability*, *11*(22), 6256–6256. https://doi.org/10.3390/su11226256

Fazili, M., Venkatadri, U., Cyrus, P., & Tajbakhsh, M. (2017). Physical Internet, conventional and hybrid logistic systems: A routing optimisation-based comparison using the Eastern Canada road network case study. *International Journal of Production Research*, *55*(9), 2703–2730. https://doi.org/10.1080/00207543.2017.1285075

Feng, Y., Song, D.-P., Li, D., & Zeng, Q. (2020). The stochastic container relocation problem with flexible service policies. *Transportation Research Part B: Methodological*, *141*, 116–163. https://doi.org/10.1016/j.trb.2020.09.006

Gao, C.-F., & Hu, Z.-H. (2021). Speed optimization for container ship fleet deployment considering fuel consumption. *Sustainability*, *13*(9), 5242–5242. https://doi.org/10.3390/su13095242

Giovannini, M., & Psaraftis, H. N. (2019). The profit maximizing liner shipping problem with flexible frequencies: Logistical and environmental considerations. *Flexible Services and Manufacturing Journal*, *31*(3), 567–597. https://doi.org/10.1007/s10696-018-9308-z

Golias, M. M., Saharidis, G. K., Boile, M., Theofanis, S., & Ierapetritou, M. G. (2009). The berth allocation problem: Optimizing vessel arrival time. *Maritime Economics & Logistics*, *11*(4), 358–377. https://doi.org/10.1057/mel.2009.12

He, J. (2016). Berth allocation and quay crane assignment in a container terminal for the trade-off between time-saving and energy-saving. *Advanced Engineering Informatics*, *30*(3), 390–405. https://doi.org/10.1016/j.aei.2016.04.006

He, J., Huang, Y., & Yan, W. (2015). Yard crane scheduling in a container terminal for the trade-off between efficiency and energy consumption. *Advanced Engineering Informatics*, *29*(1), 59–75. https://doi.org/10.1016/j.aei.2014.09.003

He, J., Huang, Y., Yan, W., & Wang, S. (2015). Integrated internal truck, yard crane and quay crane scheduling in a container terminal considering energy consumption. *Expert Systems with Applications*, *42*(5), 2464–2487. https://doi.org/10.1016/j.eswa.2014.11.016

He, W., Jin, Z., Huang, Y., & Xu, S. (2021). The inland container transportation problem with separation mode considering carbon dioxide emissions. *Sustainability*, *13*(3), 1573–1573. https://doi.org/10.3390/su13031573

Heilig, L., Lalla-Ruiz, E., & Voß, S. (2017). Multi-objective inter-terminal truck routing. *Transportation Research Part E: Logistics and Transportation Review*, *106*, 178–202. https://doi.org/10.1016/j.tre.2017.07.008

Hu, Q., Gu, W., & Wang, S. (2022). Optimal subsidy scheme design for promoting intermodal freight transport. *Transportation Research Part E: Logistics and Transportation Review*, *157*, 102561–102561. https://doi.org/10.1016/j.tre.2021.102561

Hu, Q.-M., Hu, Z.-H., & Du, Y. (2014). Berth and quay-crane allocation problem considering fuel consumption and emissions from vessels. *Computers & Industrial Engineering*, *70*, 1–10. https://doi.org/10.1016/j.cie.2014.01.003

Hu, Z.-H. (2020). Low-emission berth allocation by optimizing sailing speed and mooring time. *Transport*, *35*(5), 486–499. https://doi.org/10.3846/transport.2020.14080

Irannezhad, E., Prato, C. G., & Hickman, M. (2018). The effect of cooperation among shipping lines on transport costs and pollutant emissions. *Transportation Research Part D: Transport and Environment*, *65*(September), 312–323. https://doi.org/10.1016/j.trd.2018.09.008

Iris, Ç., & Lam, J. S. L. (2019). A review of energy efficiency in ports: Operational strategies, technologies and energy management systems. *Renewable and Sustainable Energy Reviews*, *112*, 170–182. https://doi.org/10.1016/j.rser.2019.04.069

Jiang, X., Mao, H., Wang, Y., & Zhang, H. (2020). Liner shipping schedule design for near-sea routes considering big customers' preferences on ship arrival time. *Sustainability*, *12*(18), 7828–7828. https://doi.org/10.3390/su12187828

Kanellos, F. D. (2019). Multiagent-system-based operation scheduling of large ports' power systems with emissions limitation. *IEEE Systems Journal*, *13*(2), 1831–1840. https://doi.org/10.1109/JSYST.2018.2850970

Karakas, S., Kirmizi, M., & Kocaoglu, B. (2021). Yard block assignment, internal truck operations, and berth allocation in container terminals: Introducing carbon-footprint minimisation objectives. *Maritime Economics & Logistics*, *23*(4), 750–771. https://doi.org/10.1057/s41278-021-00186-7

Kim, S., Park, M., & Lee, C. (2013). Multimodal freight transportation network design problem for reduction of greenhouse gas emissions. *Transportation Research Record: Journal of the Transportation Research Board*, *2340*(1), 74–83. https://doi.org/10.3141/2340-09

Kurtuluş, E. (2022). Optimizing inland container logistics and dry port location-allocation from an environmental perspective. *Research in Transportation Business & Management*, 100839. https://doi.org/10.1016/j.rtbm.2022.100839

Lagemann, B., Lindstad, E., Fagerholt, K., Rialland, A., & Ove Erikstad, S. (2022). Optimal ship lifetime fuel and power system selection. *Transportation Research Part D: Transport and Environment*, *102*, 103145. https://doi.org/10.1016/j.trd.2021.103145

Lam, J. S. L., & Gu, Y. (2013). Port hinterland intermodal container flow optimisation with green concerns: A literature review and research agenda. *International Journal of Shipping and Transport Logistics*, *5*(3), 257–257. https://doi.org/10.1504/IJSTL.2013.054190

Lam, J. S. L., & Gu, Y. (2016). A market-oriented approach for intermodal network optimisation meeting cost, time and environmental requirements. *International Journal of Production Economics*, *171*, 266–274. https://doi.org/10.1016/j.ijpe.2015.09.024

Lan, X., Tao, Q., & Wu, X. (2023). Liner-shipping network design with emission control areas: A real case study. *Sustainability*, *15*(4), 3734. https://doi.org/10.3390/su15043734

Lan, X., Zuo, X., & Tao, Q. (2023). Container shipping optimization under different carbon emission policies: A case study. *Sustainability*, *15*(10), 8388. https://doi.org/10.3390/su15108388

Lee, H., Aydin, N., Choi, Y., Lekhavat, S., & Irani, Z. (2018). A decision support system for vessel speed decision in maritime logistics using weather archive big data. *Computers & Operations Research*, *98*, 330–342. https://doi.org/10.1016/j.cor.2017.06.005

Li, C., Qi, X., & Lee, C.-Y. (2015). Disruption recovery for a vessel in liner shipping. *Transportation Science*, *49*(4), 900–921. https://doi.org/10.1287/trsc.2015.0589

Li, H., & Li, X. (2022). A branch-and-bound algorithm for the bi-objective quay crane scheduling problem based on efficiency and energy. *Mathematics*, *10*(24), 4705. https://doi.org/10.3390/math10244705

Li, L., Zhu, J., Ye, G., & Feng, X. (2018). Development of green ports with the consideration of coastal wave energy. *Sustainability*, *10*(11), 4270. https://doi.org/10.3390/su10114270

Li, M., & Sun, X. (2022). Path optimization of low-carbon container multimodal transport under uncertain conditions. *Sustainability*, *14*(21), 14098. https://doi.org/10.3390/su142114098

Li, S., Tang, L., Liu, J., Zhao, T., & Xiong, X. (2023). Vessel schedule recovery strategy in liner shipping considering expected disruption. *Ocean & Coastal Management*, *237*, 106514. https://doi.org/10.1016/j.ocecoaman.2023.106514

Li, S., Wu, W., Ma, X., Zhong, M., & Safdar, M. (2023). Modelling medium- and long-term purchasing plans for environment-orientated container trucks: A case study of Yangtze River port. *Transportation Safety and Environment*, *5*(1), tdac043. https://doi.org/10.1093/tse/tdac043

Li, X., Kuang, H., & Hu, Y. (2019). Carbon mitigation strategies of port selection and multimodal transport operations—A case study of northeast China. *Sustainability*, *11*(18), 4877. https://doi.org/10.3390/su11184877

Li, X., Peng, Y., Wang, W., Huang, J., Liu, H., Song, X., & Bing, X. (2019). A method for optimizing installation capacity and operation strategy of a hybrid renewable energy system with offshore wind energy for a green container terminal. *Ocean Engineering*, *186*, 106125. https://doi.org/10.1016/j.oceaneng.2019.106125

Li, X., Sun, B., Guo, C., Du, W., & Li, Y. (2020). Speed optimization of a container ship on a given route considering voluntary speed loss and emissions. *Applied Ocean Research*, *94*, 101995. https://doi.org/10.1016/j.apor.2019.101995

Li, X., Sun, B., Jin, J., & Ding, J. (2022). Speed optimization of container ship considering route segmentation and weather data loading: Turning point-time segmentation method. *Journal of Marine Science and Engineering*, *10*(12), 1835. https://doi.org/10.3390/jmse10121835

Lin, D., & Leong, P. (2022). A stochastic sailing speed optimization and vessel deployment problem in liner shipping. *Journal of Marine Science and Technology-Taiwan*, *30*(3), 249–259. https://doi.org/10.51400/2709-6998.2580

Liu, D., & Ge, Y.-E. (2018). Modeling assignment of quay cranes using queueing theory for minimizing CO_2 emission at a container terminal. *Transportation Research Part D: Transport and Environment*, *61*, 140–151. https://doi.org/10.1016/j.trd.2017.06.006

Liu, M., Liu, R., Zhang, E., & Chu, C. (2022). Eco-friendly container transshipment route scheduling problem with repacking operations. *Journal of Combinatorial Optimization*, *43*(5), 1010–1035. https://doi.org/10.1007/s10878-020-00619-8

Liu, M., Liu, X., Chu, F., Zhu, M., & Zheng, F. (2020). Liner ship bunkering and sailing speed planning with uncertain demand. *Computational and Applied Mathematics*, *39*(1), 22–22. https://doi.org/10.1007/s40314-019-0994-2

Liu, S. (2023). Multimodal transportation route optimization of cold chain container in time-varying network considering carbon emissions. *Sustainability*, *15*(5), 4435. https://doi.org/10.3390/su15054435

Liu, Y., Xin, X., Yang, Z., Chen, K., & Li, C. (2021). Liner shipping network—Transaction mechanism joint design model considering carbon tax and liner alliance. *Ocean & Coastal Management*, *212*, 105817. https://doi.org/10.1016/j.ocecoaman.2021.105817

Liu, Y., Zhao, X., & Huang, R. (2022). Research on comprehensive recovery of liner schedule and container flow with hard time windows constraints. *Ocean & Coastal Management*, *224*, 106171. https://doi.org/10.1016/j.ocecoaman.2022.106171

Lu, J., Wu, X., & Wu, Y. (2023). The construction and application of dual-objective optimal speed model of liners in a changing climate: Taking Yang Ming route as an example. *Journal of Marine Science and Engineering*, *11*(1), 157. https://doi.org/10.3390/jmse11010157

Ma, J., Wang, X., Yang, K., & Jiang, L. (2023). Uncertain programming model for the cross-border multimodal container transport system based on inland ports. *Axioms*, *12*(2), 132. https://doi.org/10.3390/axioms12020132

Ma, M., Fan, H., Jiang, X., & Guo, Z. (2019). Truck arrivals scheduling with vessel dependent time windows to reduce carbon emissions. *Sustainability*, *11*(22), 6410. https://doi.org/10.3390/su11226410

Ma, Q., Wang, W., Peng, Y., & Song, X. (2018). An optimization approach to the intermodal transportation network in fruit cold chain, considering cost, quality degradation and carbon dioxide footprint. *Polish Maritime Research*, *25*(1), 61–69. https://doi.org/10.2478/pomr-2018-0007

Ma, W., Hao, S., Ma, D., Wang, D., Jin, S., & Qu, F. (2021). Scheduling decision model of liner shipping considering emission control areas regulations. *Applied Ocean Research*, *106*, 102416. https://doi.org/10.1016/j.apor.2020.102416

Ma, W., Zhang, J., Han, Y., Zheng, H., Ma, D., & Chen, M. (2022). A chaos-coupled multi-objective scheduling decision method for liner shipping based on the NSGA-III algorithm. *Computers & Industrial Engineering*, *174*, 108732. https://doi.org/10.1016/j.cie.2022.108732

Maia, L. C., & Couto, A. (2013). Strategic rail network optimization model for freight transportation. *Transportation Research Record: Journal of the Transportation Research Board*, *2378*(1), 1–12. https://doi.org/10.3141/2378-01

Mansouri, S. A., Lee, H., & Aluko, O. (2015). Multi-objective decision support to enhance environmental sustainability in maritime shipping: A review and future directions. *Transportation Research Part E: Logistics and Transportation Review*, *78*, 3–18. https://doi.org/10.1016/j.tre.2015.01.012

Martínez-López, A. (2021). A multi-objective mathematical model to select fleets and maritime routes in short sea shipping: A case study in Chile. *Journal of Marine Science and Technology*, *26*(3), 673–692. https://doi.org/10.1007/s00773-020-00757-y

Martínez-López, A., Caamaño Sobrino, P., Chica González, M., & Trujillo, L. (2018). Optimization of a container vessel fleet and its propulsion plant to articulate sustainable intermodal chains versus road transport. *Transportation Research Part D: Transport and Environment*, *59*, 134–147. https://doi.org/10.1016/j.trd.2017.12.021

Martínez-López, A., Caamaño Sobrino, P., Chica González, M., & Trujillo, L. (2019). Choice of propulsion plants for container vessels operating under Short Sea Shipping conditions in the European Union: An assessment focused on the environmental impact on the intermodal chains. *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment*, *233*(2), 653–669. https://doi.org/10.1177/1475090218797179

Martínez-López, A., & Chica, M. (2020). Joint optimization of routes and container fleets to design sustainable intermodal chains in Chile. *Sustainability*, *12*(6), 2221. https://doi.org/10.3390/su12062221

Martínez-López, A., Sobrino, P. C., & González, M. M. (2016). Influence of external costs on the optimisation of container fleets by operating under motorways of the sea conditions. *International Journal of Shipping and Transport Logistics*, *8*(6), 653–686. https://doi.org/10.1504/IJSTL.2016.079293

Matsukura, H., Udommahuntisuk, M., Yamato, H., & Dinariyana, A. A. B. (2010). Estimation of CO_2 reduction for Japanese domestic container transportation based on mathematical models. *Journal of Marine Science and Technology*, *15*(1), 34–43. https://doi.org/10.1007/s00773-009-0069-y

Meng, Q., Wang, S., Andersson, H., & Thun, K. (2014). Containership routing and scheduling in liner shipping: overview and future research directions. *Transportation Science*, *48*(2), 265–280. https://doi.org/10.1287/trsc.2013.0461

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *BMJ*, *339*, b2535. https://doi.org/10.1136/bmj.b2535

Nadi, A., Nugteren, A., Snelder, M., Van Lint, J. W. C., & Rezaei, J. (2022). Advisory-based time slot management system to mitigate waiting time at container terminal gates. *Transportation Research Record: Journal of the Transportation Research Board*, *2676*(10), 036119812210909. https://doi.org/10.1177/03611981221090940

Niu, Y., Yu, F., Yao, H., & Yang, Y. (2022). Multi-equipment coordinated scheduling strategy of U-shaped automated container terminal considering energy consumption. *Computers & Industrial Engineering*, *174*, 108804. https://doi.org/10.1016/j.cie.2022.108804

Omran, M., Ghousi, R., & Kadkhodaei, A. (2023). Sustainable model of port-hinterland freight distribution network considering uncertainty: A case study of Iran. *Scientia Iranica*, *30*(2), 784–802. https://doi.org/10.24200/sci.2021.55884.4447

Palacio, A., Adenso-Díaz, B., & Lozano, S. (2015). A decision-making model to design a sustainable container depot logistic network: The case of the port of Valencia. *Transport*, *33*(1), 119–130. https://doi.org/10.3846/16484142.2015.1107621

Palacio, A., Adenso-Díaz, B., Lozano, S., & Furió, S. (2016). Bicriteria optimization model for locating maritime container depots: Application to the Port of Valencia. *Networks and Spatial Economics*, *16*(1), 331–348. https://doi.org/10.1007/s11067-013-9205-7

Pasha, J., Dulebenets, M. A., Fathollahi-Fard, A. M., Tian, G., Lau, Y., Singh, P., & Liang, B. (2021). An integrated optimization method for tactical-level planning in liner shipping with heterogeneous ship fleet and environmental considerations. *Advanced Engineering Informatics*, *48*, 101299. https://doi.org/10.1016/j.aei.2021.101299

Peng, Y., Li, X., Wang, W., Wei, Z., Bing, X., & Song, X. (2019). A method for determining the allocation strategy of on-shore power supply from a green container terminal perspective. *Ocean & Coastal Management*, *167*, 158–175. https://doi.org/10.1016/j.ocecoaman.2018.10.007

Peng, Y., Wang, W., Song, X., & Zhang, Q. (2016). Optimal allocation of resources for yard crane network management to minimize carbon dioxide emissions. *Journal of Cleaner Production*, *131*, 649–658. https://doi.org/10.1016/j.jclepro.2016.04.120

Pian, F., Shi, Q., Yao, X., Zhu, H., & Luan, W. (2021). Joint optimization of a dry port with multilevel location and container transportation: The case of northeast China. *Complexity*, *2021*, 5584600. https://doi.org/10.1155/2021/5584600

Pourmohammad-Zia, N., Schulte, F., Gonzalez-Ramirez, R., Voss, S., & Negenborn, R. (2023). A robust optimization approach for platooning of automated ground vehicles in port hinterland corridors. *Computers & Industrial Engineering*, *117*, 109046. https://doi.org/10.1016/j.cie.2023.109046

Psaraftis, H. N., & Kontovas, C. A. (2013). Speed models for energy-efficient maritime transportation: A taxonomy and survey. *Transportation Research Part C: Emerging Technologies*, *26*, 331–351. https://doi.org/10.1016/j.trc.2012.09.012

Qi, J., & Wang, S. (2023). LNG bunkering station deployment problem-A case study of a Chinese container shipping network. *Mathematics*, *11*(4), 813. https://doi.org/10.3390/math11040813

Qi, X., & Song, D.-P. (2012). Minimizing fuel emissions by optimizing vessel schedules in liner shipping with uncertain port times. *Transportation Research Part E: Logistics and Transportation Review*, *48*(4), 863–880. https://doi.org/10.1016/j.tre.2012.02.001

Rajkovic, R., Zrnic, N., Kirin, S., & Dragovic, B. (2016). A review of multi-objective optimization of container flow using sea and land legs together. *FME Transaction*, *44*(2), 204–211. https://doi.org/10.5937/fmet1602204R

Reinhardt, L. B., Pisinger, D., Sigurd, M. M., & Ahmt, J. (2020). Speed optimizations for liner networks with business constraints. *European Journal of Operational Research*, *285*(3), 1127–1140. https://doi.org/10.1016/j.ejor.2020.02.043

Sáinz Bernat, N., Schulte, F., Voß, S., & Böse, J. (2016). Empty container management at ports considering pollution, repair options, and street-turns. *Mathematical Problems in Engineering*, *2016*, 1–13. https://doi.org/10.1155/2016/3847163

Schmidt, J., Meyer-Barlag, C., Eisel, M., Kolbe, L. M., & Appelrath, H.-J. (2015). Using battery-electric AGVs in container terminals—Assessing the potential and optimizing the economic viability. *Research in Transportation Business & Management*, *17*, 99–111. https://doi.org/10.1016/j.rtbm.2015.09.002

Schulte, F., Lalla-Ruiz, E., González-Ramírez, R. G., & Voß, S. (2017). Reducing port-related empty truck emissions: A mathematical approach for truck appointments with collaboration. *Transportation Research Part E: Logistics and Transportation Review*, *105*, 195–212. https://doi.org/10.1016/j.tre.2017.03.008

Shi, H., Xu, P., & Yang, Z. (2016). Optimization of transport network in the Basin of Yangtze River with minimization of environmental emission and transport/investment costs. *Advances in Mechanical Engineering*, *8*(8), 168781401666092. https://doi.org/10.1177/1687814016660923

Shiri, S., & Huynh, N. (2018). Assessment of U.S. chassis supply models on drayage productivity and air emissions. *Transportation Research Part D: Transport and Environment*, *61*, 174–203. https://doi.org/10.1016/j.trd.2017.04.024

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039

Song, D.-P., Li, D., & Drake, P. (2015). Multi-objective optimization for planning liner shipping service with uncertain port times. *Transportation Research Part E: Logistics and Transportation Review*, *84*, 1–22. https://doi.org/10.1016/j.tre.2015.10.001

Sun, Y. (2020). Green and reliable freight routing problem in the road-rail intermodal transportation network with uncertain parameters: A fuzzy goal programming approach. *Journal of Advanced Transportation*, *2020*, 1–21. https://doi.org/10.1155/2020/7570686

Sun, Y., Hrušovský, M., Zhang, C., & Lang, M. (2018). A time-dependent fuzzy programming approach for the green multimodal routing problem with rail service capacity uncertainty and road traffic congestion. *Complexity*, *2018*, 1–22. https://doi.org/10.1155/2018/8645793

Sun, Y., & Lang, M. (2015). Modeling the multicommodity multimodal routing problem with schedule-based services and carbon dioxide emission costs. *Mathematical Problems in Engineering*, *2015*, 1–21. https://doi.org/10.1155/2015/406218

Sun, Y., Zheng, J., Han, J., Liu, H., & Zhao, Z. (2022). Allocation and reallocation of ship emission permits for liner shipping. *Ocean Engineering*, *266*, 112976. https://doi.org/10.1016/j.oceaneng.2022.112976

Tan, R., Duru, O., & Thepsithar, P. (2020). Assessment of relative fuel cost for dual fuel marine engines along major Asian container shipping routes. *Transportation Research Part E: Logistics and Transportation Review*, *140*, 102004. https://doi.org/10.1016/j.tre.2020.102004

Tan, R., Psaraftis, H., & Wang, D. (2022). The speed limit debate: Optimal speed concepts revisited under a multi-fuel regime. *Transportation Research Part D-Transport and Environment*, *111*, 103445. https://doi.org/10.1016/j.trd.2022.103445

Tan, Z., Wang, Y., Meng, Q., & Liu, Z. (2018). Joint ship schedule design and sailing speed optimization for a single inland shipping service with uncertain dam transit time. *Transportation Science*, *52*(6), 1570–1588. https://doi.org/10.1287/trsc.2017.0808

Tan, Z., Zeng, X., Shao, S., Chen, J., & Wang, H. (2022). Scrubber installation and green fuel for inland river ships with non-identical streamflow. *Transportation Research Part E: Logistics and Transportation Review*, *161*, 102677. https://doi.org/10.1016/j.tre.2022.102677

Tao, Y., Zhang, S., Lin, C., & Lai, X. (2023). A bi-objective optimization for integrated truck operation and storage allocation considering traffic congestion in container terminals. *Ocean & Coastal Management*, *232*, 106417. https://doi.org/10.1016/j.ocecoaman.2022.106417

Tran, N. K., Haasis, H.-D., & Buer, T. (2017). Container shipping route design incorporating the costs of shipping, inland/feeder transport, inventory and CO_2 emission. *Maritime Economics & Logistics*, *19*(4), 667–694. https://doi.org/10.1057/mel.2016.11

Trapp, A. C., Harris, I., Sanchez Rodrigues, V., & Sarkis, J. (2020). Maritime container shipping: Does coopetition improve cost and environmental efficiencies? *Transportation Research Part D: Transport and Environment*, *87*, 102507. https://doi.org/10.1016/j.trd.2020.102507

Tsao, Y., & Linh, V. (2018). Seaport-dry port network design considering multimodal transport and carbon emissions. *Journal of Cleaner Production*, *199*, 481–492. https://doi.org/10.1016/j.jclepro.2018.07.137

Tsao, Y., & Thanh, V. (2019). A multi-objective mixed robust possibilistic flexible programming approach for sustainable seaport-dry port network design under an uncertain environment. *Transportation Research Part E: Logistics and Transportation Review*, *124*, 13–39. https://doi.org/10.1016/j.tre.2019.02.006

UNCTAD. (2021). *Review of Maritime Transport.*

Venturini, G., Iris, Ç., Kontovas, C. A., & Larsen, A. (2017). The multi-port berth allocation problem with speed optimization and emission considerations. *Transportation Research Part D: Transport and Environment*, *54*, 142–159. https://doi.org/10.1016/j.trd.2017.05.002

Wang, C., & Chen, J. (2017). Strategies of refueling, sailing speed and ship deployment of containerships in the low-carbon background. *Computers & Industrial Engineering*, *114*, 142–150. https://doi.org/10.1016/j.cie.2017.10.012

Wang, C., Yu, S., & Xu, L. (2022). Decisions on sailing frequency and ship type in liner shipping with the consideration of carbon dioxide emissions. *Regional Studies in Marine Science*, *52*, 102371–102371. https://doi.org/10.1016/j.rsma.2022.102371

Wang, S. (2016). Fundamental properties and pseudo-polynomial-time algorithm for network containership sailing speed optimization. *European Journal of Operational Research*, *250*(1), 46–55. https://doi.org/10.1016/j.ejor.2015.10.052

Wang, S., Alharbi, A., & Davy, P. (2014). Liner ship route schedule design with port time windows. *Transportation Research Part C: Emerging Technologies*, *41*, 1–17. https://doi.org/10.1016/j.trc.2014.01.012

Wang, S., & Meng, Q. (2012). Sailing speed optimization for container ships in a liner shipping network. *Transportation Research Part E: Logistics and Transportation Review*, *48*(3), 701–714. https://doi.org/10.1016/j.tre.2011.12.003

Wang, S., & Meng, Q. (2015). Robust bunker management for liner shipping networks. *European Journal of Operational Research*, *243*(3), 789–797. https://doi.org/10.1016/j.ejor.2014.12.049

Wang, S., & Meng, Q. (2017). Container liner fleet deployment: A systematic overview. *Transportation Research Part C: Emerging Technologies*, *77*, 389–404. https://doi.org/10.1016/j.trc.2017.02.010

Wang, S., Meng, Q., & Liu, Z. (2013). Containership scheduling with transit-time-sensitive container shipment demand. *Transportation Research Part B: Methodological*, *54*, 68–83. https://doi.org/10.1016/j.trb.2013.04.003

Wang, S., Qu, X., & Yang, Y. (2015). Estimation of the perceived value of transit time for containerized cargoes. *Transportation Research Part A: Policy and Practice*, *78*, 298–308. https://doi.org/10.1016/j.tra.2015.04.014

Wang, S., & Wang, X. (2016). A polynomial-time algorithm for sailing speed optimization with containership resource sharing. *Transportation Research Part B: Methodological*, *93*, 394–405. https://doi.org/10.1016/j.trb.2016.08.003

Wang, S., Zhuge, D., Zhen, L., & Lee, C.-Y. (2021). Liner shipping service planning under sulfur emission regulations. *Transportation Science*, *55*(2), 491–509. https://doi.org/10.1287/trsc.2020.1010

Wang, T., Wang, X., & Meng, Q. (2018). Joint berth allocation and quay crane assignment under different carbon taxation policies. *Transportation Research Part B: Methodological*, *117*, 18–36. https://doi.org/10.1016/j.trb.2018.08.012

Wang, W., Peng, Y., Li, X., Qi, Q., Feng, P., & Zhang, Y. (2019). A two-stage framework for the optimal design of a hybrid renewable energy system for port application. *Ocean Engineering*, *191*, 106555. https://doi.org/10.1016/j.oceaneng.2019.106555

Wang, Y., Meng, Q., & Kuang, H. (2018). Jointly optimizing ship sailing speed and bunker purchase in liner shipping with distribution-free stochastic bunker prices. *Transportation Research Part C: Emerging Technologies*, *89*, 35–52. https://doi.org/10.1016/j.trc.2018.01.020

Wen, X., Ge, Y.-E., Yin, Y., & Zhong, M. (2022). Dynamic recovery actions in multi-objective liner shipping service with buffer times. *Proceedings of the Institution of Civil Engineers - Maritime Engineering*, *175*(2), 46–62. https://doi.org/10.1680/jmaen.2021.005

Wong, E. Y. C., Tai, A. H., Lau, H. Y. K., & Raman, M. (2015). An utility-based decision support sustainability model in slow steaming maritime operations. *Transportation Research Part E: Logistics and Transportation Review*, *78*, 57–69. https://doi.org/10.1016/j.tre.2015.01.013

Wong, E. Y. C., Tai, A. H., & So, S. (2020). Container drayage modelling with graph theory-based road connectivity assessment for sustainable freight transportation in new development area. *Computers & Industrial Engineering*, *149*, 106810. https://doi.org/10.1016/j.cie.2020.106810

Wu, Y., Huang, Y., Wang, H., & Zhen, L. (2022a). Joint planning of fleet deployment, ship refueling, and speed optimization for dual-fuel ships considering methane slip. *Journal of Marine Science and Engineering*, *10*(11), 1690. https://doi.org/10.3390/jmse10111690

Wu, Y., Huang, Y., Wang, H., & Zhen, L. (2022b). Nonlinear programming for fleet deployment, voyage planning and speed optimization in sustainable liner shipping. *Electronic Research Archive*, *31*(1), 147–168. https://doi.org/10.3934/era.2023008

Wu, Y., Huang, Y., Wang, H., Zhen, L., & Shao, W. (2023). Green technology adoption and fleet deployment for new and aged ships considering maritime decarbonization. *Journal of Marine Science and Engineering*, *11*(1), 36. https://doi.org/10.3390/jmse11010036

Xing, Y., Yang, H., Ma, X., & Zhang, Y. (2019). Optimization of ship speed and fleet deployment under carbon emissions policies for container shipping. *Transport*, *34*(3), 260–274. https://doi.org/10.3846/transport.2019.9317

Xu, B., Liu, X., Li, J., Yang, Y., Wu, J., Shen, Y., & Zhou, Y. (2022). Dynamic appointment rescheduling of trucks under uncertainty of arrival time. *Journal of Marine Science and Engineering*, *10*(5), 695. https://doi.org/10.3390/jmse10050695

Yang, Y., Zhu, X., & Haghani, A. (2019). Multiple equipment integrated scheduling and storage space allocation in rail–water intermodal container terminals considering energy efficiency. *Transportation Research Record: Journal of the Transportation Research Board*, *2673*(3), 199–209. https://doi.org/10.1177/0361198118825474

Yang, Z., Xin, X., Chen, K., & Yang, A. (2021). Coastal container multimodal transportation system shipping network design—Toll policy joint optimization model. *Journal of Cleaner Production*, *279*, 123340. https://doi.org/10.1016/j.jclepro.2020.123340

Yu, D., Li, D., Sha, M., & Zhang, D. (2019). Carbon-efficient deployment of electric rubber-tyred gantry cranes in container terminals with workload uncertainty. *European Journal of Operational Research*, *275*(2), 552–569. https://doi.org/10.1016/j.ejor.2018.12.003

Yu, H., Deng, Y., Zhang, L., Xiao, X., & Tan, C. (2022). Yard operations and management in automated container terminals: A review. *Sustainability*, *14*(6), 3419. https://doi.org/10.3390/su14063419

Yu, H., Fang, Z., Fu, X., Liu, J., & Chen, J. (2021). Literature review on emission control-based ship voyage optimization. *Transportation Research Part D: Transport and Environment*, *93*, 102768. https://doi.org/10.1016/j.trd.2021.102768

Yu, H., Ge, Y.-E., Chen, J., Luo, L., Tan, C., & Liu, D. (2017). CO_2 emission evaluation of yard tractors during loading at container terminals. *Transportation Research Part D: Transport and Environment*, *53*, 17–36. https://doi.org/10.1016/j.trd.2017.03.014

Yu, H., Huang, M., Zhang, L., & Tan, C. (2022). Yard template generation for automated container terminal based on bay sharing strategy. *Annals of Operations Research*, *In Press*. https://doi.org/10.1007/s10479-022-04657-9

Yu, J., Voß, S., & Song, X. (2022). Multi-objective optimization of daily use of shore side electricity integrated with quayside operation. *Journal of Cleaner Production*, *351*, 131406. https://doi.org/10.1016/j.jclepro.2022.131406

Yu, J., Voß, S., & Tang, G. (2019). Strategy development for retrofitting ships for implementing shore side electricity. *Transportation Research Part D: Transport and Environment*, *74*, 201–213. https://doi.org/10.1016/j.trd.2019.08.004

Yu, M.-M., & Chen, L.-H. (2016). Centralized resource allocation with emission resistance in a two-stage production system: Evidence from a Taiwan's container shipping company. *Transportation Research Part A: Policy and Practice*, *94*, 650–671. https://doi.org/10.1016/j.tra.2016.10.003

Yu, Y., Tu, J., Shi, K., Liu, M., & Chen, J. (2021). Flexible Optimization of International Shipping Routes considering Carbon Emission Cost. *Mathematical Problems in Engineering*, *2021*, 6678473. https://doi.org/10.1155/2021/6678473

Zacharioudakis, P. G., Iordanis, S., Lyridis, D. V., & Psaraftis, H. N. (2011). Liner shipping cycle cost modelling, fleet deployment optimization and what-if analysis. *Maritime Economics & Logistics*, *13*(3), 278–297. https://doi.org/10.1057/mel.2011.11

Zhang, M., Wiegmans, B., & Tavasszy, L. (2013). Optimization of multimodal networks including environmental costs: A model and findings for transport policy. *Computers in Industry*, *64*(2), 136–145. https://doi.org/10.1016/j.compind.2012.11.008

Zhang, Q., Wang, S., & Zhen, L. (2022). Yard truck retrofitting and deployment for hazardous material transportation in green ports. *Annals of Operations Research*, *In Press*. https://doi.org/10.1007/s10479-021-04507-0

Zhang, X., Lam, J. S. L., & Iris, Ç. (2020). Cold chain shipping mode choice with environmental and financial perspectives. *Transportation Research Part D: Transport and Environment*, *87*, 102537. https://doi.org/10.1016/j.trd.2020.102537

Zhang, Y., Atasoy, B., & Negenborn, R. R. (2022). Preference-Based Multi-Objective Optimization for Synchromodal Transport Using Adaptive Large Neighborhood Search. *Transportation Research Record: Journal of the Transportation Research Board*, *2676*(3), 71–87. https://doi.org/10.1177/03611981211049148

Zhang, Y., Liang, C., Shi, J., Lim, G., & Wu, Y. (2022). Optimal port microgrid scheduling incorporating onshore power supply and berth allocation under uncertainty. *Applied Energy*, *313*, 118856. https://doi.org/10.1016/j.apenergy.2022.118856

Zhao, S., Duan, J., Li, D., & Yang, H. (2022). Vessel scheduling and bunker management with speed deviations for liner shipping in the presence of collaborative agreements. *IEEE Access*, *10*, 107669–107684. https://doi.org/10.1109/ACCESS.2022.3211311

Zhao, W., Wang, Y., Zhang, Z., & Wang, H. (2021). Multicriteria ship route planning method based on improved particle swarm optimization–genetic algorithm. *Journal of Marine Science and Engineering*, *9*(4), 357. https://doi.org/10.3390/jmse9040357

Zhao, Y., Chen, Y., Fagerholt, K., Lindstad, E., & Zhou, J. (2023). Pathways towards carbon reduction through technology transition in liner shipping. *Maritime Policy & Management*, *In Press*. https://doi.org/10.1080/03088839.2023.2224813

Zhao, Y., Ye, J., & Zhou, J. (2021). Container fleet renewal considering multiple sulfur reduction technologies and uncertain markets amidst COVID-19. *Journal of Cleaner Production*, *317*, 128361. https://doi.org/10.1016/j.jclepro.2021.128361

Zhao, Y., Zhou, J., Fan, Y., & Kuang, H. (2020). An expected utility-based optimization of slow steaming in sulphur emission control areas by applying big data analytics. *IEEE Access*, *8*, 3646–3655. https://doi.org/10.1109/ACCESS.2019.2962210

Zhen, L., Hu, Z., Yan, R., Zhuge, D., & Wang, S. (2020). Route and speed optimization for liner ships under emission control policies. *Transportation Research Part C: Emerging Technologies*, *110*, 330–345. https://doi.org/10.1016/j.trc.2019.11.004

Zhen, L., Jin, Y., Wu, Y., Yuan, Y., & Tan, Z. (2022). Benders decomposition for internal truck renewal decision in green ports. *Maritime Policy & Management*, 1–23. https://doi.org/10.1080/03088839.2021.2021596

Zhen, L., Lin, S., & Zhou, C. (2022). Green port oriented resilience improvement for traffic-power coupled networks. *Reliability Engineering & System Safety*, *225*, 108569. https://doi.org/10.1016/j.ress.2022.108569

Zhen, L., Sun, Q., Zhang, W., Wang, K., & Yi, W. (2021). Column generation for low carbon berth allocation under uncertainty. *Journal of the Operational Research Society*, *72*(10), 2225–2240. https://doi.org/10.1080/01605682.2020.1776168

Zhen, L., Wang, S., & Wang, K. (2016). Terminal allocation problem in a transshipment hub considering bunker consumption. *Naval Research Logistics (NRL)*, *63*(7), 529–548. https://doi.org/10.1002/nav.21717

Zhen, L., Wang, S., & Zhuge, D. (2017). Dynamic programming for optimal ship refueling decision. *Transportation Research Part E: Logistics and Transportation Review*, *100*, 63–74. https://doi.org/10.1016/j.tre.2016.12.013

Zhen, L., Wu, Y., Wang, S., & Laporte, G. (2020). Green technology adoption for fleet deployment in a shipping network. *Transportation Research Part B: Methodological*, *139*, 388–410. https://doi.org/10.1016/j.trb.2020.06.004

Zheng, Y., Xu, M., Wang, Z., & Xiao, Y. (2023). A genetic algorithm for integrated scheduling of container handing systems at container terminals from a low-carbon operations perspective. *Sustainability*, *15*(7), 6035. https://doi.org/10.3390/su15076035

Zhong, M., Yang, Y., Zhou, Y., & Postolache, O. (2020). Application of hybrid GA-PSO based on intelligent control fuzzy system in the integrated scheduling in automated container terminal. *Journal of Intelligent & Fuzzy Systems*, *39*(2), 1525–1538. https://doi.org/10.3233/JIFS-179926

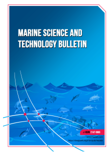
Zhu, M., Chen, M., & Kristal, M. (2018). Modelling the impacts of uncertain carbon tax policy on maritime fleet mix strategy and carbon mitigation. *Transport*, *33*(3), 707–717. https://doi.org/10.3846/transport.2018.1579

Zhu, S., Gao, J., He, X., Zhang, S., Jin, Y., & Tan, Z. (2021). Green logistics oriented tug scheduling for inland waterway logistics. *Advanced Engineering Informatics*, *49*, 101323. https://doi.org/10.1016/j.aei.2021.101323

Zhuge, D., Wang, S., & Wang, D. Z. W. (2021). A joint liner ship path, speed and deployment problem under emission reduction measures. *Transportation Research Part B: Methodological*, *144*, 155–173. https://doi.org/10.1016/j.trb.2020.12.006

Mar. Sci. Tech. Bull. (2023) 12(3): 312-321
e–ISSN: 2147–9666
info@masteb.com

dergipark.org.tr/en/pub/masteb
www.masteb.com
DOI: 10.33714/masteb.1334052



Marine Science and Technology Bulletin

PRENSIP
https://prensip.gen.tr/

RESEARCH ARTICLE

Guideline for preliminary design phase of trawler type yachts

Bülent İbrahim Turan[1]*

[1] *Muğla Sıtkı Koçman University, Bodrum Maritime Vocational School, Department of Motor Vehicles and Transportation Technologies, 48420, Muğla, Türkiye*

ARTICLE INFO

Article History:
Received: 28.07.2023
Received in revised form: 18.08.2023
Accepted: 19.08.2023
Available online: 28.09.2023

Keywords:
Design process
Motor yacht
Naval architecture
Trawler yacht
Yacht design

ABSTRACT

Yacht design is a multidisciplinary process that consists of set of iterative sub-processes. The main aim of the whole process is to reach the optimum design that satisfies not only the engineering-related requirements, but also the user's expectations. In the preliminary design process, determination of the type and the main dimensions of the yacht according to the user's preferences is followed by the processes such as the general arrangement plan, determination of the hull form and superstructure design, estimation of hydrostatic and hydrodynamic characteristics, etc. In this research, it is aimed to obtain a parametric design framework which enables to reach hull form characteristics, layout parameters and resistance estimation values with respect to various speeds, only by using only L_{OA} of trawler type motor yachts. In this content, 26 trawler type motor yachts were investigated and their hull were modeled for speed-resistance calculations. As a result of the research, graphics and tables were presented that allow to reach the characteristic parameters, which are important in terms of design and engineering, by using only the L_{OA} value in the preliminary design phase of the trawler type motor yachts.

Please cite this paper as follows:

Turan, B. İ. (2023). Guideline for preliminary design phase of trawler type yachts. *Marine Science and Technology Bulletin*, *12*(3), 312-321. https://doi.org/10.33714/masteb.1334052

Nomenclature

B	: Beam of the hull (m)
$\mathbf{B_{TRANSOM}}$	: Beam of the transom on top (m)
$\mathbf{B_{WL}}$	: Beam of waterline (m)
$\mathbf{C_B}$	: Block coefficient
$\mathbf{C_M}$	: Midship section coefficient
$\mathbf{C_P}$	: Prismatic coefficient
LCB	: Longitudinal center of buoyancy
$\mathbf{L_{HULL}}$	: Hull length (m)
$\mathbf{L_{OA}}$	: Length overall (m)
$\mathbf{L_{PLATFORM}}$	: Length of the platform (m)
$\mathbf{L_{WL}}$	: Length of waterline (m)
T	: Draft (m),
Δ	: Displacement tonnage (tonnes)

* Corresponding author
E-mail address: bulentturan@mu.edu.tr (B. İ. Turan)

Introduction

Yacht design is a process involving iterative procedures until a result is achieved that satisfies various predetermined requirements (Larsson & Eliasson, 2007). The number, sequence and the contents of these procedures may differentiate according to the type of the yacht. For instance, design spiral which is presented by Hamlin (1996) includes a procedure related with sail & rigging design (see Figure 1). If a satisfactory result is achieved at each procedure of the design spiral, the next stage is passed, otherwise the process is renewed (Arslan, 2010). To start this iterative process, the designer uses a set of assumptions (Larsson & Eliasson, 2007). Formulas and frameworks developed by utilizing previous projects in yacht design play a major role in establishing the assumptions for the desired yacht.

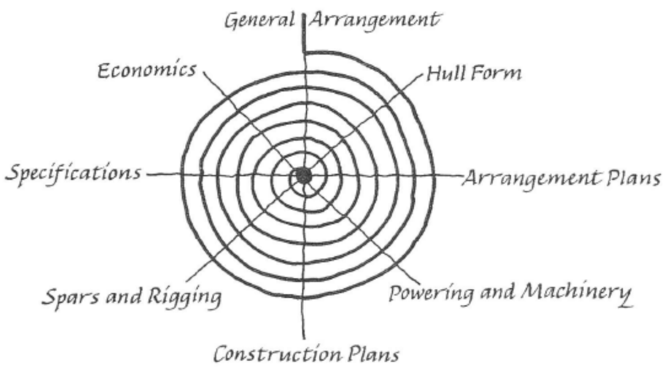


Figure 1. Design spiral presented by Hamlin (1996)

Clarifying the type of the yacht is among the initial steps in the early stage of the yacht design process. Yachts can be categorized as motoryachts and sailing yachts according to the propulsion type (Tokol, 2020). The form and variety of motor yachts differ from sailing yachts (Turan, 2021). It is very difficult to generalize the form in motor yachts that do not have a traditional form and therefore are open to diversity (Büyükkeçeci & Turan, 2018). Although it is possible to distinguish the displacement, semi-displacement or planning form for the underwater form of the hull, this distinction is not sufficient to define the above-water parts of the boats and at this point type names of lobster, trawler, open, sport, weekend, flybridge or hard-top etc. are used based on all or some of the parts of these yachts above the water (Turan, 2021). Trawler type yachts, which have been used for fishing purposes are re-designed to be used for pleasure purposes (Özgel Felek & Arabacıoğlu, 2019). These yachts are defined as motoryachts that offer spacious interior space thanks to the difference in grades on their main decks (Turan, 2021). Figure 2 shows the profile drawing and the general arrangement plan of a trawler type yacht. In these yachts, sunbathing area is located in the flybridge area.

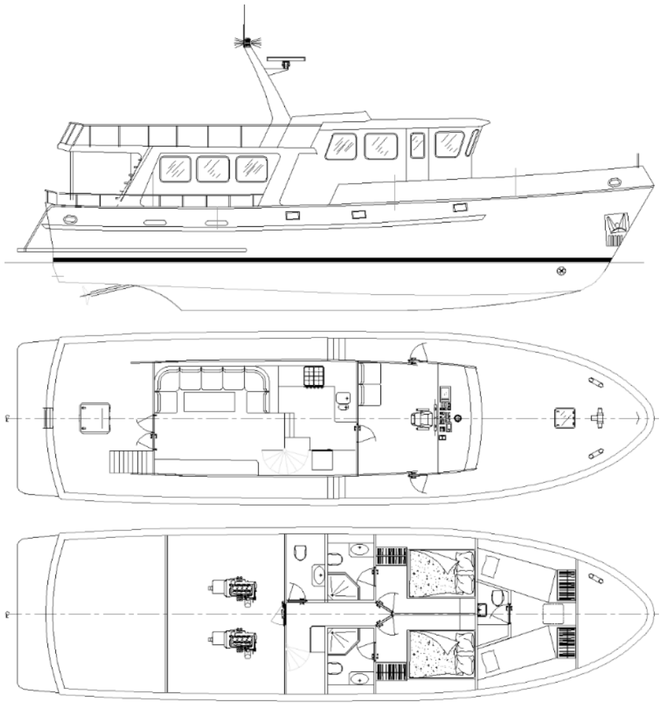


Figure 2. Profile drawing and general arrangement plan of a trawler yacht

As shown in Figure 2, trawler yachts have a stern with a transom and a platform, large closed area in the main deck and a flybridge that is located in the aft part of the yacht. Various studies address design process of different yacht types and contribute this iterative process by providing methods or guidelines. Turan (2021) presents non-dimensional parameters that indicate the location of the engine room for preliminary design stage of different yacht types. In their research, Turan & Akman (2021) investigated Bodrum Gulets with different stern forms and they developed a design framework for that specific sailing yacht type. In the research of Sarıoğlu & Kükner (2018) a numerical method to calculate the form factor of Bodrum gulets has been developed and an artificial neural network (ANN) has been used to estimate the form factor of hull forms in the design process of these yachts. The number of the studies conducted on the trawler type yachts are limited. In the research of Özgel Felek & Arabacıoğlu (2019), trawler type yachts have been investigated to obtain design parameters for general layout and superstructure design of these yachts. In another research (Lane, 2010) the effect of various bulb types on the resistance and performance characteristics of the selected trawler yacht hull have been studied. In the previous studies on trawler type yachts, these motor yacht types were handled from different disciplines and made important contributions in the design process. On the other hand, there is no design guide regarding hull form characteristics of these boat types. This study aims to fulfil this gap by providing a framework that enables the designer to obtain hull and superstructure parameters by using only L_{OA} of trawler type yachts.

Material and Method

In the research, 26 trawler type motor yachts' hulls and superstructures were investigated. L_{OA} of the investigated trawler yachts varies from 14,20 m to 36,80 m. 19 of the investigated yachts have been built between the years 1998 to 2023 while 7 of them are in the project or production phase. Table 1 includes main dimensions of the investigated trawler yachts. Figure 3 and Figure 4 illustrates render images of two different trawler yachts, which have been involved in the research.

After collecting data, investigated yachts' hulls were modelled in Rhino3D Version 7 (2020) and exported as IGES file to Maxsurf (2022) software program for hydrostatic and resistance calculations. Figure 5 represents the work flow of the research.

Figure 3. A render image of one of the investigated trawler yachts

Figure 4. A render image of one of the investigated trawler yachts

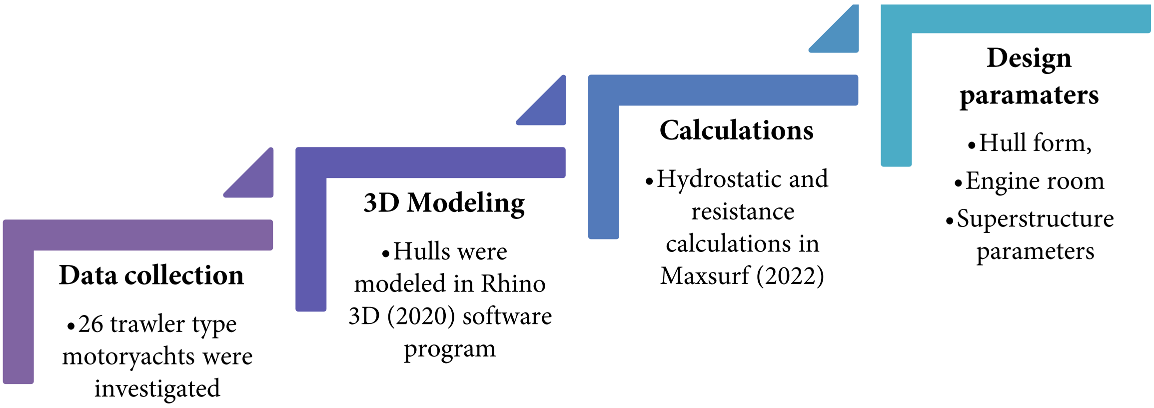


Figure 5. Workflow of the research

Table 1. Main dimensions of the investigated yachts

Yacht Code	L_{OA} (m)	L_{WL} (m)	L_{HULL} (m)	B (m)	B_{WL} (m)	$B_{TRANSOM}$ (m)	T (m)	Δ (ton)
Trawler_1	14.20	12.63	13.60	4.12	3.84	3.76	1.10	22.00
Trawler_2	15.00	13.60	14.35	4.26	4.00	3.96	1.16	24.00
Trawler_3	15.80	14.27	15.10	4.78	4.41	4.28	1.55	30.20
Trawler_4	16.50	14.45	15.80	4.68	4.33	4.31	1.28	29.00
Trawler_5	16.55	14.10	15.75	4.71	4.44	4.32	1.23	32.44
Trawler_6	18.80	16.45	18.00	5.26	4.88	4.78	1.41	40.00
Trawler_7	19.10	16.82	18.25	5.34	4.92	4.82	1.42	42.00
Trawler_8	19.38	17.56	18.48	5.23	5.07	4.92	1.58	48.51
Trawler_9	20.00	17.44	19.10	5.70	5.00	5.21	1.44	46.00
Trawler_10	20.50	18.20	19.60	5.62	5.22	5.10	1.61	57.00
Trawler_11	20.73	18.10	19.73	5.65	5.21	5.16	1.75	59.00
Trawler_12	20.80	18.92	19.70	5.82	5.51	5.24	1.68	62.00
Trawler_13	21.33	18.60	20.23	5.90	5.48	5.32	1.49	66.00
Trawler_14	21.77	19.68	20.77	5.69	5.42	5.30	1.70	68.60
Trawler_15	22.10	20.50	20.90	6.05	5.47	5.41	1.71	72.00
Trawler_16	23.60	20.91	22.35	6.46	5.83	5.76	1.68	75.00
Trawler_17	24.50	22.66	23.30	6.50	5.92	5.92	1.71	78.00
Trawler_18	24.90	22.80	23.60	6.55	6.18	5.81	1.70	76.00
Trawler_19	24.95	22.86	23.55	6.51	6.24	5.71	1.68	81.00
Trawler_20	25.00	21.50	23.50	6.62	6.32	5.84	1.71	84.00
Trawler_21	25.00	22.06	23.60	6.58	6.24	5.82	1.62	86.00
Trawler_22	25.20	23.60	23.70	6.60	6.18	5.92	1.80	92.00
Trawler_23	25.90	23.72	24.40	6.80	6.22	6.06	1.81	96.00
Trawler_24	27.00	25.70	25.40	6.88	6.61	6.11	1.81	112.00
Trawler_25	29.50	25.82	27.75	7.18	6.92	6.52	1.86	141.00
Trawler_26	36.80	34.50	34.40	7.96	7.56	7.16	2.30	248.00

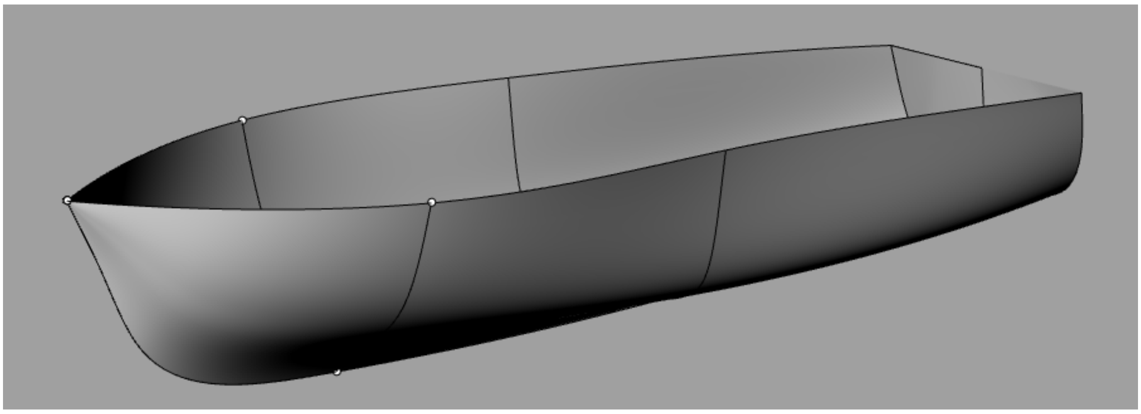


Figure 6. Modeled hull in Rhino3D

For the hydrostatic calculations, the reference point is taken as the intersection of the sternpost with the loaded waterline in the longitudinal direction; centerline for the transversal direction and baseline for the vertical direction. Figure 6 shows one of the modeled hulls for the analyses.

In the resistance calculations, Holtrop-Mennen method was used. The method is seen as a useful tool for displacement type hulls' resistance prediction calculation and it bases on the regression analysis of different scale model tests and trial data (Holtrop & Mennen, 1982; Turan, 2009). According to mathematical model of Holtrop-Mennen, viscous resistance R_V and the wave-making resistance R_W are two components of the total resistance R_T (Holtrop & Mennen, 1982; Elkafas et al., 2019). R_V is formulated as Eq (1):

$$R_V = (1+k)R_F \tag{1}$$

R_F is frictional resistance according to the ITTC-1957 formula. The form factor k is a function of following hull form parameters (Elkafas et al., 2019) and formulated as in Eq (2):

$$k = f\left(\frac{B}{L}, \frac{T}{L}, \frac{L}{L_R}, \frac{L^3}{\nabla}, C_P, c\right) \tag{2}$$

where L_R is the length of after body and c is the coefficient based on the shape after body. The second main component, R_W is estimated by the Eq (3):

$$R_W = c_1 c_2 c_3 \nabla \rho g e^{\left(m_1 F_n^d + m_2 \cos\left(\lambda F_n^{-2}\right)\right)} \tag{3}$$

where c_1, c_2, c_3, m_1, m_2 and λ are the coefficients (Holtrop & Mennen, 1982) which are the functions of the hull form. Fn is the Froude Number which depends on the speed of the vessel.

Results and Discussion

Results of the research are discussed in tree main perspectives as; hull form parameters, layout parameters and resistance characteristics. The hull form parameters perspective includes evaluation of the hydrostatic values of the investigated vessels as well as some design ratios of the hull. In the layout parameters perspective, location and proportion of the engine room and superstructure are presented. In the resistance characteristics, resistance values of the investigated yachts' hulls for different speed values are presented.

Hull Form Parameters

Hull form coefficients as well as the design ratios are among the key parameters to predict hull form characteristics in the design process of yachts. Block coefficient, C_B determines the fullness of a hull and it is one of the major factors on weight and resistance (Turan & Akman, 2021). Prismatic coefficient, C_P describes the fullness or fineness of the hull's ends by considering the immersed volume and midship section area (Killing & Hunter, 1998). Midship area coefficient, C_M is among important determinants for predicting wetted surface area, frictional resistance and pressure-viscous resistance characteristics when used with other parameters such as C_B, bilge radius and B/T ratio (Papanikolaou, 2014). Longitudinal center of buoyancy, *LCB* is an important determinant of the volume distribution of the hull when it is used with C_P (Killing & Hunter, 1998).

Beside hull form coefficients and LCB, ratios of L_{OA}/L_{WL}, L_{OA}/B, B_{WL}/T are calculated for the investigated trawler yachts. Determining L_{WL}, B, B_{WL} and T in the initial design process provides insight into not only the aesthetic aspects of the hull design, but also the hydrostatics and hydrodynamics characteristics. L_{OA}/L_{WL} ratio is used to determine overhangs of a yacht in longitudinal direction (Turan & Akman, 2021). Length-to-beam ratio has a direct effect on the resistance and consequently the power requirement of a ship (Molland, 2008). Moreover, L_{OA}/B ratio helps to understand how beamy the yacht is (Larsson & Eliasson, 2007). B_{WL}/T ratio is used to predict the resistance characteristics. The experiments show that the desired values for the frictional and the wave resistance aspects are around 2.500 for the beam to draft ratio (Papanikolaou, 2014). Table 2 represents the minimum, the maximum and the mean values of hull form parameters for the investigated trawler yachts' hulls.

Table 2. The minimum, the maximum and the mean values of hull form parameters of the investigated yachts

	Min	Mean	Max
C_B	0.302	0.360	0.424
C_M	0.562	0.599	0.656
C_P	0.511	0.603	0.702
LCB (% of L_{WL})	41.891	43.309	45.010
L_{OA}/L_{WL}	1.051	1.115	1.174
L_{OA}/B	3.305	3.715	4.623
L_{WL}/B_{WL}	3.176	3.572	4.563
B_{WL}/T	2.845	3.435	3.852

Estimation of the displacement weight of a ship depending on the sufficient comparative data from similar ships constitutes the starting point of the preliminary design (Papanikolaou, 2014). Figure 7 represents the distribution of the displacement weight in tones with respect to L_{OA} (m) for the investigated trawler type yachts.

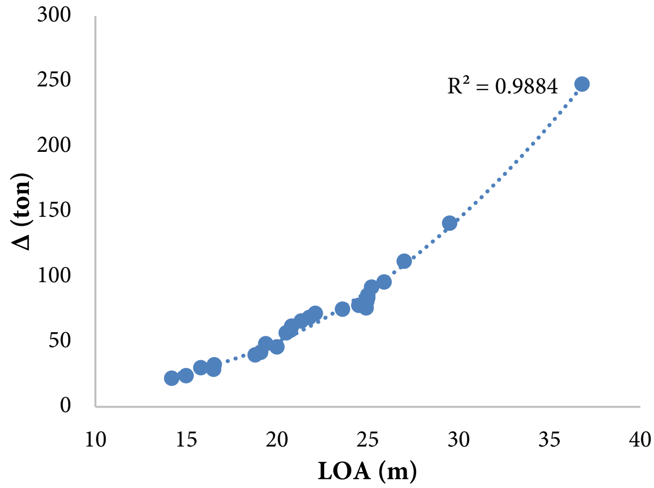


Figure 7. Distribution of displacement weight (Δ) with respect to L_{OA}

The ratios of B/B_{WL} and $B/B_{TRANSOM}$ have been calculated for the investigated trawler type yachts in order to give an idea about the hull form. The ratio of B/B_{WL} varies between 1.032 and 1.140 and the mean value of the ratio is calculated as 1.071. $B/B_{TRANSOM}$ ratio has a mean value of 1.106 and the ratio varies from 1.063 to 1.140. Moreover, Figure 8 shows the B, B_{WL} and $B_{TRANSOM}$ with respect to L_{OA} for the investigated yachts.

Angle of the stempost with the loaded waterline varies between 58° and 79° and the mean value of this parameter was calculated as 66.58° for the investigated trawlers.

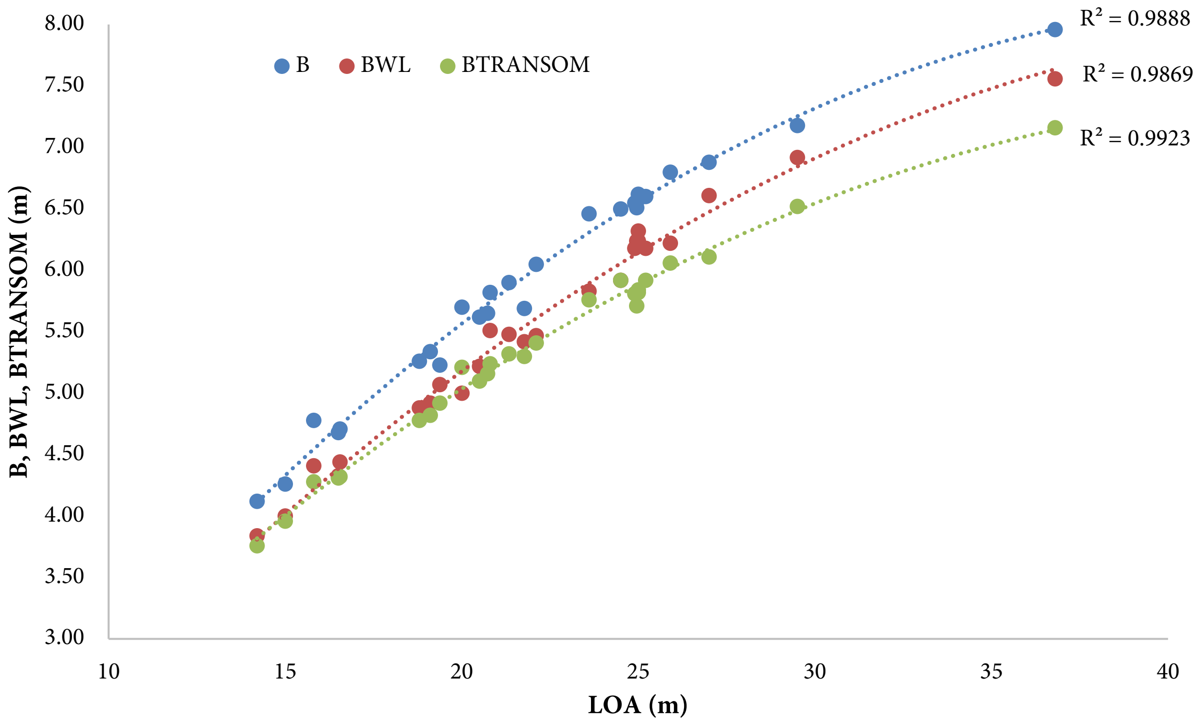


Figure 8. B, B_{WL} and $B_{TRANSOM}$ with respect to L_{OA}

Layout Parameters

The length of the platform located in the stern part of the trawler yachts varies from 0.60 m to 1.80 m. The dimension of this part is in correlation with the main dimensions of the yachts. Figure 9 shows the distribution of the length of the platform to L_{OA}. The deck clearance varies from 0.55 m to 1.00 m for the investigated yachts.

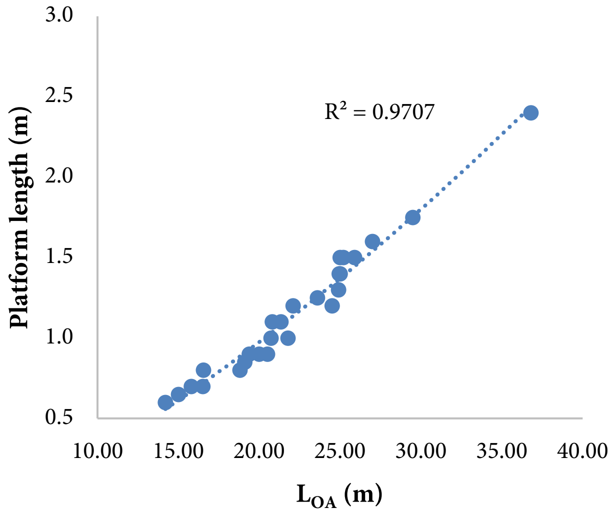


Figure 9. Platform length to L_{OA}

Voluminous closed space in the main deck that includes a saloon, galley, dining areas and the bridge space is among the characteristics of a trawler type yacht. To provide a design guideline for these closed areas, the starting point, the ending point and the part it occupies on the main deck are presented by calculating in terms of percentage of L_{OA} in Figure 10. The results show that closed areas occupy the major part of the main deck; approximately 65% of the L_{OA} and they end at approximately 85 % of the L_{OA}. Moreover, the results show that percentages that indicate the location of these closed areas do not change significantly due to change in L_{OA}.

At the beginning of the design process of marine vessels, determining technical information such as the space needed for technical equipment such as engines, installations and tanks plays an important and critical role (Özer & Tokol, 2021). In the interior design of a boat, it is of great importance to determine the location of the engine room for designing the remaining empty spaces (Arslan, 2010). To provide such data for the preliminary design, starting and end locations as well as the length of the engine room is presented as the percentage of L_{OA} in Figure 11. The results show that percentage of the length of the engine room decreases down to 15% as the L_{OA} increase for the investigated trawler type yachts.

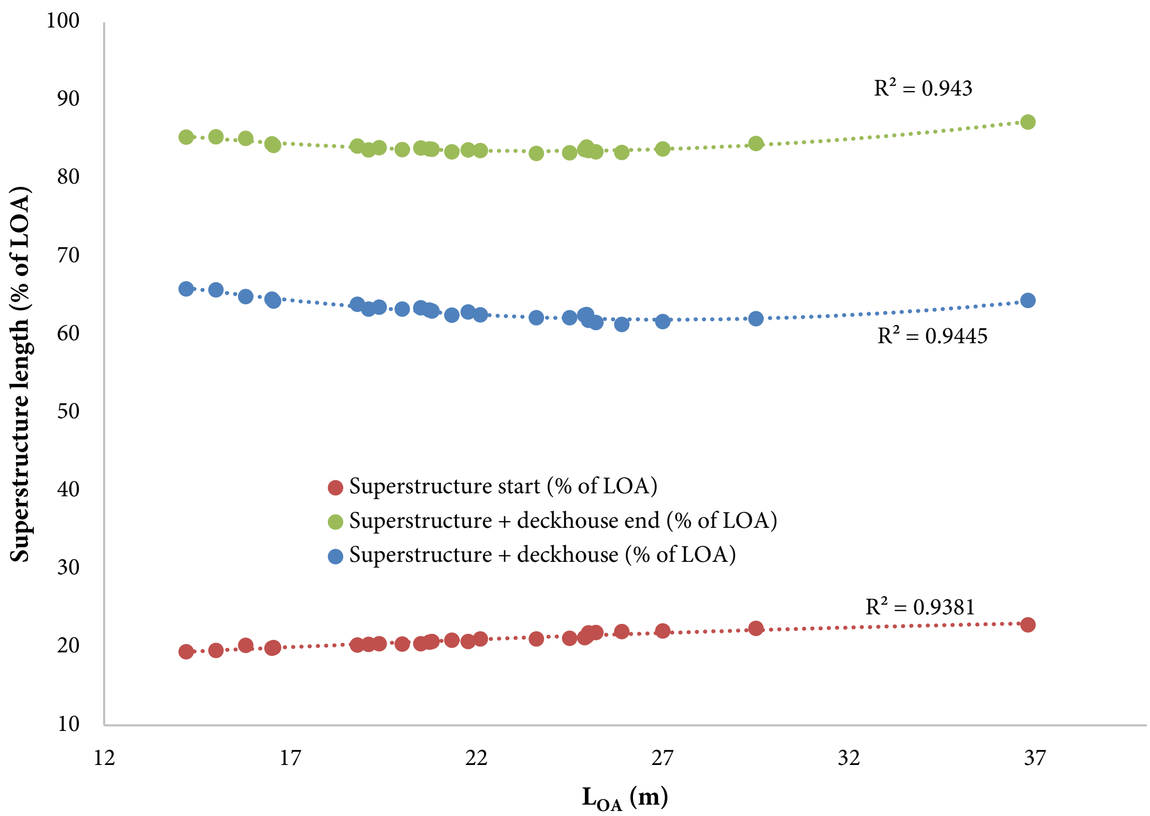


Figure 10. Percentage of the closed spaces in the main deck

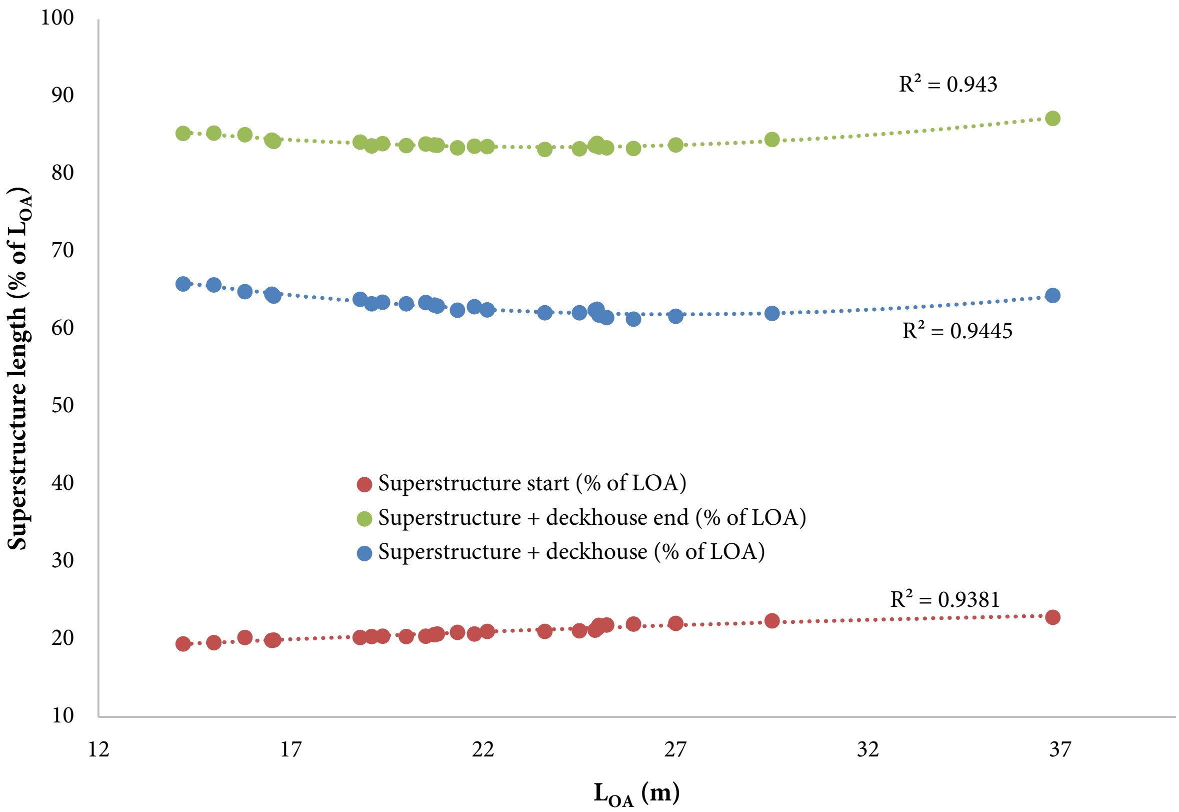


Figure 11. Engine room parameters for the trawler type yachts

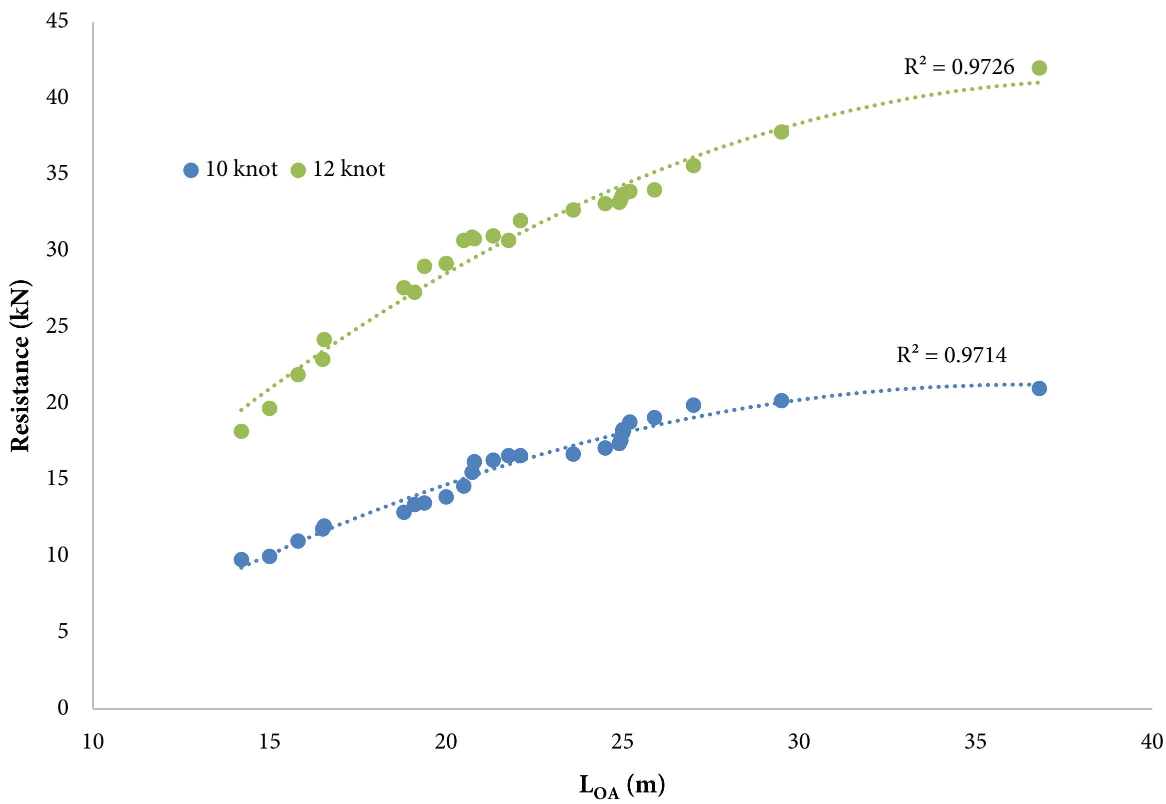


Figure 12. Resistance values with respect to LOA

Resistance Characteristics

It is seen that the maximum speed of the investigated trawler yachts range between 10 and 12.8 knots. To compare the calculated resistance values with the actual given performance values of the produced trawlers, two different speed values: 10 and 12 knots are selected for the resistance prediction calculations. Figure 12 represents the resistance values in kN of the investigated trawler hull models with respect to L_{OA}.

It is seen that investigated some of the investigated trawler yachts are equipped with a single engine while the major parts (18 of 26 trawlers) are equipped with twin-engines.

Conclusion

The study provides a design guideline that enable the designer to estimate not only layout parameters, but also some hydrostatic and hydrodynamic characteristics of the existing trawler type yachts. The following conclusions are obtained based on the results of the study:

- Even the L_{OA} of the trawler type yachts starts from 14.20 m and reaches up to 36.80 m, the common L_{OA} range was found to be 18-25 meters.
- Even the superstructure design can vary due to design characteristics and the design identity of the yacht, the results show that the location of the superstructure of trawler type yachts do not change due to change in L_{OA}. As a result, parameters related with the location of the closed spaces can be listed among distinctive characteristics of the trawler type yachts.
- It has been observed that B_{WL} and $B_{TRANSOM}$ values for the commonly used L_{OA} range are quite close to each other.
- B_{WL}/T ratio has greater values than the ratio desired ratio of 2.500 for the resistance aspects. Even the Holtrop-Mennen method is an efficient resistance prediction method and is used widely for the displacement type hull forms, there is a need for CFD analysis for further investigation of the trawler type yachts' resistance and hydrodynamic analysis.
- It is observed that hull forms of trawler yachts with a single engine do not have significant differences with the ones of the trawler yachts with twin engines. A CFD analysis, in which the appendages such as rudder and shafts are added to the model, will be of great importance in determining the total efficiency of trawler type yachts with single-engine and double-engine configurations.
- As a growing trend in marine industry, research that focuses on energy efficient trawler design with hybrid propulsion systems can be conducted as a further study. Considerably low maximum speed values and generous closed spaces that provide large areas on top that can be equipped with solar panels make trawler yachts appropriate for this purpose.

Compliance With Ethical Standards

Conflict of Interest

The author declares that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Data Availability Statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

References

Arslan, B. (2010). *Motoryatlarda İç Mekan Tasarım Süreç ve Kriterleri* [MSc Thesis]. İstanbul Teknik University.

Büyükkeçeci, E., & Turan, B. İ. (2018). Türkiye'de Tekne Tasarımında Tasarımcının Rolünün Araştırılması: Gulet ve Motor Yat Karşılaştırması. *UTAK 2018 Üçüncü Ulusal Tasarım Araştırmaları Konferansı: Tasarım ve Umut Bildiri Kitabı*, Türkiye, pp. 159–171.

Elkafas, A. E., Elgohary, M. M., & Zeid, A. E. (2019). Numerical study on the hydrodynamic drag force of a container ship model. *Alexandria Engineering Journal*, *58*(3), 849–859. https://doi.org/10.1016/j.aej.2019.07.004

Hamlin, C. (1996). *Preliminary design of boats and ships*. Cornell Maritime Press.

Holtrop, J., & Mennen, G. G. J. (1982). An approximate power prediction method. *International Shipbuilding Progress*, *29*(335), 166–170.

Killing, S., & Hunter, D. (1998). *Yacht design explained: A sailor's guide to the principles and practice of design* (1st ed.). W. W. Norton & Company.

Lane, S. E. (2010). The effect of bulbous bows on the resistance and powering performance of a forty-five foot trawler yacht [MSc Thesis]. Memorial University of Newfoundland.

Larsson, L., & Eliasson, R. E. (2007). *Principles of yacht design* (Third Edition). International Marine/McGraw-Hill.

Maxsurf (Version 23). (2022). [Computer software]. Bentley.

Molland, A. M. (2008). *The maritime engineering reference book- A guide to ship design, construction and operation*. Elsevier Butterworth-Heinemann.

Özgel Felek, S., & Arabacıoğlu, B. C. (2019). A model proposal to trawler yachts from hull form importing to superstructure, interior space arrangement and modeling with set of numerical parameters. *Online Journal of Art and Design*, 7(1), 1-22.

Papanikolaou, A. (2014). *Ship design-Methodologies of preliminary design* (1st ed.). Springer.

Rhino3D (Version 7). (2020). [Computer software]. Robert McNeel & Associates. https://www.rhino3d.com/

Sarıoğlu, B. S., & Kükner, A. (2018). Form factor prediction for Turkish type Bodrum Gulets. *3rd International Naval Architecture and Maritime Symposium Proceedings*, Türkiye, pp. 741–763.

Tokol, H. T. (2020). Yat İç mekan tasarımında tek gövdeli ile çift gövdeli (katamaran) yatların karşılaştırılması. *International Journal of Interdisciplinary and Intercultural Art*, 5(11), 59–84. https://doi.org/10.29228/ijiia.132

Turan, A. E. (2009). Türk Tipi Gulet Yatlarının Formunun Prizmatik Katsayıya Göre Belirlenmesi [MSc Thesis]. İstanbul Teknik University.

Turan, B. İ. (2021). Farklı yat tiplerinin ön tasarım aşamasında makine dairesi parametrelerinin belirlenmesi. *Gemi ve Deniz Teknolojisi Dergisi*, *220*, 175–191. https://doi.org/10.54926/gdt.1002636

Turan, B. İ., & Akman, M. (2021). Modeling and comparison of Bodrum Gulets' hull forms with round and transom sterns. *Journal of ETA Maritime Science*, *9*(2), 120–129. https://doi.org/10.4274/jems.2021.09327

Mar. Sci. Tech. Bull. (2023) 12(3): 322-331
e–ISSN: 2147–9666
info@masteb.com

dergipark.org.tr/en/pub/masteb
www.masteb.com
DOI: 10.33714/masteb.1337592

Marine Science and Technology Bulletin

PRENSIP
https://prensip.gen.tr/

RESEARCH ARTICLE

Morphometric characteristics of invasive species *Magallana gigas* (Thunberg, 1793) in Bandırma Bay, Marmara Sea

Sefa Acarlı[1*] • Harun Yıldız[1] • Pervin Vural[2]

[1] *Çanakkale Onsekiz Mart University, Faculty of Marine Sciences and Technology, Department of Aquaculture, 17020, Çanakkale, Türkiye*
[2] *Çanakkale Onsekiz Mart University, Bayramiç Vocational School, Department of Aquaculture, 17700, Çanakkale, Türkiye*

ARTICLE INFO

Article History:
Received: 04.08.2023
Received in revised form: 07.09.2023
Accepted: 08.09.2023
Available online: 28.09.2023

Keywords:
Magallana gigas
Growth patterns
Invasive species
Bandırma Bay
Marmara Sea
Morphometric characteristics

ABSTRACT

Türkiye's seas are the scene of the spread of invasive species in the entire Mediterranean basin due to the marine transportation of alien species and intensive aquaculture activities. In order to protect the natural ecosystem and track invasive species' effects, these species must first be accurately identified and their distribution areas specified. The alien species, *Magallana gigas* (Pacific oyster), has introduced along the Turkish coasts. This study was carried out to determine the morphometric characteristics of *Magallana gigas* in the Bandırma Bay-Balıkesir between November 2013 and October 2014. Shell length varied between 68.08 mm (February) and 93.14 mm (April) during the year. Shell height was measured at the lowest 41.90 mm in February, and the highest 59.46 mm in June. Shell width was 35.80 mm in November when the study started, and it decreased gradually and reached its lowest value in February. W/L relationship of *M. gigas* was calculated as $W=0.411\times L^{2.653}$(R^2=0.064) This study includes knowledges on morphometric relationships for the Pacific oyster which is crucial for the management of fisheries, aquaculture activities and native species (*Ostrea edulis*).

Please cite this paper as follows:

Acarlı, S., Yıldız, H., & Vural, P. (2023). Morphometric characteristics of invasive species *Magallana gigas* (Thunberg, 1793) in Bandırma Bay, Marmara Sea. *Marine Science and Technology Bulletin*, *12*(3), 322-331. https://doi.org/10.33714/masteb.1337592

Introduction

Pacific oyster or Japanese oyster *Magallana gigas* (Thunberg, 1793), which was previously named as *Crassostrea gigas* before molecular studies (Salvi & Mariottini, 2017), is found predominantly in the intertidal habitats and invasive, non-indigenous species. Invasive species share common characteristics such as the ability to settle, colonize, and expand their range. However, the spread of *M. gigas* has mainly occurred due to cultivation activities for growth purposes in open seas, such as lagoons and bays. Furthermore, this species has shown better growth and survival performance than native

* Corresponding author
E-mail address: sefaacarli@comu.edu.tr (S. Acarlı)

oyster species in the same population (Troost, 2010). The entry of this species into Europe and the Mediterranean coincides with the second half of the 20th century. In contrast, the native flat oyster (*Ostrea edulis*) fishery in France dates back centuries, to the Roman era. The production of oysters through cultivation has been continuously increasing for many years. However, due to the negative effects of disease and overfishing on populations, cultivation studies of *M. gigas* began. Small-scale trials were conducted between 1966 and 1970 (Grizel & Héral, 1991). *M. gigas* was imported from Canada and Japan and was planted in all production areas, including the Mediterranean coast of France (Grizel & Héral, 1991; Zibrowius, 1992). Later, it was found to be distributed in the Adriatic coast of Italy (Blundo et al., 1972), and larvae were collected from the Croatian coast (Hrs-Brenko, 1982). Subsequently, it was observed that the distribution area of this species in the Mediterranean extended from Cyprus to the Tunisian coast (Hrs-Brenko, 1982). While its presence in Black Sea was first detected in Sevastopol (Scarlato & Starobogatov, 1972), individuals were brought from Japan for cultivation purposes to the North Caucasian region in 1980 (Monina, 1987).

The native flat oyster commonly found in the subtidal habitat of Turkish seas is the European flat oyster, *O. edulis*. It is distributed intensively in the Marmara Sea, Aegean Sea, Mediterranean, and at the point where the Istanbul Strait meets the Black Sea. Despite the low world production of this species compared to *M. gigas*, it is preferred more due to its smooth shell shape, pleasant meat color, and taste, which makes it twice as expensive as *M. gigas* in markets. Özden et al. (1993) conducted the first cultivation studies of *M. gigas* in the SÜYO lagoon. In subsequent years, the presence of this species was determined in the Marmara (Albayrak et al., 2004) and Aegean Seas (Doğan et al., 2007) through field studies assessing their morphometric structures. Acarli et al. (2017) revealed the presence of the species in the Marmara Sea through genetic studies.

Bivalve shell parts are defined in terms of dimensions such as shell length, shell thickness, and shell width, and these three parameters show continuous variation (Malathi & Thippeswamy, 2011; Lucas et al., 2019). Changes in the shell ratios of bivalves during growth are generally associated with the preservation of the area/volume ratio, which is an applicable physiological ratio according to environmental conditions (Rhoads & Pannella, 1970). Due to the population density and increasing depth gradient, irregular shell thickness and shorter forms of *C. madrasensis* were observed (Santhi et al., 2021). It is known that in some bivalve species, shells become higher and wider during growth to resist involuntary displacement caused by turbulence and currents (Eagar, 1978; Hinch & Bailey, 1988). When environmental conditions deteriorate, oyster growth is negatively affected because oysters spend most of their energy adapting to the environment (Dame et al., 2001). Oysters in environments with high-quality and abundant food are larger and thicker (Kasmini et al., 2018). Oysters are irregular in shape and live densely attached to a hard substrate (rock) (Singh, 2019; Arja et al., 2020). Understanding the ecological variations and productivity of oyster populations requires defining the relationship between shell and soft body characteristics (Nagi et al., 2011). The length-weight relationship is essential in generating useful information for the assessment of the growth and production of bivalve species (Chatterji et al., 1985; Acarli et al., 2011, 2012, 2023; Idris et al., 2012; Vasconcelos et al., 2018; Derbali et al., 2019). The allometric relationship based on shell measurements is a simple way to estimate biomass and total meat production (Powell et al., 2016; Acarli et al., 2023).

The objective of this study was to assess the morphometric characteristics of *M. gigas*, a Pacific oyster species that is not indigenous to the Marmara Sea. Therefore, these statistics offer important information for understanding the development of bivalves as well as for sustainable fisheries and aquaculture.

Material and Method

Total 365 specimens of *M. gigas* were collected from Bandırma Bay, Balıkesir (Marmara Sea, Türkiye) (N 40°22'03.43" E 27°55'29.47") during the period from November 2013 to October 2013 (Figure 1). Diving was conducted to collect *M. gigas* individuals from depths ranging from 1 to 6 meters on a monthly basis.

Figure 1. Location of sampling area in from Balıkesir-Bandırma (Marmara Sea, Türkiye)

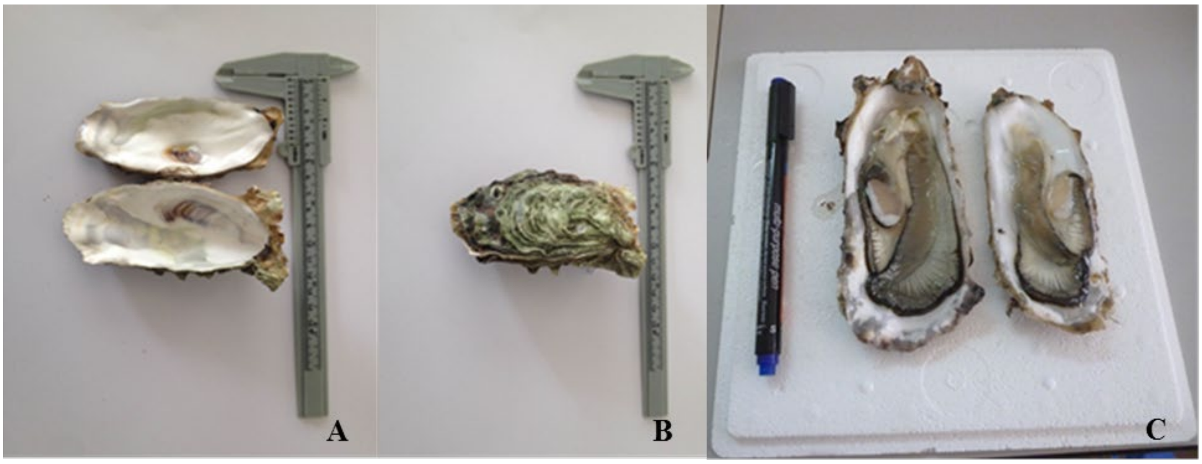


Figure 2. Inner shell (A), outer shell (B) and internal organs of *M. gigas* (C)

To prepare the *M. gigas* for analysis, they were thoroughly cleaned to remove any biofouling organisms (Figure 2). The shell length (L) (anterior-posterior axis), shell height (H) (dorsal-ventral axis), and shell width (Wi) (axis of the two thickest shell valves) were measured using an electronic caliper (Mitutoyo CD-15PK). Additionally, the total weight, wet shell weight, wet tissue weight, and dry tissue weight were determined using an electronic scale (0.01 g, Sartorius GE 412). The meat of *M. gigas* was separated from the shells and weighed separately. The shells were then dried at 60°C for 48-72 hours until a constant weight was achieved, while the soft tissues were dried using freeze-drying.

Linear regression analysis was employed to establish the relationships between length and height, length and width, as described by Ricker (1973), using the following equation:

$$LogY = loga + blogX \quad (1)$$

Where Y is either the height or the width, X is the length, a is a constant, and b is the regression coefficient.

The length and total weight, length and wet tissue weight, length and dry tissue weight, and length and dry shell weight relationship were calculated using the formula given below (Pauly, 1983):

$$Y = a * X^b \quad (2)$$

Where Y represents the total weight, wet tissue weight, dry tissue weight, or dry shell weight, while X represents the length, a is a constant, and b is the regression coefficient.

Regression analyses were used to investigate the morphometric relationships between weight and length, width and length, height and length, and width and length measurements of 365 individual Pacific oysters. Morphometric relationships were categorized as isometric growth (b=1 or b=3), positive allometry ($b > 1$ or $b > 3$), or negative allometry ($b < 1$ or $b < 3$) based on the estimated regression coefficients. t-test was performed at a 95% confidence level to test the hypothesis (H_0) that the regression coefficients were equal to 1 or 3. The statistical software SPSS 20 was used for all data analyses and calculations.

Results

M. gigas shell length, obtained monthly from natural sources, generally exhibited small sizes during winter and larger sizes in spring and summer. Throughout the year, shell length ranged from 68.08±28.69 mm in February to 93.14±14.25 mm in April. Shell height was measured at its minimum, 41.90±8.53 mm, in February, and reached its maximum, 59.46±11.20 mm, in June. Shell width varied from 26.74±7.59 mm in September to 36.17±7.47 mm in July. Total weight ranged between 44.51±43.36 g and 110.75±57.58 g (Table 1). The size-frequency graph of *M. gigas* is presented in Figure 3. During the study, the shell length of the oyster varied between 33.05 mm and 140.10 mm. Individuals with shell lengths ranging from 80 to 100 mm constituted 38.4% of the total population.

The relationships between length and total weight, length and dry shell weight, length and wet tissue weight, and length and dry tissue weight were calculated (Figure 4). The results indicated a negative allometric relationship between total weight and body length, with an increase in length leading to a disproportionate decrease in total weight. The weight/length (W/L), height/length (H/L), and width/length (Wi/L) ratios of *M. gigas* were determined as: $W = 0.0083 \times L^{2.021}$ (R^2=0.7237), $\log H = 0.4925 + 0.6227 \log L$ (R^2=0.5096) and $\log W = 0.2547 + 0.6531 \log L$ (R^2=0.6014), respectively. It was observed that there was a negative allometric relationship between *M. gigas* shell length and the other parameters ($P \leq 0.05$) (Figure 5).

Table 1. Monthly variation of shell length, shell height, shell width and total weight of *M. gigas*

Months	Mean Shell Length± SE	Mean Shell Height± SE	Mean Shell Width± SE	Mean Total Weight± SE
November	80.78±14.12	53.39±10.87	35.80±8.38	49.48±23.50
December	82.02±22.25	46.97±11.70	34.20±7.53	76.32±53.37
January	74.50±17.28	46.83±9.60	33.93±17.81	50.47±33.20
February	68.08±28.69	41.90±8.53	26.74±7.59	44.51±43.36
March	74.16±18.38	47.45±10.82	30.81±8.53	53.04±34.83
April	93.14±14.25	58.60±14.35	35.71±4.99	91.98±37.50
May	88.03±30.69	51.93±7.53	35.02±10.32	75.18±44.13
June	93.29±21.99	59.46±11.20	34.68±7.85	81.67±26.28
July	92.99±21.87	51.97±12.05	36.17±7.47	110.75±57.58
August	92.62±16.58	53.30±8.05	34.36±7.89	92.32±43.37
September	68.80±14.38	42.97±6.90	27.71±6.19	48.92±21.71
October	83.50±22.44	48.91±8.94	30.77±6.39	71.22±33.73±

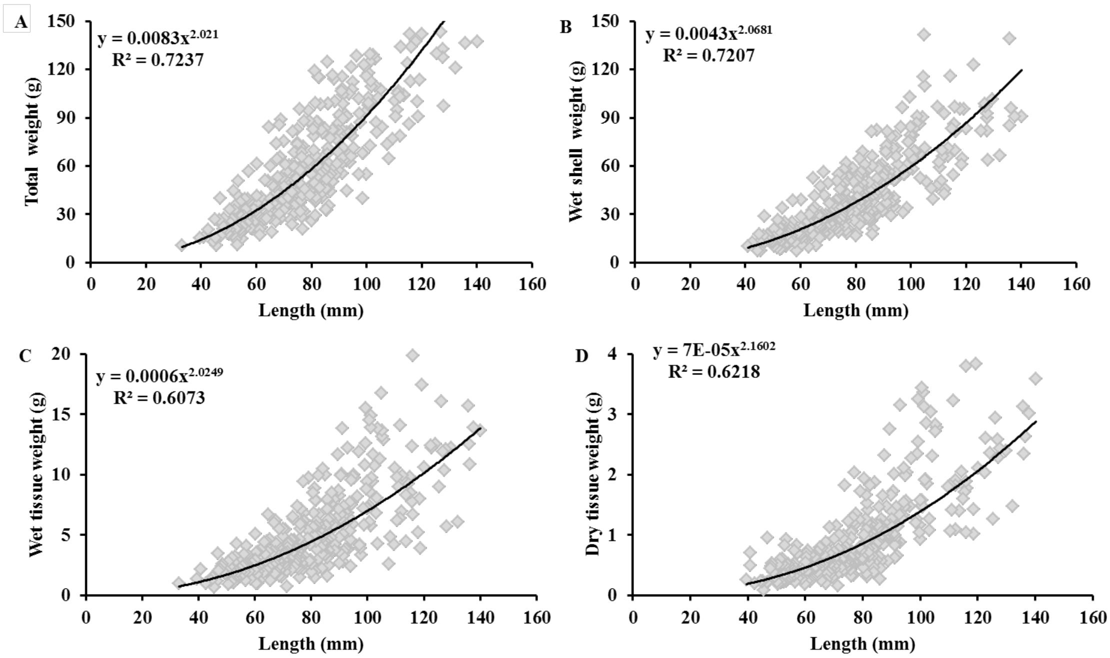


Figure 4. Relationship between length and total weight (A), length and wet shell weight (B), length and wet tissue weight, length and dry tissue weight (C) in *M. gigas.*

Although there was variation in the b value of the length-total weight relationship throughout the months, it was observed that it ranged from 2.32 to 1.91 between November and February. The highest *b* value (2.46) was recorded in March. Subsequently, it gradually decreased until July, reaching *a* value of 1.42. The *b* value then fluctuated between 1.94 and 1.74 from July to October (Figure 5).

Discussion

The growth, shape, total weight, and length-weight relationships in bivalves are influenced by physiological factors such as genetics (Hajoovsky et al., 2021) and environmental factors including temperature, salinity, turbidity, and chlorophyll-a (Acarli & Vural, 2018; Morán et al., 2022; Vural, 2022), as well as depth (Claxton et al., 1998), food availability (Dang et al., 2010), tidal currents (Fuiman et al., 1999; Akester & Martel, 2000; Dame et al., 2001), geographical variation (Beukema & Meehan, 1985), and habitat type (hanging or bottom) (Elamin & Elamin, 2014).

The relationships between length-weight, length-height, and length-width are crucial when examining the biology of molluscs since they provide insights into the environmental conditions that bivalves inhabit (Agboola & Anetekhai, 2008). In this study, the weight/length (W/L) relationship of *C. gigas* was determined as $W=0.0083\times L^{2.021}$ ($R^2=0.7237$), and the b value was found to be less than three. This indicates a negative allometric relationship (b = 2.653, b < 3) for W/L. Additionally, negative allometry was observed between length-height (H/L) and length-width (Wi/L). Similar findings have been reported by Unnikrishnan Nair & Balakrishnan Nair (1986), Yapi et al. (2016), and Aydın et al. (2021) (Table 2). In contrast, Góngora-Gómez et al. (2018) found a positive allometry for W/L in *C. cortezienzis*. The negative allometric growth in *C. gigas* suggests that the shells become thinner as they increase in length (Farías-Tafolla et al., 2015), indicating that shell length increases more rapidly relative to weight.

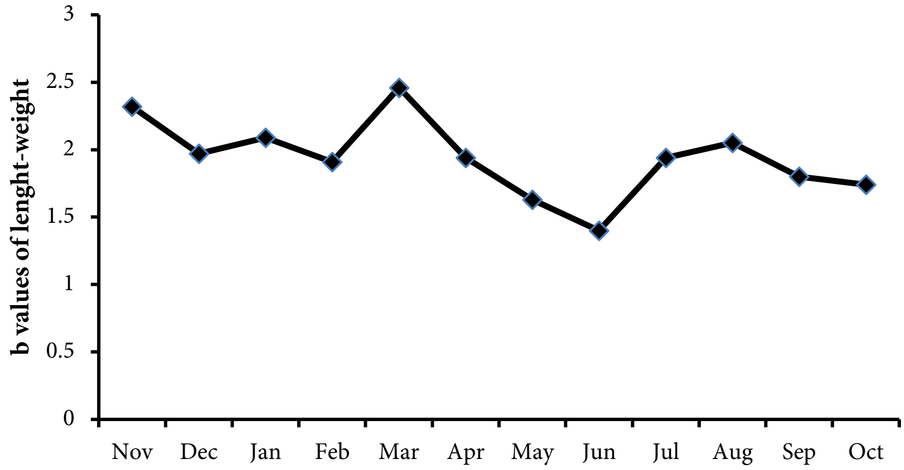


Figure 5. Changes in b value of length- total weight of relationship in *M. gigas*

Table 2. Parameters of the morphometric relationship for family species obtained from this study and available literature

Species	N	L mean ± SD (L min-L max)	Allometric relation	*a*	*b*	Determination confident (r^2)	SE of b (%95 CI of *b*)	Relationship (t-test)	Area	Reference
O. edulis			W/L	0.127	3.148	0.924			Mersin Bay, Aegean Sea, Türkiye	Acarli et al. (2011)
C. corteziensis	650	54.29±22.31 (4.31-105.06)	W/L	-3.8585	3.2023	0.98	0.015	+ allometry	Gulf of California, Mexico	Góngora-Gómez et al. (2018)
C. madrasensis	135	≥3.5	H/L	0.013	0.9866	0.931	0.332		Cochin Harbour, India	Unnikrishnan Nair & Balakrishnan Nair (1986)
C. madrasensis	291	3.5-8	H/L	0.402	0.5712	0.693	0.023		Cochin Harbour, India	Unnikrishnan Nair & Balakrishnan Nair (1986)
C. madrasensis	766	≤8	H/L	0.867	0.1669	0.096	0.062	-allometry	Cochin Harbour, India	Unnikrishnan Nair & Balakrishnan Nair (1986)
C. gasar	360	4.4-10.1	W/L	2.20	1.77	0.85		-allometry	Ebrié and Aby Lagoons, Ivory Coast, Ghana	Yapi et al. (2016)
C. gasar	360	4.1-11.2	W/L	0.2	2.82	0.85		-allometry	Ebrié and Aby Lagoons, Ivory Coast, Ghana	Yapi et al. (2016)
C. gasar	360	5.3-10.9	W/L	0.406	2.47	0.5		-allometry	Ebrié and Aby Lagoons, Ivory Coast, Ghana	Yapi et al. (2016)
C. gigas	235	59.57±13.65 (24.09-98.17)	W/L	0.0143	1.6662	0.6589		-allometry	Black Sea, Türkiye	Aydın et al. (2021)
C. gigas	235	59.57±13.65 (24.09-98.17)	Wi/L	2.6516	0.5736	0.3177		-allometry	Black Sea, Türkiye	Aydın et al. (2021)
C. gigas	235	59.57±13.65 (24.09-98.17)	H/L	1.7971	0.5228	0.1447		-allometry	Black Sea, Türkiye	Aydın et al. (2021)
C. madrasensis		25-60	W/L	-2.22269	2.0670	0.7828	0.111	-allometry	Mandovi Estuary, India	Nagi et al. (2011)
C. madrasensis		25-60	W/L	1.6477	1.7236	0.7295	0.113	-allometry	Mandovi Estuary, India	Nagi et al. (2011)
C. gryphoides		51-55	W/L	1.2468	1.4655	0.6340	0.197	-allometry	Mandovi Estuary, India	Nagi et al. (2011)
C. gryphoides		51-55	W/L	2.1179	1.9946	0.7436	0.167	-allometry	Mandovi Estuary, India	Nagi et al. (2011)
M. gigas	365	81.26±21.84 (33.05-140.1)	W/L	0.0083	2.021	0.7237	0.064	-allometry	Marmara Sea, Türkiye	This study
M. gigas	365	81.26±21.84 (33.05-140.1)	H/L	0.4925	0.6227	0.6014	0.030	-allometry	Marmara Sea, Türkiye	This study
M. gigas	365	81.26±21.84 (33.05-140.1)	Wi/L	0.2547	0.6531	0.5096	0.037	-allometry	Marmara Sea, Türkiye	This study

Note: *N*: number of individuals; *L*: shell length (mm); *H*: shell height (mm); *Wi*: shell width (mm); *W*: total weight (g); *SD*: standard deviation; *SE*: standard error; *CI*: confidence interval.

Singh (2017) and Lim et al. (2020) have indicated that the health condition or general condition of bivalves can be predicted from variations in their weight. The variations in the b values (equilibrium constant) of the length-weight relationship can be related to a wide range of metabolic processes, mainly the reproductive cycle in bivalves (Chávez-Villalba et al., 2008; Ramesha & Thippeswamy et al., 2009; Thejasvi et al., 2013; Thippeswamy et al., 2014). In this study, the monthly *b* value of the length-total weight relationship changed from 1.42 (June) to 2.46 (March). Acarli et al. (2019) reported that the spawning period of *C. gigas* in the same study area was in the spring and summer seasons. While an increase in gonad weight during periods of high maturation would be expected to result in higher *b* values, the actual influential parameter is the variability in the number of young individuals encountered during the months and, consequently, the variability in flesh or shell weight. The shapes of oyster species depend on the habitat they adhere to and the density, which differs from clams that live buried in the sand. Tanita & Kikuchi (1957) reported that the length-width ratio decreases with increasing density in *Pinctada martensii* (now revised to *Pinctada fucata*). Orton (1936) observed that the length-width ratio in *Ostrea angulata* varies with the type of substrate, with coastal *O. angulata* having longer and narrower shells, while those in tidal areas have broader shells. Consequently, in this study, parameters such as length-width and length-thickness were found to be more variable, and the determination coefficient (r^2) values of the relationships were low. The reproductive cycle of *M. gigas* does not have a primary-level effect on the variations in the b values.

Oysters are classified into two size categories: 76 mm ('petite' or 'cocktail') and 76 to 102 mm ('regular') (Grizzle et al., 2017). The average length of *C. gigas* is 46 mm at age one, 70 mm at age two, and 91 mm at age three (Diederich, 2006; Wang et al., 2007). Aydin & Gül (2021) observed that in July, the majority of the *C. gigas* population in the Black Sea consisted of young individuals with an average length of 3.3 cm. In this study, it was found that the shell length of *M. gigas* ranged from 68 mm in September and February to 70-90 mm in November, December, January, March, May, and October, and 90-100 mm in April, June, July, and August. Based on the obtained size data and population density, it can be concluded that the species has been present in this area for at least two years. The observation of newly settled Japanese oysters in the laboratory samples indicates that the species has completed its adaptation process in this area.

Conclusion

Based on the obtained size data and population density, it is believed that the invasive species *M. gigas* has been present in this area for at least two years or longer. The observation of newly settled Japanese oysters in the laboratory samples indicates that the species has completed its adaptation process in this area. This study represents the first determination of the morphometric characteristics of this species in the Marmara Sea. According to the results, a negative allometric relationship was found between *M. gigas* shell length and other parameters. Despite being an invasive species, *M. gigas* is also widely cultivated. However, it is necessary to protect the stocks of the native species *O. edulis*, which are present in Turkish waters, against invasive species. Considering the distribution history of *M. gigas* worldwide, it is understood that preventing its introduction and distribution in our waters is challenging. Therefore, the detection, monitoring, and assessment of the distribution of *M. gigas* in Turkish waters are crucial for developing action plans to sustainably conserve the ecosystem and ensure economic significance.

Acknowledgements

Lab experiments were carried out in the Fisheries Histology and Biochemistry Research Laboratory, Faculty of Marine Sciences and Technology, Çanakkale Onsekiz Mart University.

Compliance With Ethical Standards

Authors' Contributions

HY: Manuscript design, Laboratory experiments.
SA: Drafting, Editing, Laboratory experiments, Data analysis.
PV: Writing, Editing, Data analysis.
All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Data Availability Statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

References

Acarli, S., & Vural, P. (2018). Morphometric analysis of *Ensis marginatus* (Pennant, 1777) from Gallipolli, Çanakkale, Turkey. *International Marine & Freshwater Sciences Symposium Proceedings, Turkey*, pp. 391-394.

Acarlı, S., Karakoç, Ş., & Vural, P. (2023). Relationship between environmental factors, meat quality and biochemical composition bearded horse mussel (*Modiolus barbatus*, Linnaeus 1758) Ayvalık Bay, Balıkesir-Turkey. *Thalassas: An International Journal of Marine Sciences*, *39*(1), 99-109. https://doi.org/10.1007/s41208-023-00521-0

Acarli, S., Kızılkaya, B., Vural, P., Gündüz, F., & Tan, E. (2019). Reproductive strategy and gonad development of alien species Pacific oyster (*Crassostrea gigas* Thunberg, 1793) from Bandırma Bay, Marmara Sea–Turkey. *International Ecology 2018 Symposium*, Turkey. pp. 391.

Acarli, S., Lök, A., & Yiğitkurt, S. (2012). Growth and survival of *Anadara inaequivalvis* (Bruguiere, 1789) in Sufa Lagoon, Izmir, Turkey. *The Israeli Journal of Aquaculture-Bamidgeh*, *64*, 1-7

Acarli, S., Lök, A., Küçükdermenci, A., Yildiz, H., & Serdar, S. (2011). Comparative growth, survival and condition index of flat oyster, *Ostrea edulis* (Linnaeus 1758) in Mersin Bay, Aegean Sea, Turkey. *Kafkas Universitesi Veteriner Fakültesi Dergisi*, *17*(2), 203-210. https://doi.org/10.9775/kvfd.2010.2806

Acarli, S., Vural, P., & Gündüz, F. (2017). Meat yield and condition index of invasive species Pacific oyster (*Crassostrea gigas*, Thunberg 1793) in Bandirma Bay (Marmara Sea, Turkey). *International İskenderun Bay Symposium*, Turkey, pp. 120.

Agboola, J. I., & Anetekhai, M. A. (2008). Length–weight relationships of some fresh and brackish water fishes in Badagry creek, Nigeria. *Journal of Applied Ichthyology*, *24*(5), 623-625. https://doi.org/10.1111/j.1439-0426.2008.01079.x

Akester, R. J., & Martel, A. L. (2000). Shell shape, dysodont tooth morphology, and hinge-ligament thickness in the bay mussel *Mytilus trossulus* correlate with wave exposure. *Canadian Journal of Zoology*, *78*(2), 240-253. https://doi.org/10.1139/z99-215

Albayrak, S., Balkıs, H., & Balkıs, N. (2004). Bivalvia (Mollusca) fauna of the Sea of Marmara. *Acta Adriatica*, *45*(1), 9-26.

Arja, F., Sarong, M. A., Suhendrayatna, S., & Huda, I. (2020). Growth Patterns *Crassostrea sp.* in various cultural media of marine water area, Banda Aceh. *E3S Web of Conferences, Volume 151, 2020, The 1st International Conference on Veterinary, Animal, and Environmental Sciences (ICVAES 2019), Indonesia*, pp. 01032. https://doi.org/10.1051/e3sconf/202015101032

Aydin, M., & Gül, M. (2021). Presence of the Pacific oyster (*Crassostrea gigas* Thunberg, 1793) in the Black Sea. *Journal of Anatolian Environmental and Animal Sciences*, *6*(1), 14-17. https://doi.org/10.35229/jaes.800160

Aydın, M., Biltekin, D., Breugelmans, K., & Backeljau, T. (2021). First record, DNA identification and morphometric characterization of Pacific oyster, *Crassostrea gigas* (Thunberg, 1793) in the southern Black Sea. *BioInvasions Records*, *10*(4), 838-852. https://doi.org/10.3391/BIR.2021.10.4.08

Beukema, J. J., & Meehan, B. W. (1985). Latitudinal variation in linear growth and other shell characteristics of *Macoma balthica*. *Marine Biology*, *90*, 27-33.

Blundo, C., Castagnolo, L., & Lumare, F. (1972) Nota sull'accrescimento di *Crassostrea angulata* (Lmk) e *Crassostrea gigas* (Thun) nella laguna di Varano e primi tentativi di fecondazione artificiale. *Bollettino di Pesca, di Piscicoltura e di Idrobiologia*, *27*, 297-315.

Chatterji, A., Ansari, Z. A., Ingole, B. S., & Parulekar, A. H. (1985). Length-weight relationship of Giant Oyster, *Crassostrea gyphoides* (Schlotheim). Mahasagar.

Chávez-Villalba, J., Hernández-Ibarra, A., López-Tapia, M. R., & Mazón-Suástegui, J. M. (2008). Prospective culture of the Cortez oyster *Crassostrea corteziensis* from northwestern Mexico: Growth, gametogenic activity, and condition index. *Journal of Shellfish Research*, *27*(4), 711-720. https://doi.org/10.2983/0730-8000(2008)27[711:PCOTCO]2.0.CO;2

Claxton, W. T., Wilson, A. B., Mackie, G. L., & Boulding, E. G. (1998). A genetic and morphological comparison of shallow-and deep-water populations of the introduced dreissenid bivalve *Dreissena bugensis*. *Canadian Journal of Zoology*, *76*(7), 1269-1276. https://doi.org/10.1139/z98-064

Dame, R. F., Bushek, D., & Prins, T. C. (2001). Benthic suspension feeders as determinants of ecosystem structure and function in shallow coastal waters. In Reise, K. (Ed.), *Ecological Comparisons of Sedimentary Shores* (pp. 11-37). Springer.

Dang, C., de Montaudouin, X., Gam, M., Paroissin, C., Bru, N., & Caill-Milly, N. (2010). The Manila clam population in Arcachon Bay (SW France): can it be kept sustainable? *Journal of Sea Research*, *63*(2), 108-118. https://doi.org/10.1016/j.seares.2009.11.003

Derbali, A., Kandeel, K. E., & Jarboui, O. (2019). Comparison of the dynamics between coastal and midshore populations of Pinctada radiata (Leach, 1814) (Mollusca: Bivalvia) in the gulf of Gabes, Tunisia. *Turkish Journal of Fisheries and Aquatic Sciences*, *20*(4), 301-310. https://doi.org/10.4194/1303-2712-v20_4_06

Diederich, S. (2006). High survival and growth rates of introduced Pacific oysters may cause restrictions on habitat use by native mussels in the Wadden Sea. *Journal of Experimental Marine Biology and Ecology*, *328*(2), 211-227. https://doi.org/10.1016/j.jembe.2005.07.012

Doğan, A., Önen, M. & Öztürk, B. (2007). A new record of the invasive Red Sea mussel *Brachidontes pharaonis* (Fischer P., 1870). (Bivalvia: Mytilidae) from the Turkish coasts. *Aquatic invasions*, *2*(4), 461-463.

Eagar, R. M. C. (1978). Shape and function of the shell: a comparison of some living and fossil bivalve mussels. *Biological Reviews*, *53*(2), 169-210. https://doi.org/10.1111/j.1469-185X.1978.tb01436.x

Elamin, E. M., & Elamin, S. E. M. (2014). Biometric relationships of the mother of pearl oyster (*Pinctada margaritifera* var. *erythraensis*) from Dongonab Bay, Red Sea. *International Journal of Science, Environment and Technology*, *3*(3), 1193-1204.

Farías-Tafolla, B., De La Cruz-Torres, J., Ponce-Rodríguez, A., Gersenowies-Rodríguez, J. R., Martínez-Pérez, J. A., & Chávez-Arteaga, M. M. (2015). Comparison of the allometry coefficient of the length-weight and length-length relationship between *Selene brownii, S. vomer* and *S. setapinnis* caught in the Gulf of Mexico. *International Journal of Morphology, 33*(4), 1237-1242.

Fuiman, L. A., Gage, J. D., & Lamont, P. A. (1999). Shell morphometry of the deep sea protobranch bivalve *Ledella pustulosa* in the Rockall Trough, north-east Atlantic. *Journal of the Marine Biological Association of the United Kingdom*, *79*(4), 661-671. https://doi.org/10.1017/S0025315498000824

Góngora-Gómez, A. M., Domínguez-Orozco, A. L., Villanueva-Fonseca, B. P., Muñoz-Sevilla, N. P., & García-Ulloa, M. (2018). Seasonal levels of heavy metals in soft tissue and muscle of the pen shell *Atrina maura* (Sowerby, 1835) (Bivalvia: Pinnidae) from a farm in the southeastern coast of the Gulf of California, Mexico. *Revista Internacional de Contaminación Ambiental*, *34*(1), 57-68. https://doi.org/10.20937/rica.2018.34.01.05

Grizel, H., & Heral, M. (1991). Introduction into France of the Japanese oyster (*Crassostrea gigas*). *ICES Journal of Marine Science*, *47*(3), 399-403. https://doi.org/10.1093/icesjms/47.3.399

Grizzle, R. E., Ward, K. M., Peter, C. R., Cantwell, M., Katz, D., & Sullivan, J. (2017). Growth, morphometrics and nutrient content of farmed eastern oysters, *Crassostrea virginica* (Gmelin), in New Hampshire, USA. *Aquaculture Research*, *48*(4), 1525-1537. https://doi.org/10.1111/are.12988

Hajovsky, P., Beseres Pollack, J., & Anderson, J. (2021). Morphological assessment of the eastern oyster *Crassostrea virginica* throughout the Gulf of Mexico. *Marine and Coastal Fisheries*, *13*(4), 309-319. https://doi.org/10.1002/mcf2.10156

Hinch, S. G. & Bailey, R. C. (1988). Within- and among-lake variation in shell morphology of the freshwater clam *Elliptio complanata* (Bivalvia: Unionidae) from south-central Ontario lakes. *Hydrobiologia, 157*, 27-32. https://doi.org/10.1007/BF00008807

Hrs-Brenko, M. (1982). *Ostrea edulis* (Linnaeus) and *Crassostrea gigas* (Thunberg) larvae in the plankton of Limski Kanal in the northern Adriatic Sea. *Acta Adriatica, 23*, 399-407.

Idris, M. H., Arshad, A., Amin, S. M. N., Japar, S. B., Daud, S. K., Mazlan, A. G., Zakaria, M. S., & Yusoff, F. M. (2012). Age, growth and length–weight relationships of *Pinna bicolor* Gmelin (Bivalvia: Pinnidae) in the seagrass beds of Sungai Pulai Estuary, Johor, Peninsular Malaysia. *Journal of Applied Ichthyology*, *28*(4), 597-600. https://doi.org/10.1111/j.1439-0426.2011.01807.x

Kasmini, L., Barus, T. A., Sarong, M. A., Mulya, M. B. (2018). Morphometric study of Pacific oyster (*Crassostrea gigas)* in the coastal area of Banda Aceh. *Journal of Physics: Conference Series, 116*(5), 052037. https://doi.org/10.1088/1742-6596/1116/5/052037

Lim, L. S., Liew, K. S., Yap, T. K., Tan, N. H., & Shi, C. K. (2020). Length-weight relationship and relative condition factor of pearl oyster, *Pinctada fucata martensii*, cultured in the Tieshangang Bay of the Beibu Gulf, Guangxi Province, China. *Borneo Journal of Marine Science and Aquaculture, 4*(1), 24-27. https://doi.org/10.51200/bjomsa.v4i1.2048

Lucas, J. S., Southgate, P. C., & Tucker, C. S. (Eds.). (2019). *Aquaculture: Farming aquatic animals and plants*. John Wiley & Sons.

Malathi, S., & Thippeswamy, S. (2011). Morphometry, length-weight and condition in *Parreysia corrugata* (Mullar 1774) (Bivalvia: Unionidae) from river Malthi in the Western Ghats, India. *International Journal of Biological Sciences*, *2*(1), 43-52.

Monina, O. B. (1987). Growth and condition factors of Pacific oyster implanted in the Black Sea. In I. A. Sadykhova (Ed.), *Biology and Cultivation of Molluscs* (pp. 39-49). VNIRO.

Morán, G. A., Martinez, J. J., Reyna, P. B., Martín, J., Malits, A., & Gordillo, S. (2022). Identifying environmental drivers of shell shape and size variation in a widely distributed marine bivalve along the Atlantic Patagonian coast. *Zoologischer Anzeiger, 299*, 49-61. https://doi.org/10.1016/j.jcz.2022.05.003

Nagi, H. M., Shenai-Tirodkar, P. S., & Jagtap, T. G. (2011). Dimensional relationships in *Crassostrea madrasensis* (Preston) and *C. gryphoides* (Schlotheim) in Mangrove ecosystem. *Indian Journal of Geo-Marine Sciences,40*(4), 559-566.

Orton, J. H. (1936). Habit and shell-shape in the Portuguese oyster, *Ostrea angulata*. *Nature*, *138*(3489), 466-467. https://doi.org/10.1038/138466b0

Özden, O., Alpbaz, A. G. & Tekin, M. (1993). Süyo (Homa) dalyanında istiridye (*Crassostrea gigas*) yetiştiriciliği üzerinde bir araştırma. *E.Ü. Eğitiminin 10. Yılında Su Ürünleri Sempozyumu,* Turkey, pp. 609-621.

Pauly, D. (1983). *Some simple methods for the assessment of tropical fish stocks. FAO Fisheries Technical Papers.* Rome. pp. 1-5.

Powell, E., Mann, R., Ashton-Alcox, K., Kim, Y., & Bushek, D. (2016). The allometry of oysters: Spatial and temporal variation in the length–biomass relationships for *Crassostrea virginica*. *Journal of the Marine Biological Association of the United Kingdom*, *96*(5), 1127-1144. https://doi.org/10.1017/S0025315415000703

Ramesha, M. M., & Thippeswamy, S. (2009). Allometry and condition index in the freshwater bivalve *Parreysia corrugata* (Muller) from river Kempuhole, India. *Asian Fisheries Science*, *22*(1), 203-214.

Rhoads, D. C. & Pannella, G. (1970). The use of molluscan growth patterns in ecology and paleoecology. *Lethaia, 3*(2), 143-161. https://doi.org/10.1111/j.1502-3931.1970.tb01854.x

Ricker, W.E. (1973). Linear regression in the fishery research. *Journal of Fisheries Research Board of Canada*, *30*(3), 409-434. https://doi.org/10.1139/f73-072

Salvi, D., & Mariottini, P. (2017). Molecular taxonomy in 2D: A novel ITS2 rRNA sequence-structure approach guides the description of the oysters' subfamily Saccostreinae and the genus *Magallana* (Bivalvia: Ostreidae). *Zoological Journal of the Linnean Society*, *179*(2), 263-276. https://doi.org/10.1111/zoj.12455

Santhi, V. V., Antony, M. M., Lopez, L., Vasanthi, L., & Joseph, J. (2021). Evolution of ecophenotypic plasticity in Indian oyster, *Crasssostrea madrasensis* (Preston) population from Ashtamudi Lake, Kerala, India. *International Journal of Aquatic Biology*, *9*(5), 290-296. https://doi.org/10.22034/ijab.v9i5.1167

Scarlato, O. A., & Starobogatov, Y. E. (1972). Class-Bivalvia: In *Keys to the Fauna of the Black and Azov Seas* (pp. 178-249). Nauk. Dumka.

Singh, Y. T. (2019). Biometrics, condition index and meat yield of edible rock oyster, *Saccostrea cucullata* (Born, 1778). *Journal of the Marine Biological Association of the United Kingdom*, *99*(2), 385-392. https://doi.org/10.1017/S0025315418000309

Singh, Y.T. (2017). Relationship between environmental factors and biological parameters of Asian wedge clam, *Donax scortum,* morphometric analysis, length-weight relationship and condition index: a first report in Asia. *Journal of Marine Biology of the United Kingdom*, *97*(8), 1617-1633. https://doi.org/10.1017/S002531541600103X

Tanita, S., & Kikuchi, S. (1957). On the density effect of the raft cultured oysters. I. The density effect within one plate. *Bulletin of the Tohoku Regional Fisheries Research Laboratory, 9*, 133-142.

Thejasvi, A., Chandrakala Shenoy, K., & Thippeswamy, S. (2013). Allometry of the green mussel *Perna viridis* (linnaeus) from the intertidal rocky habitat of Mukka, Karnataka, India. *Journal of Theoretical and Experimental Biology*, *9*(3), 105-112.

Thippeswamy, S., Malathi, S., & Anupama, N. M. (2014). Allometry and condition index in the freshwater bivalve *Parreysia favidens* (Benson, 1862) from river Bhadra, India. *Indian Journal of Fisheries*, *61*(4), 47-53.

Troost, K. (2010). Causes and effects of a highly successful marine invasion: case-study of the introduced Pacific oyster *Crassostrea gigas* in continental NW European estuaries. *Journal of Sea Research*, *64*(3), 145-165. https://doi.org/10.1016/j.seares.2010.02.004

Unnikrishnan Nair, N., & Balakrishnan Nair, B. (1986). Height-Length relationship of shell in the Indian Backwater oyster *Crassostrea madrasensis* (Preston) of the Cochin Harbour. *Fishery Technology*, *23*, 27-31.

Vasconcelos, P., Moura, P., Pereira, F., Pereira, A. M., & Gaspar, M. B. (2018). Morphometric relationships and relative growth of 20 uncommon bivalve species from the Algarve coast (southern Portugal). *Journal of the Marine Biological Association of the United Kingdom*, *98*(3), 463-474. https://doi.org/10.1017/S002531541600165X

Vural, P. (2022). Monthly variation of biochemical composition of lagoon cockle (*Cerastoderma glaucum*, Bruguière, 1789), from Çardak Lagoon (Turkey). *Thalassas, 38*, 885-893. https://doi.org/10.1007/s41208-022-00423-7

Walles, B., Mann, R., Ysebaert, T., Troost, K., Herman, P. M. J. & Smaal, A. C. (2015). Demography of the ecosystem engineer *Crassostrea gigas* related to vertical reef accretion and reef persistence. *Estuarine Coastal and Shelf Science*, *154*, 224-233. https://doi.org/10.1016/j.ecss.2015.01.006

Wang, J., Christoffersen, K., Buck, S., Tao, Y. & Hansen, B. W. (2007). The Pacific oyster (*Crassostrea gigas*) in the Isefjord. Denmark. Student Report, Roskilde University, Department of Environmental, Social and Spatial Change. 49p.

Yapi, J. N., Blé, M. C., Etchian, A. O., Kadjo, V., Soro, D., & Yao, K. (2016). Actors and effort of the artisanal harvesting of mangrove oyster *Crassostrea gasar* along the littoral lagoons Ebrié and Aby (Côte d'Ivoire), *International Journal of Biosciences, 9*(6), 45-54

Zibrowius, H. (1992). Ongoing modification of the Mediterranean marine fauna and flora by the establishment of exotic species. *Mésogée, 51*, 83-107.

Mar. Sci. Tech. Bull. (2023) 12(3): 332-351
e–ISSN: 2147–9666
info@masteb.com

dergipark.org.tr/en/pub/masteb
www.masteb.com
DOI: 10.33714/masteb.1330955

Marine Science and Technology Bulletin

PRENSIP
https://prensip.gen.tr/

RESEARCH ARTICLE

The challenges on talent management in Turkish container shipping industry

Ramazan Özkan Yıldız[1*]

[1] *Iskenderun Technical University, Barbaros Hayrettin Naval Architecture and Maritime Faculty, Department of Maritime Business Management, Hatay, Türkiye*

ARTICLE INFO

Article History:
Received: 21.07.2023
Received in revised form: 22.08.2023
Accepted: 22.08.2023
Available online: 28.09.2023

Keywords:
Talent management
Challenges on talent management
Container shipping
Qualitative methods
Content analysis

ABSTRACT

Talent management (TM) is a critical aspect of organizational success, particularly in industries characterized by constant change and intense competition, such as the Turkish container shipping industry. This study aimed to explore the barriers to talent management practices and identify potential actions that companies in this industry can take to overcome these challenges. Through structured interviews with 31 participants employed in Turkish shipping companies, a range of barriers emerged, including economic conditions, the employment of incompetent individuals, lack of investment in talent management, disregard for employee value and development, lack of institutionalism, high employee turnover, failure to implement education effectively, and time constraints. In response to these barriers, potential actions were identified, including the development and utilization of innovative and remedial strategies, valuing employee development, providing employee welfare, and allocating adequate time and budget resources. These findings provide valuable insights into the challenges faced by organizations in the Turkish container shipping industry and offer actionable recommendations to enhance talent management practices. By implementing these actions, companies can create an environment that attracts, develops, and retains talented individuals, contributing to their long-term success in a competitive industry. Acknowledging and addressing these challenges is crucial for organizations seeking to improve talent management practices and remain competitive in the Turkish container shipping industry.

Please cite this paper as follows:

Yıldız, R. Ö. (2023). The challenges on talent management in Turkish container shipping industry. *Marine Science and Technology Bulletin*, *12*(3), 332-351. https://doi.org/10.33714/masteb.1330955

* Corresponding author
E-mail address: rozkan.yildiz@iste.edu.tr (R. Ö. Yıldız)

Introduction

Talent management is a new and emerging research field (Cooke et al., 2014; Gallardo-Gallardo & Thunnissen, 2016). Despite an increase in the number of studies in talent management (particularly conceptual studies), many authors continue to emphasize the scarcity of experimental research (Cappelli & Keller, 2014; Anlesinya et al., 2019; Joos et al., 2021).

The majority of talent management research focuses on the service industry, specifically the tourism and hospitality sectors. Maritime is another growing service industry (Stopford, 2009; Lun et al, 2011; Balci et al., 2018; Bratton & Watson, 2018; Pantouvakis & Karakasnaki, 2018; Yildiz et al., 2023). Talent management is viewed as a crucial driving factor in the shipping industry, allowing the attainment of company objectives and the successful execution of corporate strategy (Progoulaki & Theotokas, 2016; Pantouvakis & Karakasnaki, 2018, Yildiz & Esmer, 2021).

Upon reviewing the literature, it is evident that the talent management field, which has not yet reached a mature stage, can be clearly examined in institutionalized and multinational companies (Yildiz & Esmer, 2021). According to Haralambides (2019), talent management in the shipping industry may be best investigated in the context of container shipping because to the involvement of several international corporations and high institutionalization. Furthermore, Pantouvakis & Karakasnaki (2018) demonstrated that, owing to the exceptional human skills and abilities required in the business, investigating the core components of talent management within the container shipping is essential.

This research examines the key players in the container shipping industry, mainly container shipping lines and maritime logistics companies, in this setting. Maritime logistics companies, which occasionally act as carriers, suppliers, and agents, have begun to serve as shipping lines through long-term agreements (Yildiz & Esmer, 2021). Previous studies on the container shipping, in the literature found that, in addition to container shipping lines, maritime logistics companies are also the sector's main representatives (Balci et al., 2018, 2019; Yildiz & Esmer, 2021; Yildiz et al., 2023).

Examining the challenges on talent management in the container shipping industry is critical owing to the sector's significant effect on operational efficiency, sustainability, and growth. Container shipping, as a cornerstone of global trade, relies significantly on talented people in a variety of jobs, from container agent officials to logistics specialists and managers. However, the sector has a number of significant issues, including a lack of skilled and qualified staff, a lack of institutionalization, and a lack of attention on talented employees and their growth (Yildiz & Esmer, 2021).

Based on this point, the aim of the study is to identify the barriers to talent management in the Turkish container shipping industry and present alternative solutions and strategies to overcome these obstacles. In line with the purpose of the study, an interview study conducted on 31 participants from 29 different companies operating within the sector. The study utilized a structured interview method to collect data from the participating container shipping companies. This method allowed for an in-depth exploration of the challenges faced by these companies in managing talent. The collected data was then analysed using the MAXQDA content analysis tool, enabling a systematic and rigorous examination of the themes and patterns that emerged from the interviews. The methodologies and analysis used to reach the main goal of the research have been driven by two key research questions:

Research Question 1: What are the primary challenges on TM within the context of Turkish container shipping industry?

Research Question 2: What are the countermeasures and strategies that can be utilized to overcome these obstacles?

The findings of the study shed light on the key barriers identified by 31 participants, who were employees of various companies within the Turkish container shipping industry. These barriers can be categorized into several distinct codes: economic conditions, employing and authorizing incompetent individuals, lack of investment in talent management, disregard for employee value and development, lack of institutionalism, high employee turnover rate, failure to put education into practice, and time constraints. These challenges, if left unaddressed, can hinder organizations from effectively attracting, developing, and retaining talented individuals within the Turkish container shipping industry.

However, the study also revealed potential actions that companies can take to overcome these barriers. The identified actions encompass developing and utilizing innovative and remedial strategies, valuing employee development, providing employee welfare, and allocating sufficient time and budget resources. By implementing these actions, organizations can foster a supportive environment that promotes talent management practices and enhances the overall performance and competitiveness of the Turkish container shipping industry.

Understanding the challenges and potential actions in talent management is of paramount importance for companies operating in the Turkish container Shipping Industry. The findings from this study provide valuable insights into the specific challenges faced by organizations within this sector and offer potential solutions to address these challenges. By acknowledging and acting upon these findings, companies can better position themselves to attract, nurture, and retain talented individuals, contributing to their long-term success in a rapidly evolving and competitive industry.

In conclusion, this study highlights the significance of effective talent management system in the Turkish container shipping industry. By recognizing the barriers and potential actions identified through the structured interview study, companies operating in this industry can develop comprehensive strategies to address these challenges. Ultimately, such efforts will contribute to the overall growth and success of organizations within the Turkish container shipping industry, positioning them for sustained competitiveness in the global market.

Talent Management in Shipping Industry

Talent management in the maritime industry encompasses various aspects that are crucial for the success and sustainability of shipping companies. Several factors and challenges need to be considered in order to effectively manage talent in this industry. One important aspect is the retention of talent, particularly in the context of work-life balance. Research has shown that creating a work-family balance logic is essential for retaining talent, especially women managers in the shipping sector (Lavissière & Lavissière, 2022). This includes providing support and flexibility to employees to manage their work and personal responsibilities. Additionally, promoting gender equality and addressing gender biases in the industry can help enlarge the talent pool and foster innovation and smart growth (Gissi et al., 2018).

Knowledge management is another critical factor in talent management for shipping companies. The shipping industry is both capital and knowledge-intensive, and human resources and knowledge management capabilities are essential for sustaining industry competitiveness (Lin et al., 2009). Effective knowledge sharing and management practices, such as training and education programs, can enhance the skills and competencies of employees and contribute to the overall success of the organization. The implementation of new technologies, such as block-chain, presents both challenges and opportunities in talent management. Factors such as sufficient capital, staff training, ease of local legislation, and support from senior management and the shipping community are critical for successful block-chain implementation in the shipping industry (Zhou et al., 2020). Shipping companies need to invest in talent acquisition and development in the field of block-chain to leverage its potential benefits.

Soft skills development is also important in talent management for the shipping industry. Employees need to possess transferable soft skills, such as effective communication, teamwork, and problem-solving abilities, to perform effectively in the workplace (Chala & Bouranta, 2021). These skills contribute to employee contextual performance and overall organizational success. Furthermore, the welfare and quality of work-related life for shipping workers are crucial considerations in talent management. Organizational culture, support, and employee well-being play significant roles in enhancing the health and quality of work-related life for shipping employees (Kim & Jang, 2018). Shipping companies need to prioritize the welfare and talent development of their employees to ensure a motivated and competent workforce.

Ultimately, talent management in the shipping industry involves addressing various challenges and factors, including work-life balance, knowledge management, technological advancements, soft skills development, employee welfare, and gender equality. Shipping companies need to implement effective strategies and practices to attract, retain, and develop talent in order to thrive in this competitive industry.

Talent management in the container shipping industry is a critical aspect for the success and competitiveness of shipping companies. Several factors and challenges need to be considered in order to effectively manage talent in this industry. One important consideration is the definition and approach to talent in the container shipping industry. The concept of talent is often associated with employees and their development, including competence and knowledge management (Yildiz & Esmer, 2021). However, it is important to strike a balance between focusing on individual employees and considering broader talent development practices.

Sustainable shipping practices are also relevant in talent management for container shipping companies. The integration of stakeholder and behavioral theories can help identify the antecedents and outcomes of sustainable shipping practices (Yuen et al., 2017). This includes considering factors such as company policies, procedures, shipping equipment, and environmental responsibility. The container shipping industry is characterized by complex networks and vertical integration. Understanding the main processes of vertical integration and the evolution of major shipping companies is crucial in talent management (Wang et al., 2020). This knowledge can inform strategies for talent acquisition, development, and retention.

Risk management is another important aspect in talent management for container shipping companies. Identifying and addressing risk factors related to management, operations, and external factors is crucial for ensuring the safety and efficiency of container supply chains (Wan et al., 2019). This includes managing human resources and working environments effectively to mitigate risks. The implementation of new technologies, such as block-chain, can also impact talent management in the container shipping industry. Smart contracts and automation can streamline processes, reduce paperwork, and optimize resource allocation (Kaur et al., 2022). Shipping companies need to adapt to these technological advancements and invest in talent development in relevant areas.

Efficiency and performance evaluation are key considerations in talent management for container shipping companies. Assessing the cargo and eco-efficiencies of shipping companies can provide insights into their performance and identify areas for improvement (Kuo et al., 2020; Hsieh et al., 2021). This includes evaluating inputs such as employee numbers, total assets, and capital expenditures, as well as outputs such as sales and market performance. Finally, talent management in the container shipping industry involves addressing various challenges and factors, including talent development practices, sustainable shipping practices, complex networks and vertical integration, risk management, technological advancements, and efficiency evaluation. Shipping companies need to implement effective strategies and practices to attract, retain, and develop talent in order to thrive in this competitive industry.

Challenges on Talent Management for Shipping Companies

Talent management in the shipping industry faces several challenges that need to be addressed by shipping companies. One of the key challenges is the retention of ship officers and cadets at sea. Research has identified factors such as job satisfaction, opportunities for career progression, and good working conditions as crucial for retaining seafarers (Caesar et al., 2015). Shipping industry employers need to focus on managing these factors effectively to improve retention rates. Another challenge is the shortage of qualified seafarers. The industry has been experiencing recurrent shortages for some officer positions, and there is a need to attract and increase the supply of suitably qualified seafarers (Thai et al., 2013). This requires effective marketing of the shipping industry and seafaring career to enhance its image and appeal to potential candidates.

Cultural diversity and intercultural relations also pose challenges in talent management. The mix of different nationalities on board ships can create problems at the managerial level, particularly in crew management strategies and the philosophy of shipping companies regarding multiculturalism (Progoulaki & Theotokas, 2016). Managing cultural diversity and promoting cultural awareness become essential competencies for shipping companies. Additionally, the implementation of new technologies, such as block-chain, presents challenges in talent management. The successful implementation of block-chain in the maritime industry requires factors such as sufficient capital, staff training, ease of local legislation, support from the shipping community, support from senior management, and professional consultation and assistance (Zhou et al., 2020). Shipping companies need to address these challenges to effectively utilize new technologies and stay competitive.

Furthermore, gender equality is an important issue in talent management. The maritime industry has traditionally been male-dominated, and there is a need to address gender disparities and promote gender equality (Dragomir, 2019). Research has highlighted the complexity of intercultural relations and the role of shipping companies, ship management practices, and maritime education and training institutions in addressing gender equality issues (Dragomir, 2019). Lastly, the human element onboard ships are crucial in emergency situations. The prompt response of ship's officers is essential in controlling and preventing the escalation of threats during major emergencies (Aly et al., 2023). Therefore, training and competency development in emergency response become critical for shipping companies to ensure the safety and security of their operations. In conclusion, talent management in the shipping industry faces challenges related to retention, shortage of qualified seafarers, cultural diversity, technological advancements, gender equality, and emergency response training. Shipping companies need to address these challenges by implementing effective strategies, promoting job satisfaction and career progression, attracting and retaining qualified seafarers, managing cultural diversity, embracing new technologies, promoting gender equality, and providing comprehensive training for emergency situations.

To overcome the challenges on TM, shipping companies can take various actions. One important action is adopting an inclusive approach to talent management. This approach considers talent as something owned by all employees and emphasizes the discovery and development of talent through necessary practices and processes (Yildiz & Esmer, 2021). An inclusive approach fosters a pleasant working environment characterized by openness, trust, and overall employee well-being, which can serve as a catalyst for motivation and determination.

Furthermore, shipping companies can focus on talent acquisition, development, and retention practices. Talent acquisition can involve utilizing appropriate available sources to reach out for available talent, especially in the context of talent scarcity (Kravariti et al., 2021). Talent development can include the implementation of innovative and remedial strategies, valuing employee development, and providing employee welfare (Yildiz & Esmer, 2021). Talent retention can be enhanced by offering a range of intrinsic and extrinsic incentives to retain the talented workforce (Kravariti et al., 2021). In addition, shipping companies can prioritize the development of a strong organizational culture that values talent and promotes employee engagement. This can be achieved by aligning talent management practices with strategic business objectives, hiring employees who are empathetic to the business values, and building a healthy mix of perspectives through collaboration between internal and external talent (Kumar, 2019). Creating a culture of continuous learning and development can also contribute to talent management success.

Moreover, shipping companies can leverage technology and digitalization to enhance talent management practices. This can involve the use of digital tools for talent acquisition, development, and performance management. Additionally, container shipping companies can invest in training and development programs to equip employees with the necessary skills to adapt to technological advancements in the industry.

Methodology

The phenomenology approach was used in the study's research design. The goal of phenomenology research design is to reveal an individual's original ideas and interpretations about the phenomena (social conditions/events, business processes, etc.) that he/she experiences and observes throughout his/her working life from the researcher's perspective (Bloor & Wood 2006). The interview data collecting method is an appropriate tool for use in phenomenological research to understand and interpret ongoing events shaped around the respondent (Sığrı, 2018). In this scenario, a structured interview format was developed using open-ended questions found in relevant literature. These questions were organized based on research questions and design. The interview format was then applied to human resources officials employed in the container shipping industry. Prior to conducting the interviews, the questions were translated and checked for accuracy and content.

Structured interviews involve researchers asking pre-arranged open-ended questions to participants in a consistent and standardized manner. This approach ensures that data production is consistent and allows for appropriate comparisons between participants' responses (Savin-Baden & Howell-Major, 2013). Since the specific and clear points that the study aims to investigate and address are defined, a structured interview method has been employed to obtain more precise answers to the same research questions. Considering the time constraints of the respondents as well as the possibility of deviation from the target subjects and the risk of obtaining unanswered questions in various areas, the structured interview method has been utilized.

The validity of the interview method is determined by expert opinions and follows several steps, including establishing the research framework, designing the data collection form, preparing an interview guide, and posing questions to participants. The validity of the data collection tool is determined by its comprehensiveness, while the reliability of the results is assessed through factors such as credibility, transferability, dependability, confirmability, and integrity (Wallendorf & Belk, 1989). The Wallendorf & Belk (1989) methodology was used to assure the reliability of the qualitative study, and the activities listed in Table 1 were taken (Sağlam & Karataş Çetin, 2022).

The data collected from interviews was analyzed using MAXQDA 2020, a software for qualitative content analysis. MAXQDA offers a more systematic approach to data analysis compared to manual methods (Kuckartz & Rädiker, 2019). During the analysis process, two experienced coders were selected from experts who had participated in similar studies one is the author's itself and the other is a qualitative methodology analyst working in a company which serves as the distributor and official representative of MAXQDA in Türkiye. The author attended a total of 16 hours of training provided by the official representative of MAXQDA program for content analysis. The other coder is already the qualitative analysis expert of this company. This expert holds a bachelor's degree in psychology and a master's degree in human resource management. Additionally, she has participated in certificate programs related to talent management and talent acquisition. By comparing the coding results, it was found that the Cohen's Kappa coefficient scores were consistently above 0.75, indicating a high level of agreement between the coded texts (McHugh, 2012). The inter-coder reliability regarding the coding of the qualitative data was calculated using the Eq. (1):

$$Ir = \sqrt{\left\{\left[\left(F_o/_N\right) - \left(1/_k\right)\right]\left[k/_{(k-1)}\right]\right\}} \tag{1}$$

F_o demonstrates the amount of coder agreements, N stands for the total number of coder decisions, and k identifies the number of categories (Perreault Jr & Leigh, 1989; Bitiktas & Tuna, 2020). The inter-coder reliability value for this study was calculated as 0.83.

The coding methodology developed by Corbin & Strauss (1990) was used as the foundation for the analysis. The coding process began with open coding, followed by the combination of axis codes. Selective coding was then employed to develop themes for the research. Throughout the coding process, the data was read repeatedly, and primary codes were generated. Initially, the interview questions were treated as a broad category, but as codes emerged, interrelated codes were grouped under themes. The obtained themes were then visually presented in a way that would be easily understood by readers (Yildiz et al., 2023). Finally, the findings were interpreted to give meaning to the results obtained from the analysis. Table 2 provides an example of how codes and categories were created during this process.

Table 1. Rigor of the study

Criteria	Action
Credibility	• Structured questions were conducted. Concepts were explained whenever requested from the interviewee. Supportive questions were asked to clarify and refine the points further. • The interview coding was done independently by the author and the other expert. When there was a discrepancy between the codes, additional examination was performed. MAXQDA 20 software was used for code comparison.
Transferability	• Participants were selected through purposive sampling based on their areas of expertise and industry involvement. All hierarchical levels of the HRM department attempted to be included in the sample.
Dependability	• The number of interviews was not fixed, and the data gathering phase was extended until theoretical saturation was reached. • Participants shared instances of the phenomenon across a wide time span.
Confirmability	• Prior to the interviews, all personal information about the topic was documented to guarantee awareness of any previous biases. • Where interviewers inquired about how other interviews answered a certain question, it was left unanswered. • The results section was created to reflect the number of matches between interpretations and quotations.
Integrity	• The names of the interviewees and their companies were kept private. • In the event that respondents supplied examples involving other firms, the identities of those companies were likewise withheld. • When interviewees requested that any of their comments be kept "off the record," their responses were not transcribed or cited in the study.

Table 2. Example coding and categorization

Theme	Category	Code	Raw Data	Researcher's Interpretation
TM in Turkish Shipping Industry	Challenges on TM	Shortfall of Time	The biggest obstacle is time. Being a people-oriented sector, we often lack the time to apply the appropriate coaching methods. The demands of the job don't always allow for it.	Participant states that the main challenge in the Turkish container shipping industry is the lack of time in a labour-intensive sector.

Table 3. Interview questions and referring studies

Question	Referring Study
Do you have an effectively functioning talent management system in place?	Makram et al. (2017)
Do you think talent management is being implemented correctly in our country, especially in the container shipping industry?	Cooke et al. (2014)
In your opinion, what are the main obstacles to talent management in our country, especially in the container shipping industry?	Wiblen & McDonnell (2019)
What countermeasures are you taking in response to these obstacles?	Cooke et al. (2014)
In your view, what other countermeasures could be employed?	Cooke et al. (2014)
What strategies need to be developed to address these obstacles?	McCracken et al. (2015)

The reporting of the findings began by presenting the main themes identified. Subsequently, theme-based categories were elaborated on with the aid of visual representations, and the findings were interpreted. The organization of the findings involved demonstrating the relationships between the codes, establishing cause-effect relationships, and drawing conclusions based on the obtained findings. This process aimed to develop a comprehensive understanding by examining the connections and implications derived from the data (Yildiz & Esmer, 2021; Yildiz et al., 2023).

Data Collection

The data for this study were collected through online, structured interviews. The data collection tool was developed based on questions gathered from relevant literature (see Table 3). The form was carefully reviewed by five academics from different institutions: one professor from the University of Piraeus, one assistant professor from Warsaw University of Technology, one professor and one associate professor from Dokuz Eylul University, and one assistant professor from Ankara Science University. Their goal was to assess whether the questions were comprehensive and appropriate for obtaining reliable data. Additionally, to test the construct validity, five human resources specialists were interviewed using the structured form. The interviews were repeated one week later to determine if the responses would be consistent. Obtaining similar answers confirmed that the data collection tool demonstrated the expected validity.

Purposeful sampling, also known as purposive sampling, is a commonly used technique in qualitative research. Its aim is to select individuals or groups with extensive knowledge and familiarity with the phenomenon under investigation, allowing for efficient analysis and utilization of limited resources (Palinkas et al., 2015). In this study, a sample of 13 HR officials from 11 different container shipping lines and 18 HR executives from 18 different maritime logistics companies was specifically chosen using purposive sampling. The selection criteria included their active involvement in the industry, as well as their expertise and command in the field. The 11 container shipping lines participating in the research are among the top 20 listed in the Alphaliner Top 100, while 8 of the maritime logistics companies belong to the Top Ocean Freight Forwarders NVOCC 2022 list. The remaining 10 companies were selected based on their well-established and rooted HR departments, along with their active implementation of a talent management system. Data collection took place between January and June 2023. The interviews lasted approximately 45 minutes, and audio recording was not feasible in most cases to respect the privacy concerns of the participants and organizations. Therefore, the interviewer carefully transcribed the participants' opinions verbatim into written texts.

Descriptive information about the participants was categorized into five main groups. Out of the total 31 participants, 17 were female, and the remaining 14 were male. In terms of educational qualifications, 19 participants had completed bachelor's degrees, while 12 participants held master's degrees. Upon examining the occupations of the participants, it was found that 15 of them held positions as HR managers, 11 were HR specialists, 2 were HR assistant managers, 2 were HR business partners, and 1 participant held the role of HR chief. Furthermore, when considering their experience levels, 11 participants had 1-5 years of experience, 9 participants had 6-10 years, 4 participants had 16-20 years, 4 participants had 21 years or more, and 3 participants had 11-15 years of experience. Lastly, in terms of age distribution, the screening revealed that 8 participants were between 20-30 years old, 16 participants were between 31-40 years old, and 7 participants were 41 years old or older.

Findings

The theme of talent management in the Turkish container shipping industry have been examined under two categories. These are barriers to talent management practices and potential actions against these barriers. The category of barriers to talent management practices is defined by participants as economic conditions, employing and authorizing incompetent individuals, lack of investing in TM, disregarding, ignoring the value and development of employees, lack of institutionalism, high employee turnover rate, failure to put education into practice, and shortfall of time (see Table 4). The category of potential actions against these barriers is defined by codes such as developing, utilizing innovative and remedial strategies, valuing the employee development, providing employee welfare, and time and budget allocation.

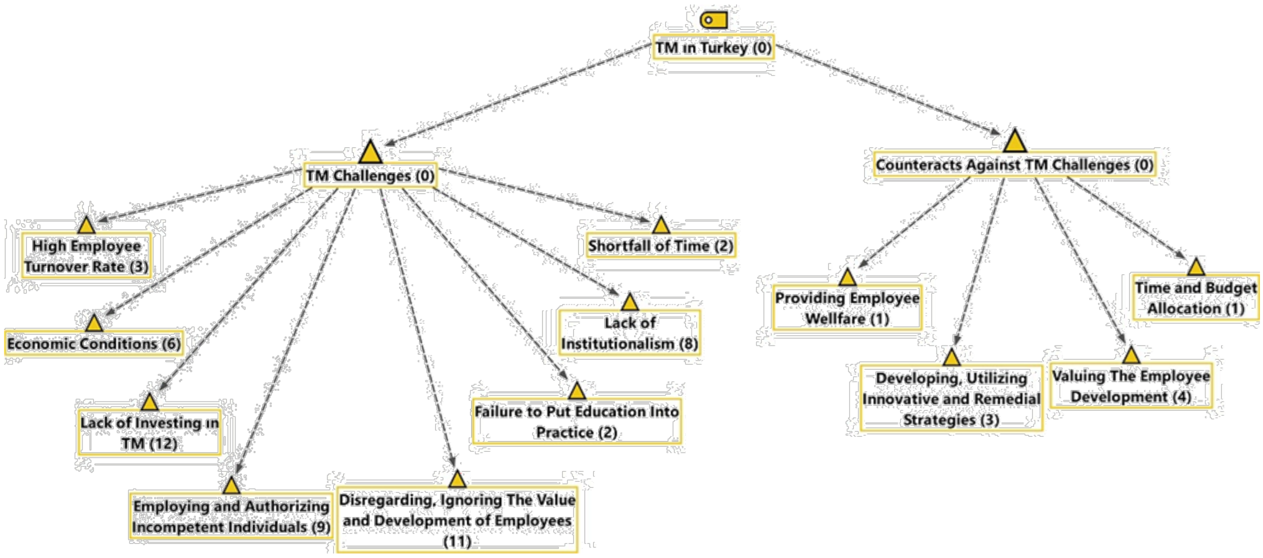


Figure 1. The theme of talent management in the Turkish container shipping industry code / sub-code sections model

Table 4. Brief explanation of identified challenges

Challenge	Explanation
Lack of Investing in TM	The Turkish container shipping industry has shown a remarkable lack of investment in talent management systems. Despite obvious benefits such as encouraging employee growth, improving labor skills, and nurturing long-term organizational sustainability, the industry has been slow to fully embrace talent management ideas. This is due to a variety of issues, including a lack of knowledge about the benefits of talent management, a lack of understanding of its implementation tactics, and a predominance of short-term operational concerns over long-term human capital development. Furthermore, the industry's historical reliance on old hierarchical structures may impede the implementation of modern personnel management approaches. To reap the potential advantages of talent management, players in the Turkish container shipping business must acknowledge the importance of investing in talent.
Disregarding, ignoring the value and development of employees	The Turkish container shipping companies have a troubling propensity to overlook and dismiss the importance of their employees' growth. Despite the numerous advantages of a highly motivated and trained staff, such as increased operational efficiency, greater customer service, and overall organizational growth, the industry has generally ignored the necessity of investing in employee development. This is due to cost-cutting initiatives, a concentration on urgent operational demands, and a lack of emphasis on long-term human capital improvement. Employee unhappiness and potential contributions to the sector may be hampered by a lack of thorough training, career growth chances, and recognition methods. To ensure long-term prosperity, the Turkish container shipping industry must adjust its focus and prioritize the environment.
Employing and authorizing incompetent individuals	The Turkish container shipping industry has been dealing with the issue of hiring and approving inept people. This practice, which involves putting people in crucial positions who lack the essential skills and certifications, can have a negative impact on operational performance, safety, and the overall industry reputation. Inadequate recruiting methods, nepotism, and a failure to emphasize merit-based selection are all factors contributing to this problem. Allowing people without the necessary skills to maintain positions of responsibility risks undermining decision-making, stifling innovation, and potentially jeopardizing the safety of both workers and cargo. To address this, the sector should focus on creating strong recruiting and promotion policies based on competency and credentials, ensuring that individuals entrusted with critical tasks are capable of navigating the industry's complexity.

Table 4 (continued)

Challenge	Explanation
Lack of institutionalism	The Turkish container shipping industry has been plagued by a noticeable lack of institutionalism, which refers to the absence of long-standing organizational structures, procedures, and conventions. This shortcoming can be linked to causes such as frequent leadership changes, a lack of consistent methods, and a focus on short-term goals rather than long-term stability. In the absence of solid institutional underpinnings, inconsistent decision-making, low operational predictability, and difficulty responding to changing market conditions might occur. A lack of institutionalism limits the industry's capacity to establish long-term competitive advantages and may make obtaining investments and maintaining consumer trust difficult. To overcome this, the industry must emphasize the creation of long-term structures, established methods, and a culture of long-term planning.
Economic conditions	Within the Turkish container shipping industry, economic constraints have emerged as a serious hurdle to efficient people management. Market volatility, currency depreciation, and economic uncertainty can all have an influence on the industry's capacity to devote resources to talent development programs. Companies may emphasize short-term cost-cutting measures above long-term expenditures in staff training, growth, and retention during times of economic uncertainty. Furthermore, economic constraints may limit the industry's ability to offer competitive salary packages and incentives in order to recruit and retain top employees. These economic conditions make it difficult to implement comprehensive talent management strategies, emphasizing the need for industry stakeholders to find innovative ways to navigate economic fluctuations while still prioritizing workforce development and engagement.
High Employee Turnover Rate	Because of its high staff turnover rate, the Turkish container shipping sector presents a substantial hurdle to efficient personnel management. The demanding nature of the profession, which frequently requires long working hours, time away from home, and exposure to volatile market circumstances, leads to a tough work environment. This, along with restricted professional growth possibilities and an insufficient work-life balance, can lead to increasing employee discontent and consequent attrition. High turnover destroys continuity, erodes institutional knowledge, and strains resources since businesses must continually recruit and educate new employees. Overcoming this obstacle necessitates a comprehensive strategy that addresses employee well-being, provides clear routes for career progression, and improves job satisfaction, all of which may lead to lower turnover and a more stable and engaged workforce.
Shortfall of Time	Time constraints are a significant impediment to successful people management in the Turkish container shipping business. The sector operates in a fast-paced and time-critical environment marked by tight timetables, stringent deadlines, and the need to adapt quickly to market dynamics. This makes it difficult to implement complete talent development efforts, training programs, and performance reviews. The ongoing emphasis on operational efficiency sometimes takes precedence over devoting adequate time to cultivate employee skills, growth, and engagement. As a result, talent management practices may fall by the wayside, hampering the industry's capacity to build a talented and motivated staff. To tackle this difficulty, the sector must strike a balance between operational demands and investing time and money in good personnel management techniques, realizing that long-term performance is dependent on successful talent management practices.
Failure to put education into practice	In the Turkish container shipping industry, a fundamental impediment to successful personnel management is the failure to put knowledge into practice. While the sector may provide personnel with training and education programs, there is sometimes a disconnect between academic knowledge and its practical application in real-world settings. This might be due to reasons such as a lack of hands-on training opportunities, insufficient alignment between school programs and industry demands, and a lack of mechanisms to reinforce learning on the job. This barrier causes a mismatch between the talents people have and the skills needed to flourish in their professions, affecting operational efficiency and overall performance. To overcome this issue, the industry must improve the integration of practical training, simulations, and real-life scenarios into classroom instruction.

The category of challenges on talent management in the Turkish container shipping industry is defined by 8 different codes. The participants have extensively mentioned the lack of investment in talent management. They emphasize that the importance of investment in talent management is not yet understood by companies. They also state that when investments are made in employees, the company can also thrive. The statements of participants with codes P5 and P16 regarding the lack of investment in talent management are as follows:

"The biggest barrier to talent management in our country, in my opinion, is at the level of mindset. There is a prevalent tendency to perceive it as a burden or solely as a practice for the benefit of employees. However, the truth is that as employees develop, their contribution to the job increases, their perspective improves, and their productivity enhances (P5)."

Table 5. Brief explanation of identified countermeasures

Countermeasure	Explanation
Valuing the employee development	To solve difficulties on TM, valuing employee development is a critical countermeasure in the Turkish container shipping industry. The industry may develop a culture of continual learning and progress by recognizing the need to foster and strengthen the skills and capacities of its workers. This means investing in extensive training programs, mentorship activities, and possibilities for professional progression. Employee development not only improves individual performance but also adds to the long-term success of the business by boosting operational efficiency, customer service, and overall competitiveness. The container shipping sector may alleviate talent-related difficulties and establish a resilient and adaptive workforce positioned for long-term success by emphasizing employee growth and providing an atmosphere that encourages skill acquisition and professional advancement.
Developing, utilizing innovative and remedial strategies	To address barriers to TM, the Turkish container shipping sector might use a multidimensional strategy that includes creating, implementing, and adapting novel and corrective techniques. The industry may improve the efficiency and efficacy of talent development programs by embracing innovative technology and techniques such as digital training platforms and simulation tools. Adopting remedial tactics customized to specific skill gaps helps guarantee that existing employees receive the required training and support to flourish in their professions at the same time. This dual approach not only provides the workforce with up-to-date skills but also provides fast remedies to performance difficulties. The industry can build a dynamic learning environment that supports continual development, adaptation, and long-term success in the ever-changing container shipping sector by combining innovation and correction.
Providing employee welfare	Implementing comprehensive employee welfare programs is critical in the Turkish container shipping business as a countermeasure to talent management challenges. Prioritizing employee well-being through programs like work-life balance assistance, health and safety precautions, and mental health services may result in higher job satisfaction, engagement, and retention. Companies may establish an atmosphere that honors employees' holistic needs by understanding and addressing the industry's physical and emotional demands. As a result, their loyalty, motivation, and general performance improve, resulting in a more resilient and productive staff. Employee welfare tackles current concerns while also positioning the sector for long-term prosperity by cultivating a skilled and contented workforce pool.
Time and budget allocation	A strategic allocation of time and budget within the Turkish container shipping sector is critical as a countermeasure to issues in personnel management. The sector may support skill enhancement and employee growth by allocating enough money and time to talent development activities such as training, mentorship, and career progression programs. This necessitates a proactive approach to training budgeting, employing qualified trainers, and developing defined development programs. It is critical to balance the needs of day-to-day operations with long-term investments in human resources. Allocating time and resources wisely not only tackles present personnel management concerns but also sets the sector up for future success by creating a skilled, flexible, and motivated staff.

"The lack of sufficient support and investment from management is the biggest barrier to talent management practices (P16)."

Another code expressed by participants in the category of challenges on talent management is the disregarding, ignoring the value and development of employees. According to the participants, necessary trainings, additional tasks, and responsibilities are not provided to employees. They emphasize that this hinders the development of both employees and the company, and can even lead to the loss of employees. The statements of participants with codes P11 and P26 regarding the code are as follows:

"Giving mediocre tasks to talented individuals, not providing opportunities and initiatives for them to showcase their talents (P11)."

"Not providing education or providing incorrect education, not evaluating the suitability of the employee for the position, persistently keeping them in the same position, and not giving importance to the employees' desires. As a result, the talent that could be suitable for a different job is lost due to improper management. At this point, the most important task falls on the unit managers (P26)".

The third most frequently expressed code in the category of barriers to talent management practices, according to the participants, is employing and authorizing incompetent individuals. Participants state that one of the biggest barriers to talent management practices is that those managing the process are not experts in their field and, instead of using objective assessment tests to discover talents, they consider personal relationships. The statements of participants with codes P17 and P31 regarding the employment of unskilled individuals are as follows:

"In our country, particularly in companies that lack global standards and culture of supervision, there is a lack of meritocracy in the recruitment processes. When acquaintances and similar individuals are hired, it results in incorrect recruitment. This, in turn, leads to the misdirection of talent (P17)."

"Prioritizing personal relationships in talent identification or career development, non-objective and non-transparent practices, and the failure to delegate talent management responsibilities to competent professionals in the field and the lack of expertise among those managing the process are among the most important barriers (P31)."

Another obstacle expressed by participants in the category of talent management is the lack of institution culture and mentality in Turkish shipping companies. According to the participants, one of the major challenges on talent management in Turkish container shipping industry is the limited number of companies that are corporate and aim to enhance workplace productivity. The statements of participants with codes P12 and P23 regarding the lack of institutionalism in companies are as follows:

"There is a limited number of truly institutionalized and efficiency-focused companies in the industry (P12)."

"An employee who is part of a talent pool that has received investment through various training and development seminars may decide to leave their job for higher salary or promotion opportunities. This is not attributed to any fault on the part of the employee or the employer, but rather stems from the industry's limited presence of institutionalized, systematic, and international companies (P23)."

The fifth obstacle, which is reiterated by a significant number of participants, is economic conditions. According to the participants, companies are unable to invest in talent management due to unfavorable economic circumstances. The statements of participants with codes P20 and P22 regarding economic conditions are as follows:

"The economic constraints and uncertainties in the container shipping industry pose some serious obstacles (P20)."

"For instance, when we cannot find candidates through job postings, we should resort to headhunting, but in such cases, we need to offer salaries above average. However, existing salary policies, increasing personnel costs, and Türkiye's economic situation hinder this. (P23)."

According to the statements of the participants, another category that emerges under the theme of talent management in the Turkish maritime sector is the actions that can be taken against obstacles. The category of actions that can be taken against obstacles is defined by four different codes: valuing the employee development, developing, utilizing innovative and remedial strategies, providing employee welfare, and time and budget allocation (see Table 5).

Participants extensively emphasized the importance of prioritizing employee development. They mentioned that practices such as training and rotation can be implemented to enhance employee development. The statements of participants with codes P1 and P17 regarding prioritizing employee development are as follows:

"In my opinion, in order to retain talents, the future career advantages of working in this field in the country should be highlighted more. Emphasis should be placed on the development and rotation of forward-thinking talents, rather than just focusing on individuals who will perform the job (P1)."

"The education and training practices provided for the development of employees can be increased (P17)."

The second most emphasized code expressed by participants in the category of actions that can be taken against obstacles is the development of new strategies. Participants emphasize the importance of academic studies in this field and highlight those new strategies can be developed based on the findings obtained from these studies. The statement of the participant with code P2 regarding the development of new strategies is as follows:

"We can review and analyze national and international academic studies conducted on the subject, and then adapt the strategies outlined in those studies to align with our own company (P12)."

When we examine talent management in Turkish container shipping industry based on the challenges on TM and actions can be taken to overcome them, it is evident from Figure 2 that participants who express that these policies are not implemented correctly in Türkiye mainly emphasize the lack of investment in talent management, lack of emphasis on employee development, and the employment of unskilled individuals. Furthermore, participants who indicate that talent management policies are not implemented correctly in Türkiye also express a stronger focus on employee development when it comes to overcoming barriers to talent management practices. They have also provided ideas regarding other barriers and potential solutions to address these obstacles.

When examining the theme of talent management in Turkish container shipping industry based on logistics companies and container lines, as seen in Figure 2, participants working in both logistics companies and container lines have evaluated talent management in Turkish container shipping industry within a broad framework. It is evident that participants employed in logistics companies predominantly

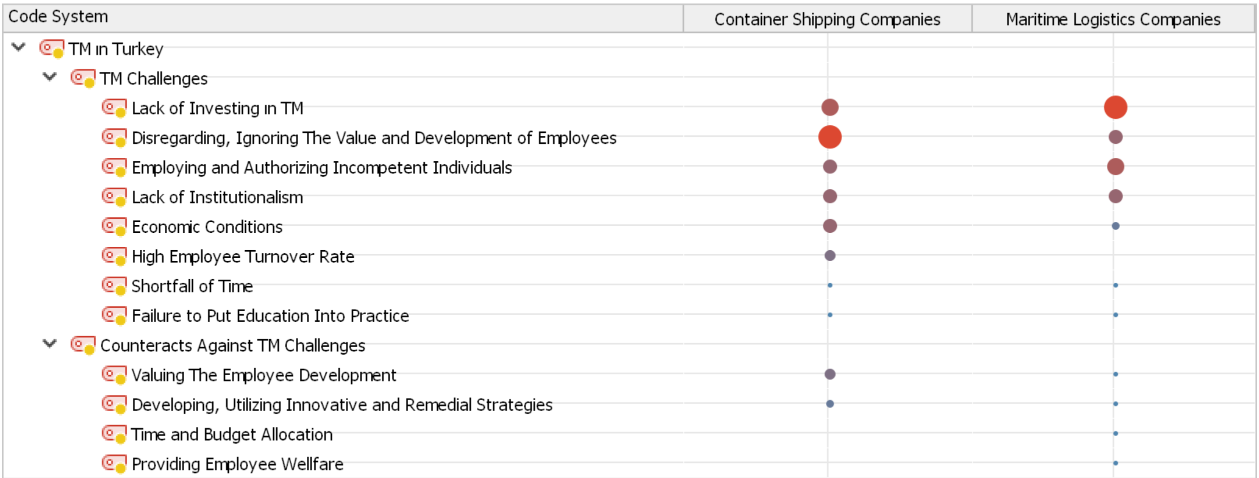


Figure 2. Barriers to talent management in the Turkish container shipping sector and countermeasures based on participant company profiles

Figure 3. Code cloud of barriers and countermeasures to tm in Turkish container shipping industry.

expressed their views on the lack of investment in talent management. Additionally, they provided insights regarding the lack of emphasis on employee development, employment of unskilled individuals, and the absence of corporate culture within companies. Participants working in container lines primarily expressed their views on the inadequate focus on employee development. The other codes they frequently mentioned align with those of participants employed in logistics companies.

The distribution of participants' statements regarding the theme of talent management in Türkiye, based on intensity, is presented in Figure 3. The codes shown in larger font sizes indicate more frequently used expressions, while the ones in smaller font sizes indicate less frequent usage of the codes. It's seen from the code cloud that the biggest challenge on TM in Turkish container shipping industry is seen as Disregarding, Ignoring the Value and the Development of Employees, it is common in collectivist societies like Türkiye for individuals to be seen as mere instruments or tools (Yildiz et al., 2023). The findings of the study also indicate that this perception is recognized as a problem within the sector. The findings of study also create an impression that the barriers to TM are more prevalent throughout the sector and that the countermeasures in place are still not at a satisfactory level. However, it is understood that despite these challenges, participants perceive placing importance and value on employee development as a key countermeasure and the main solution to the problems. In this case, it is believed that talent-focused approaches, and therefore, people-centered approaches, need to be adopted for talent management to become widespread and feasible in Turkish container shipping companies. The mentality of valuing individuals, their talents, and the development of existing skilled personnel should be widely promoted in the industry. The prevailing view is that by cultivating this mindset and removing the barriers to talent management, the implementation of talent management practices in the sector can be achieved.

Discussion

The challenges highlighted in the literature regarding talent management in the shipping industry exhibit notable similarities and comparisons with the findings of our study. By examining these challenges, we can gain a deeper understanding of their implications and the potential overlap with our study's results. Retention of employees at sea is identified as a key challenge in the shipping industry (Caesar et al., 2015). While the study did not specifically focus on ship crew, the high employee turnover rate revealed in the research aligns with the broader issue of retention. Factors such as job satisfaction, career progression opportunities, and good working conditions mentioned in the related literature resonate with the study's findings regarding the importance of valuing employee development and providing employee welfare.

Another challenge emphasized is the shortage of qualified employees, which impacts talent acquisition in the shipping industry (Thai et al., 2013). Although the study did not directly investigate this shortage, the barrier of employing and authorizing incompetent individuals identified in our research aligns with the need to attract and increase the supply of suitably qualified seafarers mentioned in the above text. Cultural diversity and intercultural relations also pose challenges in talent management within the shipping industry (Progoulaki & Theotokas, 2016). While the study did not explicitly explore cultural diversity, the challenges associated with managing cultural diversity and promoting cultural awareness highlighted in the regarding literature align with the study's findings regarding the broader challenge of lack of institutionalism. This indicates that companies must recognize and value employees' diverse backgrounds and experiences to effectively manage talent.

The implementation of new technologies is another significant challenge in talent management, as mentioned in the engaged literature (Zhou et al., 2020). Although the study did not specifically examine this aspect, the need for companies to address challenges related to new technologies, such as securing sufficient capital, providing staff training, and obtaining support from senior management, can be related to the barrier of lack of investment in talent management identified in the research. According to Dragomir (2019), gender equality is identified as an important issue in talent management within the shipping industry. Although our study did not specifically investigate gender equality, the need to address gender disparities and promote gender equality highlighted in the interrelating literature aligns with our study's findings regarding the broader challenge of disregarding and ignoring the value and development of employees.

Lastly, the significance of training and competency development in emergency response is mentioned as a challenge in the engaged literature (Aly et al., 2023). While our study did not focus on emergency response training specifically, the importance of developing employees' skills and putting education into practice, which were identified as barriers in our research, can be related to the need for effective training and competency development in emergency situations. In conclusion, an evaluation of the challenges discussed in the literature reveals similarities and comparisons with the findings of our study on the barriers to talent management in the Turkish container shipping industry. These challenges underscore the importance of addressing various aspects of talent management to enhance overall practices within the shipping industry. By recognizing and tackling these challenges, companies can create an environment that attracts, develops, and retains talented individuals, contributing to their long-term success in this competitive industry.

One important action highlighted in the previous literature is adopting an inclusive approach to talent management (Yildiz & Esmer, 2021). This aligns with the broader challenge identified in our study of disregarding and ignoring the value and development of employees. By recognizing talent as something owned by all employees and fostering a pleasant working environment, the proposed inclusive approach resonates with the need to value employee development and provide employee welfare. Another action emphasized in the related literature is talent acquisition, development, and retention practices (Kravariti et al., 2021). Talent acquisition strategies, as discussed in the regarding literature, align with the need to address the challenge of the shortage of qualified personnel identified in our study. Similarly, the actions of implementing innovative and remedial strategies, valuing employee development, and providing employee welfare align with the study's findings regarding the barriers of employing and authorizing incompetent individuals, lack of investment in talent management, and disregarding employee value and development.

The focus on developing a strong organizational culture that values talent and promotes employee engagement, as mentioned by Kumar (2019), parallels the need for addressing the challenge of lack of institutionalism identified in our study. Both highlight the significance of aligning talent management practices with strategic objectives and creating a culture of continuous learning and development. The use of technology and digitalization to enhance talent management practices, as proposed in the interrelating literature (Yildiz & Esmer, 2021), aligns with the broader challenge of the implementation of new technologies discussed in the study. Leveraging digital tools for talent acquisition, development, and performance management can address the need to invest in training and development programs and adapt to technological advancements in the industry.

There are also studies in the existing literature that draw contradictory and opposing conclusions to the findings presented in this study on barriers to talent management in the Turkish container shipping sector. These studies offer insight on various views and outcomes related to talent management strategies and the issues they entail.

Cho & Ahn (2018), for example, question the concept that investment in talent management is the key barrier in the sector. They underline in their research that, while investment is clearly significant, it is not the only factor in efficient talent management. They contend that company culture and leadership have a significant impact on talent management strategies. According to their research, companies with excellent leadership and a culture that appreciates people tend to thrive in talent management even in the absence of considerable financial investments. This viewpoint differs from the current study's emphasis on a lack of investment as a key obstacle.

In addition, Chen & Chen (2022) performed research on the impact of economic situations on talent management techniques. Contrary to the present study's statement that economic restrictions are the key impediment, Johnson and Brown's research reveals that resilient businesses discover inventive methods to manage talent even in difficult economic situations. They suggest that dynamic adaptability to market swings and resource restrictions can lead to the creation of innovative talent acquisition, development, and retention strategies. This frame of view contradicts the notion that economic constraints are insurmountable obstacles to successful talent management.

Another study, conducted by Lu et al. (2022), investigates the effect of employee turnover on talent management system. While the current study identified high personnel turnover rates as a serious concern, Lu et al. (2022) contend that a modest amount of turnover might potentially benefit firms. According to their findings, a certain level of turnover promotes variety, introduces fresh viewpoints, and discourages complacency in the workplace. They believe that businesses that deliberately manage turnover through well-defined succession planning and knowledge transfer systems can capitalize on its positive elements, differing from the current study's unfavorable picture of turnover.

Finally, Gardiner et al. (2023) offer insights on talent management strategies in collectivist cultures, which are applicable to the Turkish container shipping industry. In contrast to the current study's argument that collectivist nations such as Türkiye overlook employee worth, Gardiner et al. (2023) show how these societies frequently, encourage cooperation and mutual assistance. According to their findings, firms in such societies tend to prioritize collective growth above individual talent, and this strategy can result in good talent management results. This opposing viewpoint calls into question the widely held belief that collectivist cultures impede individual talent development.

In short, while the current study focuses on specific difficulties and potential solutions linked to personnel management in the Turkish container shipping sector, the literature indicates a variety of perspectives and outcomes. These opposing viewpoints highlight the importance of leadership, corporate culture, adaptation, turnover, and cultural context in defining talent management techniques and outcomes. Recognizing and resolving these disparate points of view can help build a more complete knowledge of the industry's personnel management dynamics.

In the context of the Turkish container shipping industry, the concept of "investing in talent management" carries significant implications. It signifies a strategic approach by companies to nurture, develop, and harness the skills, capabilities, and potential of their workforce. This investment extends beyond traditional monetary expenditures, encompassing efforts to provide targeted training, mentorship, and growth opportunities to employees. By prioritizing talent management, companies acknowledge the pivotal role that skilled and motivated individuals play in achieving organizational success and maintaining a competitive edge within the dynamic global shipping environment. Through effective talent management practices, companies in the Turkish container shipping industry strive to cultivate a pool of capable and adaptable professionals who can not only navigate industry challenges but also drive innovation and sustainable growth (Yildiz & Esmer, 2021). The current study has revealed that overlooking these investments is perceived as a significant obstacle to the development of talent management. The absence of investments in talent management can have detrimental effects on Turkish container shipping companies. Without adequate focus on nurturing and developing their workforce, these companies may face challenges in attracting, retaining, and effectively utilizing skilled personnel. The lack of targeted training, mentorship, and growth opportunities can result in decreased employee morale, reduced job satisfaction, and lower productivity. Additionally, the inability to identify and groom potential leaders within the organization could lead to a leadership gap, hindering the company's ability to navigate industry complexities and drive innovation. Furthermore, the competitive global shipping landscape demands a workforce that can adapt to evolving trends and technologies. Failing to invest in talent management may leave companies ill-equipped to keep up with industry changes, potentially leading to decreased competitiveness and sustainable growth prospects.

Significant contributions to the existing literature have been produced, in addition to findings that are consistent with earlier investigations. Time limits and economic challenges, in particular, are viewed as significant barriers by the participants. The mention of time restrictions reveals a belief that the concept of talent management is still perceived as an additional burden and a system that demands extra time, whether thought required or not, by employers in the industry. Furthermore, participant responses indicate that these investments are not prioritized, and investments in talent management are not viewed as lucrative. From this vantage point, it appears that industry executives do not fully comprehend the notion of people management, its advantages to organizations, and its importance in today's global competitive market. One of the primary causes for this predicament is that Türkiye is a collectivist nation (Tatoglu et al., 2016; Yildiz & Esmer, 2021).

Investing time and money in talent management and employee development provides a slew of intangible advantages that reverberate throughout an organization's performance and longevity. To begin with, developing and sharpening the abilities of brilliant employees improves overall productivity and performance, resulting in improved operational outcomes and higher-quality outputs. Furthermore, a significant emphasis on personnel development fosters a culture of constant learning and innovation, allowing businesses to quickly adjust to changing market dynamics and technological breakthroughs. As a result, the organization's competitiveness improves, and it is positioned as an industry leader. Furthermore, a focus on personnel management increases employee loyalty and satisfaction, lowering attrition rates and the expenses associated with recruiting and onboarding. As these individuals advance within the firm, they provide a source of future leaders, supporting smooth succession planning and organizational stability. Finally, deliberate investments in talent management not only cultivate a talented and engaged staff but also move the company toward long-term growth, adaptation, and success in an ever-changing business landscape.

As seen in previous studies that also investigate the concepts of the Turkish container industry and talent management together, such as Yildiz & Esmer (2021) and Yildiz et al. (2023), container lines, mostly of foreign origin and with a global nature, approach the concept of talent management in a more established and systematic manner in this study as well. Building on this point, it is discovered that in the current study, representatives of container lines value talent development more than representatives of marine logistics firms. In the obstacles part, they identify a lack of adequate attention to talent development as the key problem, and in the solutions section, they highlight talent development the most. It is possible to exemplify the importance attached to talent development by container lines through actual implementations.

For example, the Mediterranean Shipping Company (MSC) implements a specialized training and learning program called the Talent Development Center. This center continually assesses the training and learning needs of existing talents and offers personalized learning programs to enhance their performance and potential. Another example is, MAERSK globally implements a "Student Assistant" program for all new and prospective talents. This program aims to accelerate their onboarding process and equip them with the necessary competencies related to best business practices. Additionally, MSC operates an adaptation and job rotation program named "MyRoute," enabling new talents to gain experience in various positions over a three-month period. This process is further complemented by overseas training, which allows new talents to cultivate diverse perspectives and acquire the essential competencies required for global workflow.

Another distinction is observed in terms of investments made in talent management. Maritime logistics companies express greater concerns about the scarcity of investments. One possible reason for this is that investments in container lines are often planned from the central headquarters, which is the global structure located abroad. This global structure is well aware of the impact of individuals, i.e., talents, within its dynamic and competitive environment. The prevalence of Turkey-based companies among participating maritime logistics firms could potentially be a fundamental reason for this difference, stemming from cultural disparities in their approaches.

In summary, it is seen that the actions proposed in the previous literature mostly align with and complement the findings of this study. However, some critical differences also provide significant inferences, which will be a valuable addition for the current concept. The research address key challenges such as the shortage of qualified employees, lack of institutionalism, disregarding employee value and development, and the implementation of new technologies. By adopting an inclusive approach, focusing on talent acquisition, development, and retention practices, building a strong organizational culture, and leveraging technology, shipping companies can overcome these challenges and enhance their talent management practices. Further research could explore the specific implementation and effectiveness of these actions within the context of the Turkish container shipping industry to provide deeper insights into their impact on talent management success.

Conclusion

Talent management in the Turkish container shipping industry presents various challenges that require careful consideration and strategic actions. The findings from the conducted study shed light on these challenges and provide insights into potential actions that container shipping companies in Türkiye can take to overcome them. The challenges identified in talent management for container shipping companies include economic conditions, employing and authorizing incompetent individuals, lack of investment in talent management, disregarding the value and development of employees, lack of institutionalism, high employee turnover rate, failure to put education into practice, and a shortfall of time (Tafti et al., 2017; Anlesinya et al., 2019; Kajwang, 2022). These challenges highlight the need for proactive measures to address talent management issues in the industry.

To overcome these challenges, container shipping companies can take several actions. Firstly, adopting an inclusive approach to talent management can foster a positive working environment and enhance employee engagement and retention (Yildiz & Esmer, 2021). This can be achieved by valuing employee development, providing welfare programs, and utilizing innovative strategies (Yildiz & Esmer, 2023). Secondly, container shipping companies can focus on talent acquisition, development, and retention practices. This includes utilizing appropriate sources for talent acquisition, implementing training and development programs, and offering intrinsic and extrinsic incentives to retain talented employees (Yildiz et al., 2023). Thirdly, prioritizing organizational culture and employee engagement is crucial. Container shipping companies can align talent management practices with strategic business objectives, hire employees who align with the company's values, and foster a culture of continuous learning and development.

Furthermore, leveraging technology and digitalization can enhance talent management practices in the container shipping industry. This can involve the use of digital tools for talent acquisition, development, and performance management, as well as investing in training programs to equip employees with the necessary skills to adapt to technological advancements. Additionally, container shipping companies can address the challenges by investing in talent management integration programs, employee developmental planning, and effective reward programs (Tafti et al., 2017; Kajwang, 2022). These actions can contribute to attracting and retaining talented individuals in the industry.

In conclusion, talent management in the Turkish container shipping industry faces various challenges. However, by implementing strategic actions such as adopting an inclusive approach, focusing on talent acquisition, development, and retention, prioritizing organizational culture and employee engagement, leveraging technology and digitalization, and investing in talent management integration programs, container shipping companies can overcome these challenges and enhance their competitiveness in the industry. These actions will contribute to attracting and retaining talented individuals, fostering a positive work environment, and ensuring the long-term success of container shipping companies in the Turkish shipping industry.

This study holds significant importance for both academic literature and the practice of talent management in the Turkish container shipping industry. Academically, this study contributes to the existing literature by providing insights into the specific challenges faced by shipping companies in talent management practices. The findings shed light on barriers such as economic conditions, incompetence in hiring, lack of investment, disregard for employee value, institutional deficiencies, high turnover rates, failure to implement education effectively, and time constraints. Additionally, the study identifies potential actions to address these challenges, including innovative strategies, employee development, welfare provisions, and resource allocation. This research adds to the body of knowledge on talent management in a specific industry context, allowing scholars to further explore and expand upon these themes.

In terms of practical implications, this study offers valuable guidance to shipping companies operating in the Turkish container shipping industry. By highlighting the challenges and proposing potential actions to overcome them, the study provides a roadmap for improving talent management practices. The unique contribution of this research lies in its industry-specific focus, considering the Turkish container shipping industry. The findings provide a tailored understanding of the challenges and actions that are particularly relevant to this specific sector. This offers practical insights and recommendations that companies in the industry can directly apply to enhance their talent management strategies, thereby promoting employee engagement, talent acquisition, development, and retention. The study's unique focus on a specific industry context strengthens its relevance and applicability to the practice of talent management in the Turkish container shipping industry.

While the study on talent management practices in the Turkish container shipping industry provides valuable insights, there are several constraints that should be acknowledged. The study's sample size of 31 participants from various shipping companies within the Turkish container shipping industry may limit the generalizability of the findings. A larger and more diverse sample could provide a broader perspective on the challenges and actions related to talent management practices in the industry. The study focused specifically on the challenges and potential actions within the Turkish container shipping industry. While this specificity is useful for industry practitioners, it may limit the transferability of findings to other industries or contexts. Future studies could consider conducting comparative research across different industries to gain a broader understanding of talent management challenges and actions. The study relied solely on qualitative data gathered through structured interviews. While qualitative data provides rich insights, the absence of quantitative data limits the ability to establish statistical relationships and measure the magnitude of the identified challenges and actions. Future research could incorporate quantitative data to complement the qualitative findings.

Future research can also investigate the effectiveness and outcomes of the actions recommended in the study. By examining the impact of innovative strategies, employee development initiatives, welfare provisions, and resource allocation on talent management practices, researchers can provide valuable insights into which actions yield the most significant benefits and contribute to organizational success. To further strengthen the link between talent management and organizational outcomes, future research can investigate the direct relationship between effective talent management practices and key performance indicators within the Turkish container shipping industry. By examining metrics such as employee productivity, retention rates, customer satisfaction, and financial performance, researchers can demonstrate the tangible benefits and return on investment associated with robust talent management practices.

Compliance With Ethical Standards

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

Aly, S., Gadalla, H. E., & Esmail, A. (2023). Towards enhancing major emergency initial response training: A comparative study of STCW and OPITO standards. *Maritime Research and Technology*, *2*(1), 1-17. https://doi.org/10.21622/MRT.2023.02.1.001

Anlesinya, A., Amponsah-Tawiah, K., & Dartey-Baah, K. (2019). Talent management research in Africa: Towards multilevel model and research agenda. *African Journal of Economic and Management Studies*, *10*(4), 440-457. https://doi.org/10.1108/AJEMS-12-2018-0371

Balci, G., Caliskan, A., & Yuen, K. F. (2019). Relational bonding strategies, customer satisfaction, and loyalty in the container shipping market. *International Journal of Physical Distribution and Logistics*, *49*(8), 816-838. https://doi.org/10.1108/IJPDLM-02-2019-0051

Balci, G., Cetin, I. B., & Tanyeri, M. (2018). Differentiation of container shipping services in Turkey. *Transport Policy*, *61*(1), 26-35. https://doi.org/10.1016/j.tranpol.2017.10.004

Bitiktas, F, & Tuna, O. (2020). Social media usage in container shipping companies: analysis of Facebook messages. *Research in Transportation Business and Management*, 34(1), 100454. https://doi.org/10.1016/j.rtbm.2020.100454

Bloor, M., & Wood, F. (2006) *Keywords in Qualitative Methods: A Vocabulary of Research Concepts*. Sage.

Bratton, J., & Watson, S. (2018). Talent management, emotional labour and the role of line managers in the Scottish hospitality industry. *Worldwide Hospitality and Tourism Themes*, 10(1), 57-68. https://doi.org/10.1108/WHATT-10-2017-0063

Caesar, L. D., Cahoon, S., & Fei, J. (2015). Exploring the range of retention issues for seafarers in global shipping: Opportunities for further research. *WWMU Journal of Maritime Affairs*, *14*(1), 141-157. https://doi.org/10.1007/s13437-015-0078-0

Cappelli, P., & Keller, J. R. (2014). Talent management: conceptual approaches and practical challenges. *Annual Review of Organizational Psychology and Organizational Behaviour*, *1*(1), 305-331. https://doi.org/10.1146/annurev-orgpsych-031413-091314

Chala, F. M., & Bouranta, N. (2021), Soft skills enhance employee contextual performance: The case of the maritime industry. *KnE Social Sciences/Economies of the Balkan and Eastern European Countries Volume 2021*, *5*(9), 126-138. https://doi.org/10.18502/kss.v5i9.9890

Chen, C, & Chen, Y. (2022). Influence of intellectual capital and integration on operational performance: Big data analytical capability perspectives. *Chinese Management Studies*, *16*(3), 551-570. https://doi.org/10.1108/CMS-02-2021-0037

Cho, H. -J., & Ahn, J. -Y. (2018). The dark side of wars for talent and layoffs: Evidence from Korean firms. *Sustainability*, *10*(5), 1365. https://doi.org/10.3390/su10051365

Cooke, F. L., Saini, D. S., & Wang, J. (2014). Talent management in China and India: a comparison of management perceptions and human resource practices. *Journal of World Business*, *49*(1), 225-235. https://doi.org/10.1016/j.jwb.2013.11.006

Corbin, J., & Strauss, A. (1990). Grounded theory research: procedures, canons, and evaluative criteria. *Qualitative Sociology*, *13*(1), 3-21. https://doi.org/10.1007/BF00988593

Dragomir, C. M. (2019). Gender in postmodernism maritime transport. *Postmodern Openings*, *10*(1), 182-192. https://doi.org/10.18662/po/61

Gallardo-Gallardo, E., & Thunnissen, M. (2016). Standing on the shoulders of giants? a critical review of empirical talent management research. *Employee Relations*, *38*(1), 31-56. https://doi.org/10.1108/ER-10-2015-0194

Gardiner, R., Fox-Kirk, W., & Javaid, S. (2023). Exploring the authenticity, or lack thereof, of the discourse of talent management. *European Journal of Training and Development*, *47*(3/4), 421-434. https://doi.org/10.1108/EJTD-12-2021-0203

Gissi, E., Portman, M. E., & Hornidge, A. -K. (2018). Un-gendering the ocean: Why women matter in ocean governance for sustainability. *Marine Policy*, *94*(1), 215–219. https://doi.org/10.1016/j.marpol.2018.05.020

Haralambides, H. E. (2019). Gigantism in container shipping, ports and global logistics: A time-lapse into the future. *Maritime Economics and Logistics*, *21*(1), 1–60. https://doi.org/10.1057/s41278-018-00116-0

Hsieh, H. P., Kuo, K., Le, M., Lu, W. W. (2021). Exploring the cargo and eco-efficiencies of international container shipping companies: A Network-based ranking approach. *Managerial and Decision Economics*, *42*(1), 45-60. https://doi.org/10.1002/mde.3212

Jooss, S., Burbach, R., & Ruël, H. (2021). Examining talent pools as a core talent management practice in multinational corporations. *The International Journal of Human Resource Management*, *32*(11), 2321-2352. https://doi.org/10.1080/09585192.2019.1579748

Kajwang, B. (2022). Global challenges and their role in talent management crisis facing insurance industry. *International Journal of Business Strategies*, 7(1), 1-10. https://doi.org/10.47672/ijbs.921

Kaur, A., Singh, G., Kukreja, V., Sharma, S., Singh, S., & Yoon, B. (2022). Adaptation of IOT with blockchain in food supply chain management: An analysis-based review in development, benefits and potential applications. *Sensors*, *22*(21), 8174. https://doi.org/10.3390/s22218174

Kim, J. H., & Jang, S. N. (2018). Seafarers' quality of life: Organizational culture, self-efficacy, and perceived fatigue. *International Journal of Environmental Research and Public Health*, *15*(10), 2150. https://doi.org/10.3390/ijerph15102150

Kravariti, F., Oruh, E. S., Dibia, C., Tasoulis, K., Scullion, H., & Mamman, A. (2021). Weathering the storm: Talent management in internationally oriented Greek small and medium-sized enterprises. *Journal of Organizational Effectiveness: People and Performance*, *8*(4), 444-463. https://doi.org/10.1108/JOEPP-01-2021-0022

Kuckartz, U., & Rädiker, S. (2019) *Analysing Qualitative Data with MAXQDA: Text, Audio, and Video*. Springer.

Kumar, A. P. S. (2019). Aligning talent acquisition practices to strategic business objectives. *NHRD Network Journal*, *312*(3), 261-269. https://doi.org/10.1177/2631454119888092

Kuo, K., Lu, W., Kweh, Q. L., & Le, M. (2020). Determinants of cargo and eco-efficiencies of global container shipping companies. *The International Journal of Logistics Management*, *31*(4), 753-775. https://doi.org/10.1108/IJLM-01-2020-0016

Lavissière, M. C., & Lavissière, A. (2022). Retaining talent in the maritime sector by creating a work-family balance logic: implications from women managers navigating work and family. *International Journal of Physical Distribution and Logistics Management*, *53*(1), 133-155. https://doi.org/10.1108/ijpdlm-09-2021-0409

Lin, H., Lee, H., & Wang, D. (2009). Evaluation of factors influencing knowledge sharing based on a fuzzy AHP approach. *Journal of Information Science*, *35*(1), 25-44. https://doi.org/10.1177/0165551508091310

Lu, W., Xiaolang, L., Liu, S., Wu, H., Qin, C., & Ma, B. (2022). On the link between job insecurity and CWB: Moderated mediation by employment status and turnover intention. *Chinese Management Studies*, *17*(3), 683-700. https://doi.org/10.1108/CMS-05-2020-0215

Lun, V. Y. H., Lai, K. H., Wong, C. W. Y., Ng, C. T. D., & Cheng, T. C. E. (2011). Research in shipping and transport logistics. *International Journal of Shipping and Transport Logistics*, *3*(1), 1-5.

Makram, H., Sparrow, P., & Greasley, K. (2017). How do strategic actors think about the value of talent management? Moving from talent practice to the practice of talent. *Journal of Organizational Effectiveness People and Performance*, *4*(4), 259-378. https://doi.org/10.1108/JOEPP-06-2017-0051

McCracken, M., Currie, D., & Harrison, J. (2015). Understanding graduate recruitment, development and retention for the enhancement of talent management: Sharpening 'the edge' of graduate talent. *The International Journal of Human Resource Management*, *27*(22), 2727-2752. https://doi.org/10.1080/09585192.2015.1102159

McHugh, M. L. (2012). Interrater reliability: The kappa statistic. *Biochemia Medica*, *22*(3), 276-282.

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2015). Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. *Administration and Policy in Mental Health and Mental Health Services Research*, *42*(5), 533-544. https://doi.org/10.1007%2Fs10488-013-0528-y

Pantouvakis, A., & Karakasnaki, M. (2018). The human talent and its role in ISM Code effectiveness and competitiveness in the shipping industry. *Maritime Policy and Management*, *45*(5), 649-664. https://doi.org/10.1080/03088839.2018.1454989

Perreault, W.D., Jr & Leigh, L. E. (1989). Reliability of nominal data based on qualitative judgments. *Journal of Marketing Research*, *26*(2), 135-148.

Progoulaki, M., & Theotokas, I. (2016). Managing culturally diverse maritime human resources as a shipping company's core competency. *Maritime Policy and Management*, *43*(7), 860-873. https://doi.org/10.1080/03088839.2016.1173734

Sağlam, B. B., & Karataş Çetin, Ç. (2022). Scrutinizing the manifestation of relational norms: A study of terminal operating company-liner shipping agency relations. *Transactions on Maritime Science*, *11*(02), 1-19. https://doi.org/10.7225/toms.v11.n02.002

Savin-Baden, M., & Howell Major, C. (2013) *Qualitative Research: The Essential Guide to Theory and Practice*. Routledge.

Sığrı, Ü. (2018) *Nitel Araştırma Yöntemleri*. Beta.

Stopford, M. (2009) *Maritime Economics*, 3rd ed. Routledge.

Tafti, M. M., Mahmoudsalehi, M., & Amiri, M (2017). Critical success factors, challenges and obstacles in talent management. *Industrial and Commercial Training*, *49*(1), 15-21. https://doi.org/10.1108/ICT-05-2016-0036

Tatoglu, E., Glaister, A. J., & Demirbag, M. (2016). Talent management motives and practices in an emerging market: A comparison between MNEs and local firms. *Journal of World Business*, *51*(1), 278–293. https://doi.org/10.1016/j.jwb.2015.11.001

Thai, V. V., Balasubramanyam, L., Yeoh, K., & Norsofiana, S. (2013). Revisiting the seafarer shortage problem: The case of Singapore. *Maritime Policy and Management*, *40*(1), 80-94. https://doi.org/10.1080/03088839.2012.744480

Wallendorf, M., & Belk, R. W. (1989). Assessing trustworthiness in naturalistic consumer research. In Hirschman, E. C. (Ed.), *Interpretive Consumer Research, Association for Consumer Research* (pp. 69-84). Association for Consumer Research.

Wan, C., Yan, X., Zhang, D., & Yang, Z. (2019). Analysis of risk factors influencing the safety of maritime container supply chains. *International Journal of Shipping and Transport Logistics*, *11*(6), 476-507.

Wang, L., Zhang, N., Ye, F., Lau, Y. P., & Ducruet, C. (2020). The complex network analysis of liner shipping networks: Lessons from the merger between COSCO and CSCL. *Growth and Change: A Journal of Urban and Regional Policy*, *51*(4), 1877-1893. https://doi.org/10.1111/grow.12428

Wiblen, S., & McDonnell, A. (2019). Connecting 'talent' meanings and multi-level context: A discursive approach. *The International Journal of Human Resource Management*, *31*(4), 474-510. https://doi.org/10.1080/09585192.2019.1629988

Yildiz, R. Ö., & Esmer, S. (2021). Talent management related concepts and debates in container shipping industry by an emerging market perspective. *Journal of Shipping and Trade*. *6*, 6. https://doi.org/10.1186/s41072-021-00090-6

Yildiz, R. O., & Esmer, S. (2023). Talent management strategies and functions: A systematic review. *Industrial and Commercial Training*, *55*(1), 93-111. https://doi.org/10.1108/ICT-01-2022-0007

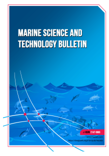
Yildiz, R. O., Bastug, S., & Esmer, S. (2023). Talent management functions: A qualitative research on container shipping industry. *International Journal of Shipping and Transport Logistics*, *16*(3/4), 320-359. https://doi.org/10.1504/IJSTL.2023.129875

Yuen, K. F., Wang, X., Wong, Y. D., & Zhou, Q. (2017). Antecedents and outcomes of sustainable shipping practices: The integration of stakeholder and behavioral theories. *Transportation Research Part E: Logistics and Transportation Review*, *108*(1), 18-35. https://doi.org/10.1016/j.tre.2017.10.002

Zhou, Y. S., Soh, Y. H., Loh, H. S., & Yuen, K. F. (2020). The key challenges and critical success factors of blockchain implementation: Policy implications for Singapore's maritime industry. *Marine Policy*, *122*(1), 104265. https://doi.org/10.1016/j.marpol.2020.104265

Mar. Sci. Tech. Bull. (2023) 12(3): 352-369
e–ISSN: 2147–9666
info@masteb.com

dergipark.org.tr/en/pub/masteb
www.masteb.com
DOI: 10.33714/masteb.1337231



Marine Science and Technology Bulletin

PRENSIP
https://prensip.gen.tr/

RESEARCH ARTICLE

Bioinformatics studies and examining the tissue distribution of glutathione reductase and glucose-6-phosphate dehydrogenase genes to investigate gender differences in differences in stress tolerance in zebrafish (*Danio rerio*)

Burcu Naz Uzun[1] • Mehtap Bayır[1*]

[1] *Atatürk University, Faculty of Agriculture, Department of Agricultural Biotechnology, 25240. Erzurum, Türkiye*

ARTICLE INFO

Article History:
Received: 03.08.2023
Received in revised form: 17.08.2023
Accepted: 17.08.2023
Available online: 28.09.2023

Keywords:
Zebrafish
In silico analysis
gsr
g6pd
Gene expression

ABSTRACT

The study aimed to investigate the bioinformatics of zebrafish glutathione reductase (*gsr*) and glucose-6-phosphate dehydrogenase (*g6pd*) genes, as well as their tissue-specific distribution. To achieve this, samples of various tissues were taken from female and male zebrafish and total RNA was extracted to obtain cDNA. qPCR was performed to determine the transcripts of *gsr* and *g6pd* genes. The structure of the genes, conserved gene maps, and phylogenetic tree were also designed. The results showed that the liver was the most dominant tissue for both *gsr* and *g6pd* genes in both female and male zebrafish. The expression of *gsr* gene was significantly higher in male zebrafish's liver, intestine, heart, eye, gills, and gonad tissues compared to female fish, while *g6pd* gene transcription was found to be significantly higher in the male liver, intestine, muscle, brain, eye, gill, kidney, stomach, and gonad tissues. Overall, this study provides valuable insights into the bioinformatics of *gsr* and *g6pd* genes in zebrafish and their tissue-specific distribution, which could help in understanding their roles in various physiological and pathological processes in zebrafish and other related species.

Please cite this paper as follows:

Uzun, B. N., & Bayır, M. (2023). Bioinformatics studies and examining the tissue distribution of glutathione reductase and glucose-6-phosphate dehydrogenase genes to investigate gender differences in differences in stress tolerance in zebrafish (*Danio rerio*). *Marine Science and Technology Bulletin*, *12*(3), 352-369. https://doi.org/10.33714/masteb.1337231

* Corresponding author
E-mail address: mehtap.bayir@atauni.edu.tr (M. Bayır)

Introduction

Bioinformatics studies deal with topics such as protein structures and functions, enzyme activities and pathways, and are used to analyze genomic data (Kumar et al., 2008). Genetic data, protein structures and functions, enzyme activities and pathways related to glutathione reductase (*gsr*) and glucose-6-phosphate dehydrogenase (*g6pd*) enzyme genes can be investigated with bioinformatics analysis. The *gsr* and *g6pd* are important enzymes involved in maintaining cellular redox balance and energy metabolism, respectively (Li et al., 2020). Dysregulation of these enzymes can lead to various pathological conditions, including cancer, neurodegenerative diseases, and diabetes (Traverso et al., 2013). In fish, both *gsr* and *g6pd* have been studied extensively. For example, a study on *gsr* gene in rainbow trout showed that its expression was induced by oxidative stress caused by exposure to pollutants (García-Meilán et al., 2022). Another study on zebrafish found that *gsr* gene expression was higher in liver tissues of fish exposed to high levels of heavy metals (Xu et al., 2020). As for *g6pd* gene, a study on Nile tilapia (*Oreochromis niloticus*) showed that its expression was significantly higher in liver and muscle tissues of fish exposed to hypoxia (Osman, 2012). Since mitochondria are the primary source of reactive oxygen species (ROS) production in cells, the first release of ROS after exposure to stress in organisms can lead to longer and more extensive ROS release, which can cause long-term negative effects in the organism (Zorov et al., 2014). Therefore, mitochondrial function appears to be a key mechanism that emphasizes phenotypic variation between sexes, and mitonuclear interactions may be critical determinants of the life histories of organisms (Wolff et al., 2014). Consequently, organisms have developed a series of antioxidant defense systems that play a critical role in maintaining cellular function and eliminating the toxic effects of ROS in the face of a threat caused by oxidative stress (Dowling & Simmons, 2009; Hill, 2014; Espinosa-Diez et al., 2015).

Zebrafish (*Danio rerio*) has emerged as an important model organism in biomedical research due to its ease of maintenance, rapid development, and similarity to humans in terms of genetic and physiological characteristics (Kari et al., 2007). Zebrafish has become a popular model organism due to its numerous advantages, such as transparent embryos, rapid development, and genetic similarities with humans (Veldman & Lin, 2008). In recent years, there have been the studies on the bioinformatics and tissue-specific expression of genes in zebrafish (Parmar et al., 2012). These studies have provided valuable insights into the roles of these genes in zebrafish and their potential involvement in various physiological and pathological processes.

The stress responses of vertebrates involve different interactions between physiological pathways that can be characterized in both acute and chronic conditions (Bayır et al., 2020). Genetic similarities among species that are found in all organisms mean that studies conducted on one organism can serve as a source of data for other species (Collins et al., 1998; Bayır & Arslan, 2021). Therefore, completing the bioinformatics studies of the *gsr* and *g6pd* genes in the zebrafish, a model aquatic organism, will provide pioneering data for molecular studies in other species. The current study employed molecular biology techniques, such as qPCR and RT-qPCR, to determine the transcripts and transcript amounts of *gsr* and *g6pd* genes in various tissues of male and female zebrafish. This study aims to investigate the differences in expression levels of antioxidant enzyme genes between male and female zebrafish, the differences in stress tolerance of fish in males and females, and the causes of these differences. The study also included *in silico* analyses, such as conserved gene maps and phylogenetic tree construction, to determine the evolutionary relationship and similarity of these genes with other related fish species. The findings of this study could have significant implications in understanding the molecular mechanisms underlying various physiological processes in zebrafish and other related species.

Material and Method

Fish Sampling and Experimental Designs

A total of 6 zebrafish (*Danio rerio*), weighting approximately 2.49±0.1 g were obtained from the Trout Production and Research Center of Atatürk University and transferred to the Laboratory of Agricultural Biotechnology. Three females and three males were used to determine the distribution of tissue-specific gene expression. Fish were anaesthetized with clove oil before dissection. Atatürk University Local Ethical Committee for Animal Studies Experimental protocols were followed. The liver, gill, testis, ovary, intestine, kidney, stomach, eye, heart, muscle, spleen, and brain tissues from fish which were kept at 28°C taken for determine the mRNA expression. To ensure the integrity of RNA in the samples, strict measures were taken to avoid RNA degradation. Prior to the dissection, all instruments and the working bench were thoroughly sterilized and cleaned using a cleaning agent designed to remove RNases, which are enzymes that can degrade RNA. After the dissection, the samples were immediately transferred into nuclease-free tubes containing RNAlater, a solution that stabilizes RNA and prevents degradation. The tubes were kept at 4°C overnight to allow the RNAlater to penetrate the tissues and stabilize the RNA. The samples were then stored at -80°C until RNA isolation, to further prevent RNA degradation. These measures ensure the quality of the RNA extracted from the samples, which is crucial for downstream applications such as qPCR and RT-qPCR.

RNA Isolation and cDNA Synthesis and Real-Time PCR (qPCR) Analysis

Tissue samples were firstly removed from the RNAlater and transferred to nuclease-free tubes containing 1 ml of trizol reagent (Life Technologies) and homogenized. Trizol protocol was applied for RNA isolation. RNA concentrations were measured by Nanodrop 8000 spectrophotometer and quality of total RNA determined by agarose gel-electrophoresis. Before the cDNA synthesis all the RNAs were treated with DNase (DNase I, Amplification Grade, Life Technologies) for to avoid genomic contamination and the High-Capacity cDNA Reverse Transcription Kit (Life Technologies) was used for the cDNA synthesis.

Quantitative PCR A Rotor-Gene 6000 thermal cycler system (Qiagen GmbH, Düsseldorf, Germany) and QuantiTect SYBR Green PCR kit (Qiagen) were used for determination of tissue-specific distribution ((copy number/µL) of zebrafish target (*gsr* and *g6pd)* and reference (*rpl7* and *eef1a1)* genes. 20µl (10 µL SYBR Green, 4 µL forward and reverse primer, 5 µL nuclease free water and 1 µL cDNA) for each tissue and a negatif control which includes nuclease free water instead of cDNA were used for each Quantitative PCR reaction. RT-qPCR steps were 1) initial denaturation (95.0°C for 15 min), 2) 40 cycles-denaturation (95.0°C for 20 s), 3) primer annealing [optimum temperature for each primer (Table 1) for 30 s] and elongation (72.0°C for 30 s). mRNA transcript level of *gsr* and *g6pd* genes in zebrafish tissues were normalized to *rpl7* and *eef1a1* for evaluate tissue-specific distribution after the qPCR reaction. The level of the gene expression was given consistent to the mean value of the control groups (Torstensen et al., 2009).

Primer Optimization

The forward and reverse primers were designed using NCBI Primer-BLAST for real time qPCR amplification of zebrafish target (*gsr* and *g6pd*) and reference genes (*eef1α1*and *rpl7*) (Table 1). Exon-exon junction model was used for primers designing for avoid PCR amplification of a product from any contaminating hnRNA or genomic DNA. Ordered lyophilized primers diluted in TE buffer (10mM Tris, 1mM EDTA and pH 8.0) in such a way that the stock concentration for each primer was100 pmol/µl.

Identification and Structural Determination of Zebrafish gsr and g6pd Genes

The Ensembl database was used for bioinformatic identification of glutathione reductase *gsr* and *g6pd* genes. To confirm the accuracy of the obtained cDNA from this database, a BLAST search was performed in the NCBI database (https://www.ncbi.nlm.nih.gov/). It was found that both *gsr* and *g6pd* genes, which were the target genes used in this study, have a single isoform each. The Ensembl gene IDs, NCBI accession numbers, amino acid numbers, and chromosomal locations of these genes and their respective regions on the chromosome are provided in the Table 2.

The BLOSUM62 matrix algorithm (Gromiha, 2010) was used to determine the similarity and identity rates of zebrafish *gsr* and *g6pd* genes with those of other teleost fish and vertebrates. Similarity-identity rates were calculated using the protein sequences synthesized by *gsr* and *g6pd* genes of medaka (*Oryzias latipes*), stickleback (*Gasterosteus aculeatus*), goldfish (*Carassius auratus*), fugu (*Fugu rubripes*), platyfish (*Xiphophorus maculatus*), and vertebrates such as human (*Homo sapiens*) and mouse (*Mus musculus*) through the BioEdit program (Table 3).

Table 1. Primer sequences of *gsr*, *g6pd, eef1a1* ve *rpl7* genes in zebrafish

Zebrafish	**Forward Primer (5′ → 3′)**	**Reverse Primer (5′ → 3′)**	**Tm (°C)**
gsr	CCTGCGTCAATGTTGGATGT	CAACTGTGGGTTCAGGGTCA	62
g6pd	ATGACAAGATGAGCCTTCCG	GAGCGAGCAAAACCCACAAA	61.5
eef1α1	TGCAGAGATGGGAAAAGGCT	ACACCAGCCGCTACAATCAA	61
rpl7	ATGAGCAGGATGGCTCGTAA	GTAGCCCCAGGCAATGTAGG	62

Table 2. The Ensembl gene IDs, NCBI accession numbers, amino acid numbers, and chromosomal locations of *gsr* and *g6pd* genes in zebrafish

Gen	Ensembl gen ID	NCBI ID	Amino Acid Numbers	Chromosome Regions
Zebrafish *gsr*	ENSDART00000047050.8	NM_001020554.1	425	Chromosome 14: 38,852,969
Zebrafish *g6pd*	ENSDARG00000071065	LR812085.1	523	Chromosome 23: 13,844,920

Table 3. The nucleotide sequences of zebrafish *gsr* and *g6pd* genes

ENSDART00000047050.8 (*gsr*)

```
5’aaaatctgcggaattctgcgtgcgcaggtcccttgttggcctaattatgaggcatatt
ttaaaacgtatttcaatatttttaagtgtttttagtgcaatttattgtttactccctat
aaatatacatttgtacatatttatcatcatttttaaacttgctaacctttatcagccct
gaatatggccattttagtcatcaaaaaaaaaataatTATAttccctcctgtgccgctgct
gactccgcgcatgcgcagtccagctcagctccacacggttccgttccgaaacattccgtt
+1
ATAAACAAAACCGAAGATGGGCACCATAGCTAACCCTAAAGAGCTCATATCGTAACACCT
CTAAATAATGATACTCCATTTACTTCAAGGATGTTAATAATATAAGTTACAGCAAACGGC
TTTCGGCTACAGGTTTAAGCTGCACTCCACCGgtaag’N356’ctcagTCTCGGACGCTC
GCTGTCATCTTCCTGCAAACTCCTTGGTCGCAGCATGGCTTCTGGATCCGTCTCGCGCTT
TGATTTTCTGGTGGTCATGGCTTCTGGATCCGTCTCGCGCTTTGATTTTCTGGTGGTCGG
                -M--A--S--G--S--V--S--R--F--D--F--L--V--V--G
CGGAGGATCCGGTGGGCTGGCCGGTGCGAGGAGAGCGGCTGAACTCGGTGCCACCACTGC
--G--G--S--G--G--L--A--G--A--R--R--A--A--E--L--G--A--T--T--A
CGTGATCGAAAGTCACAGACTCGGAGGTACgtgag’N1680’ctcagCTGCGTCAATGTT
--V--I--E--S--H--R--L--G--G--T                 --C--V--N--V-
GGATGTGTTCCTAAAAAGgtaat’N878’tccagGTTATGTGGAACACATCCACTCATGC
-G--C--V--P--K--K-                -V--M--W--N--T--S--T--H--A
AGAGTATCTCCATGATCATGAAGACTATGGATTTGAGGGAGCAAAAGCACATTTCAGCTG
--E--Y--L--H--D--H--E--D--Y--G--F--E--G--A--K--A--H--F--S--W
GCAgtaag’N1207’ttcagAATCATAAAACACAAAAGGGATGCTTACGTGAGTCGCCTG
--Q                 --I--I--K--H--K--R--D--A--Y--V--S--R--L-
AATCAGATTTACAGGAGCAACCTTGAAAAGgtaag’N2151’cacagGGCAAAATTGAGT
-N--Q--I--Y--R--S--N--L--E--K-                 -G--K--I--E--
TTATTCATGGCTATGCAAGGTTCACAGATGACCCTGAACCCACAGTTGAAGTCAATGGGA
F--I--H--G--Y--A--R--F--T--D--D--P--E--P--T--V--E--V--N--G--
AGAAATACACAGCAACCCATATCTTAATCTCCACTGGCGGCCATCCATCCACAGTCAGTG
K--K--Y--T--A--T--H--I--L--I--S--T--G--G--H--P--S--T--V--S--
AGGATGATGTGCCAGgtggg’N124’ttcagGATCCAGTTTAGGCATCACCAGTGATGGG
E--D--D--V--P--                G--S--S--L--G--I--T--S--D--G-
TTCTTTGAACTTGAGTCTTGCCCTAAgtaag’N62’cctagACGTAGTGTTATAGTTGGA
-F--F--E--L--E--S--C--P--K               --R--S--V--I--V--G-
GCAGGCTATATTGCTGTGGAAATGGCTGGTATTCTTTCCACTCTTGGGTCTAAAACGTCC
-A--G--Y--I--A--V--E--M--A--G--I--L--S--T--L--G--S--K--T--S-
ATCATCATACGACAAGGAGGGgtaag’N77’ccaagGTGCTGAGGAACTTCGATGCCTTG
-I--I--I--R--Q--G--G-               -V--L--R--N--F--D--A--L-
ATAAGCTCCAATTGCACCAAAGAATTGCAAAATAATGGTATTGACTTACGGAAAAATACT
-I--S--S--N--C--T--K--E--L--Q--N--N--G--I--D--L--R--K--N--T-
CAGgtaat’N2879’cacagGTGAAGTCAGTGAAGAAGAATGGCAAAGGCCTCTCTATAA
-Q-                 -V--K--S--V--K--K--N--G--K--G--L--S--I--
CACTGGTTACAAAAGACCCTGATGACAAGGATTCACAGGAGAAGTTTGACACTATTAATG
T--L--V--T--K--D--P--D--D--K--D--S--Q--E--K--F--D--T--I--N--
ATGTAGACTGTCTGCTGTGGGCCATTGGCAGAGAACCCAACACCGCCGGCCTCAACCTCA
D--V--D--C--L--L--W--A--I--G--R--E--P--N--T--A--G--L--N--L--
GTCAAATAgtagg’N1766’ttcagGGTGTGAAACTTGATGAACGGGGTCATATCGTGGT
```

Table 3 (continued)

```
S--Q--I-                   -G--V--K--L--D--E--R--G--H--I--V--V
GGATGAGTTCCAGAACACCTCTCGTCCAGGCGTCTATGCAGTCGGGGATGTTTGCGGACG
--D--E--F--Q--N--T--S--R--P--G--V--Y--A--V--G--D--V--C--G--R
AGCCCTTCTGACACCTGgtacg’N6775’tgtagATGAAGCAGTTAAGACGTATGGAAAA
--A--L--L--T--P--                    D--E--A--V--K--T--Y--G--K-
GACAAGGTGAAGGTTTACACCACTTCTTTCACCCCCATGTATTACGCCATTACCACTCGA
-D--K--V--K--V--Y--T--T--S--F--T--P--M--Y--Y--A--I--T--T--R-
AAGAGTCAGTGCATCATGAAGTTGGTGTGCGCTGGTGAAAATGAAAAGgtgag’N96’at
-K--S--Q--C--I--M--K--L--V--C--A--G--E--N--E--K-
tagGTGGTCGGTCTCCACATGCAGGGTTTTGGCTGTGATGAGATGCTTCAGGGTTTTGCC
   -V--V--G--L--H--M--Q--G--F--G--C--D--E--M--L--Q--G--F--A-
GTAGCCGTTAACATGGGGGCGACTAAAGCAGACTTTGACAGAACCATTGCCATCCACCCA
-V--A--V--N--M--G--A--T--K--A--D--F--D--R--T--I--A--I--H--P-
ACGTCCTCAGAGGAGCTAGTAACACTGCGCTAAtcagtgccttttcattacatctccact
-T--S--S--E--E--L--V--T--L--R--*-
gcaatccaaagagtgtaaatgtaaacaaatgtaattccctggactattgttccatctaca
gaactaacagtgtaacaccacaagcatatgtttgatattggttgtgtagaagttgcacac
agtacaaccatttatcaggctgcgtctcttgtacagtacctcagatttttcacaggtatt
attgtctgcttggaacggagtcaggtaaaggcttgattatgttatagggtaAAATTAAAt
ctgtttaaagtcaaacactgttgcttttctcttatatttccagaatattatattcag 3’
```

ENSDART00000138696.2 (*g6pd*)

```
5'atatgtatacaaatacatctacataaaaataagcgccgtgttttaatgtgatccagtt
atgttgaaattttacaactgtgtttctgtgactgttggtgttggttgttatatagtttaa
aagcctgacaaataaagtaactaggctaatttctgattaaattaaataaaacattagcca
atatttagggcgtttttttgcgggttttggacagcttttgggctggaaaccgtcagcTATA
tctggcgaccctgacatttacacacaaataaataaatggactaaatgatggcctaaaaat
+1
GTGCTACTTTCTGCGTGCACAGATTCCGTGTGGGCCCAGTCACCAATGTTTGACTACTTT
TGACTACAAAAGgtaaa’N3037’tctagCGTCGTCGCGTCGCTGACGTCAGTTTACTCC
AGCCTTCTGAAATGATGGGCAGTCGAGCGAGCGCTGgtgag’N2140’ggcagACAAGAT
           -M--M--G--S--R--A--S--A--                 D--K--M
GAGCCTTCCGCTCTCACGTTCAGAAGTGTTTGGGCAGTTGAGGAAAGAACTGCATGATGA
--S--L--P--L--S--R--S--E--V--F--G--Q--L--R--K--E--L--H--D--D
TACCGCATTTCACCAGTCAGATGTGCATATTTTCATCATCATGGGCGCTTCGgtaag’N8923’
--T--A--F--H--Q--S--D--V--H--I--F--I--I--M--G--A--S-
tgtagGGAGATCTGGCCAAAAAGAAAATCTATCCAACTTTGTGgtgag’N1932’tgtag
-G--D--L--A--K--K--K--I--Y--P--T--L--W
GTGGTTATTCAGAGATGGTCTCCTCCCTGAACAGACATATTTTGTGGGTTTTGCTCGCTC
--W--L--F--R--D--G--L--L--P--E--Q--T--Y--F--V--G--F--A--R--S
AGATCTGACTGTGGATGCCATACGCATAGCCTGCATGCCCTACATGAAGgtcac’N866'
--D--L--T--V--D--A--I--R--I--A--C--M--P--Y--M--K-
ttcagGTAGTAGACAATGAGGCAGAGCGTCTTGCTGCTTTCTTCAGCCGAAACTCTTACA
     -V--V--D--N--E--A--E--R--L--A--A--F--F--S--R--N--S--Y--
TCAGTGGGAAGTATGTGGAAGAATCCTCTTTCTCTGACCTGAACACACACCTACTGTCTC
I--S--G--K--Y--V--E--E--S--S--F--S--D--L--N--T--H--L--L--S--
TGCCTGGAGGTGCTGAGGCCAACCGGCTCTTCTACCTGGCCCTGCCACCCAGCGTCTACC
L--P--G--G--A--E--A--N--R--L--F--Y--L--A--L--P--P--S--V--Y--
ATGATGTCACCAAAAATATCAAACATCAGTGCATGAGCACCAAAgtgag’N2812’cgca
H--D--V--T--K--N--I--K--H--Q--C--M--S--T--K-
gGGCTGGAACAGGGTGATTGTGGAGAAGCCGTTTGGCCGTGATCTGCAGAGCTCAGAGGA
 -G--W--N--R--V--I--V--E--K--P--F--G--R--D--L--Q--S--S--E--E
GTTATCCAGTCATCTATCCTCTCTCTTCACTGAGGAGCAAATCTACCGTATAGACCATTA
--L--S--S--H--L--S--S--L--F--T--E--E--Q--I--Y--R--I--D--H--Y
CCTGGGCAAAGAGATGGTGCAGAACCTGATGGTCCTCAGgtgtg’N156’taaagGTTTG
--L--G--K--E--M--V--Q--N--L--M--V--L--R                  --F—
```

Table 3 (continued)

```
GAAATCGGATTTTTGGTCCCATATGGAACCGAGACAGCGTGGCGTGTGTGGTTCTGACCT
G--N--R--I--F--G--P--I--W--N--R--D--S--V--A--C--V--V--L--T--
TCAAAGAGCCGTTTGGTACCCAGGGCCGCGGAGGATATTTTGACGATTTTGGTATCATTC
F--K--E--P--F--G--T--Q--G--R--G--G--Y--F--D--D--F--G--I--I--
Ggttag’N1980’tgcagTGATGTGATGCAGAACCACCTGCTTCAGATGCTGAGTCTGGT
R                 --D--V--M--Q--N--H--L--L--Q--M--L--S--L--V
GGCGATGGAGAAGCCTGCTTCCACCAGCTCTGATGATGTGCGGGATGAGAAGgtaac’N3500’
--A--M--E--K--P--A--S--T--S--S--D--D--V--R--D--E--K-
tacagGTAAAAGTGCTGAAGTGCATTGAGCCGGTCACTCTCTCAGATGTGGTTCTGGGTC
     -V--K--V--L--K--C--I--E--P--V--T--L--S--D--V--V--L--G--
AGTATGTCGGAGATCCAGATGGAGAAGGGGAGGCAAAACTGGGGTATCTAGATGACAAAA
Q--Y--V--G--D--P--D--G--E--G--E--A--K--L--G--Y--L--D--D--K--
CGGTCCCGAAAGGCTCCACTCAGGCTACATTTGCCACAGCAGTGCTTTATGTAAAGAACG
T--V--P--K--G--S--T--Q--A--T--F--A--T--A--V--L--Y--V--K--N--
AACGCTGGGATGgtgag’N772’tctagGCGTCCCGTTTATTCTCCGGTGTGGAAAGGCT
E--R--W--D--                G--V--P--F--I--L--R--C--G--K--A-
CTGAATGAGAGGAAAGCGGAGGTGCGTCTGCAGTTCACTGATGTTCCTGGAGACATCTTT
-L--N--E--R--K--A--E--V--R--L--Q--F--T--D--V--P--G--D--I--F-
AGCTCTCAGTGCCGGAGAAATGAGCTGGTGGTCCGTGTGCAGCCCAATGAGGCCATTTAC
-S--S--Q--C--R--R--N--E--L--V--V--R--V--Q--P--N--E--A--I--Y-
GCCAAGATGATGAGCAAGAAACCTGGAGTCTATTTTAGCCCTGAGGAGACCGAGCTGGAC
-A--K--M--M--S--K--K--P--G--V--Y--F--S--P--E--E--T--E--L--D-
CTGACCTACCATAGCAGATACAGGgtaaa’N1667’tacagGATGTAAAGCTGCCTGATG
-L--T--Y--H--S--R--Y--R-                 -D--V--K--L--P--D—
CTTATGAACGTCTGATTTTGGACGTCTTTTGTGGCAGTCAGATGCATTTTGTACGCAGgt
A--Y--E--R--L--I--L--D--V--F--C--G--S--Q--M--H--F--V--R--S
aag’N909’cacagTGATGAGTTGAGGGAAGCCTGGAGGATCTTCACTCCTCTCCTTCAT
              --D--E--L--R--E--A--W--R--I--F--T--P--L--L--H-
CAGATAGAGTCTGAGAAAACACCACCCATCAAATACAAATACGGGAGgtaat’N75’taa
-Q--I--E--S--E--K--T--P--P--I--K--Y--K--Y--G--S
agTCGTGGTCCCGCTGAGGCTGATGAGCTGGTGCAGAAAGTGGGCTTCCGCTACGAGGGA
  --R--G--P--A--E--A--D--E--L--V--Q--K--V--G--F--R--Y--E--G-
ACATACAAATGGGTGAATCCACACAAACTGTGAaagcagcagatgcggaagctgaagcct
-T--Y--K--W--V--N--P--H--K--L--*-
gtttaaaaacaaaaaatcagcagtcgagtgcctgaaacgagcactttaaacaaactaaat
attgaaaattcgttctgtttaagcactgcatttacagaaagaccaacgtgattggaaaac
ctttttttttagcatgttatgaatcataaccagctccttgtggtatatgatttagaacag
tgtttgttaaccaagttcctggaggaccaccagctctgcacattttccatgtcgttttaa
ctaaacacacctgattaagatgatcagctcattagcagagactgaaagacctgtaacggt
tgtgacagacaaaggagacatccaaaacatgcagtgttggtggtcctccggcaacgtggt
tgagaaacaatgctttAAAATAtcttattattatttcattttatattttattgtacat 3’
```

Note: * The exons of the *gsr* and *g6pd* genes of zebrafish are shown in capital letters. The starting points of transcription are indicated as +1, while the 5' upstream and 3' downstream sequences are shown in lowercase letters. The TATA boxes and polyadenylation signals are shown in capital letters and highlighted in yellow.

Phylogenetic Analysis

CLUSTALW (Thompson et al., 1994) at BioEdit software (http://www.mbio.ncsu.edu/bioedit/page2.html) used for sequence alignment of *gsr* and *g6pd* genes in zebrafish. The protein sequence of zebrafish Gsr was aligned with Gsr/GSR and protein sequences from zebrafish ENSDART00000047050.8, goldfish (*Carassius auratus*) ENSCART00000094324.1, Makobe Island cichlid (*Pundamilia nyererei*) ENSPNYT00000010747.1, platyfish (*Xiphophorus maculatus*) ENSXMAT00000016312.2, coho salmon (*Oncorhynchus kisutch*) ENSOKIT00005024463.1, golden line barbel (*Sinocyclocheilus grahami*) ENSSGRT00000113615.1, guppy (*Poecilia reticulata*) ENSPRET00000020656.1, amazon molly (*Poecilia formosa*) ENSPFOT00000030758.1, brown trout (*Salmo trutta*) ENSSTUT00000009463.1, chinook salmon (*Oncorhynchus tshawytscha*) ENSOTST00005067468.1, northern pike (*Esox lucius*) ENSELUT00000029343.2, channel bull blenny (*Cottoperca gobio*) ENSCGOT00000009735.1, Three-spined stickleback (*Gasterosteus aculeatus*) ENSGACT00000023248.1, pike perch (*Sander lucioperca*) ENSSLUT00000058070.1, *common carp* (*Cyprinus carpio*) ENSCCRT00000052099.2, spotted gar (*Lepisosteus oculatus*) ENSLOCG00000012126, human (*Homo sapiens*) ENST00000221130.11, mouse (*Mus musculus*) ENSMUST00000033992.9 and protein sequence of zebrafish G6pd was aligned with G6pd/G6PD protein sequences from zebrafish (*Danio rerio*) ENSDART00000138696.2, *common carp* (*Cyprinus carpio*) ENSCCRT00000130811.1, goldfish (*Carassius auratus*), Nile tilapia *(Oreochromis niloticus)* ENSONIT00000083037.1, Three-spined stickleback (*Gasterosteus aculeatus*) ENSGACT00000004028.1, Mexican tetra (*Astyanax mexicanus*) ENSAMXT00000018040.2, gilthead seabream (*Sparus aurata*) ENSSAUT00010033966.1, princess cichlid (*Neolamprologus brichardi*) ENSNBRT00000031013.1, electric ell (*Electrophorus electricus*) ENSEEET00000052901.1, human (*Homo sapiens*) ENST00000393562.10, mouse *(Mus musculus)* ENSMUSG00000089992. The protein sequence of human (*Homo sapiens*) catalase (ENST00000241052.5) was used as an external reference in this study (Figure 1).

In order to determine the evolutionary relationship of zebrafish and its *gsr* and *g6pd* genes with other fish species, as well as mouse and human, a pairwise alignment was conducted using the BLOSUM62 matrix to calculate sequence identity and similarity. Then, a maximum-likelihood tree was created using MEGA11 software, which was based on the Poisson correction distance model and the number of amino acid substitutions per site. The constructed tree was used to identify the evolutionary relationships of zebrafish with other fish species, mouse, and human.

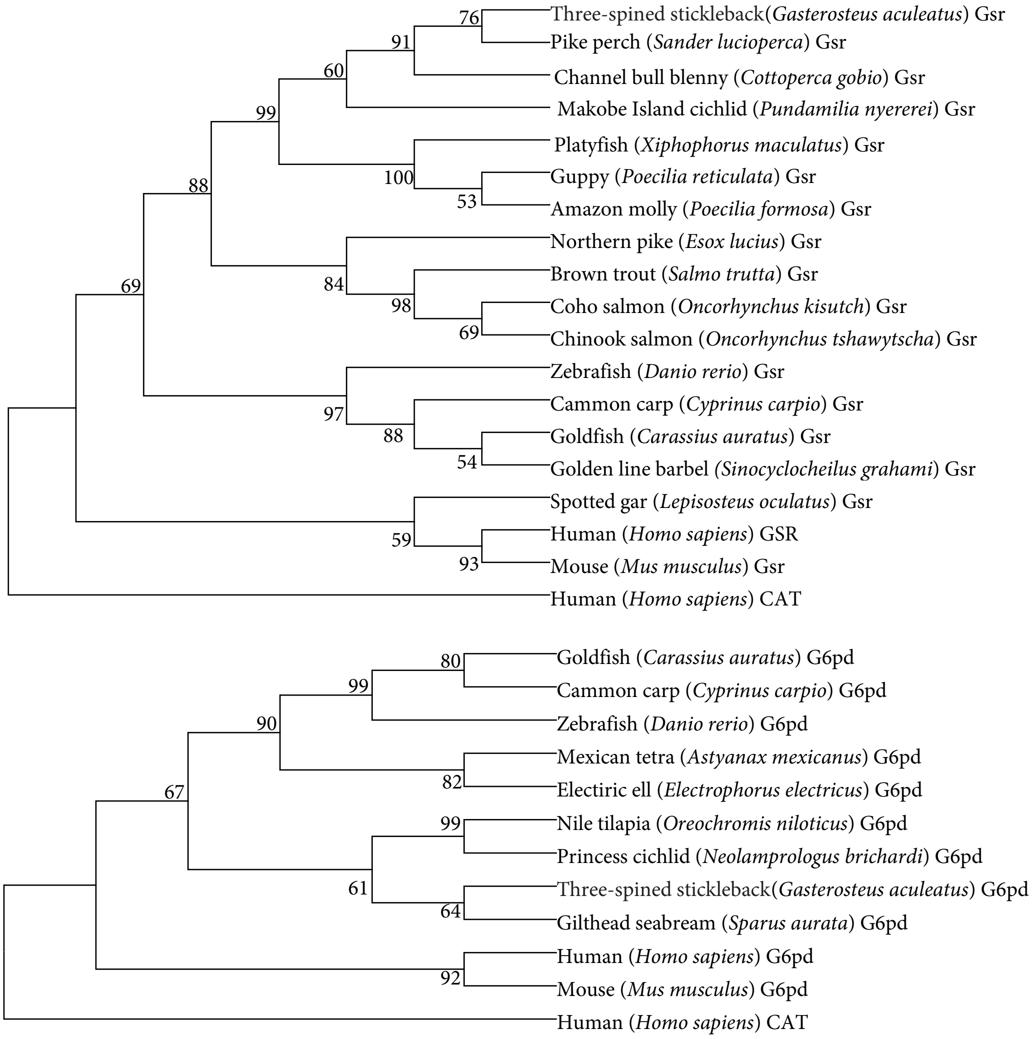


Figure 1. Phylogenetic relationship of zebrafish *gsr* and *g6pd* genes with other vertebrates

Conserved Gene Synteny

To generate a conserved gene synteny map for the zebrafish, medaka, and human *gsr/GSR* and *g6pd/G6PD* genes of, we used the Ensembl database to identify co-localized genes and manually arranged the gene synteny. We selected the relevant regions of the genomes using the region conceptus selection and identified the co-localized genes within those regions. This allowed us to create a conserved gene synteny map that showed the relationship among the *gsr/GSR* and *g6pd/G6PD* genes of zebrafish, medaka, and human (Figure 2).

Statistical Analysis

In our study, we used SPSS Statistics 17.0 software to perform a one-way analysis of variance (ANOVA) and Duncan's multiple comparison tests. We used these statistical tests to compare the levels of expression of the *gsr* and *g6pd* genes across different tissues of both zebrafish. We considered a p-value of less than 0.05 to be statistically significant, which means that there was a significant difference between the groups being compared.

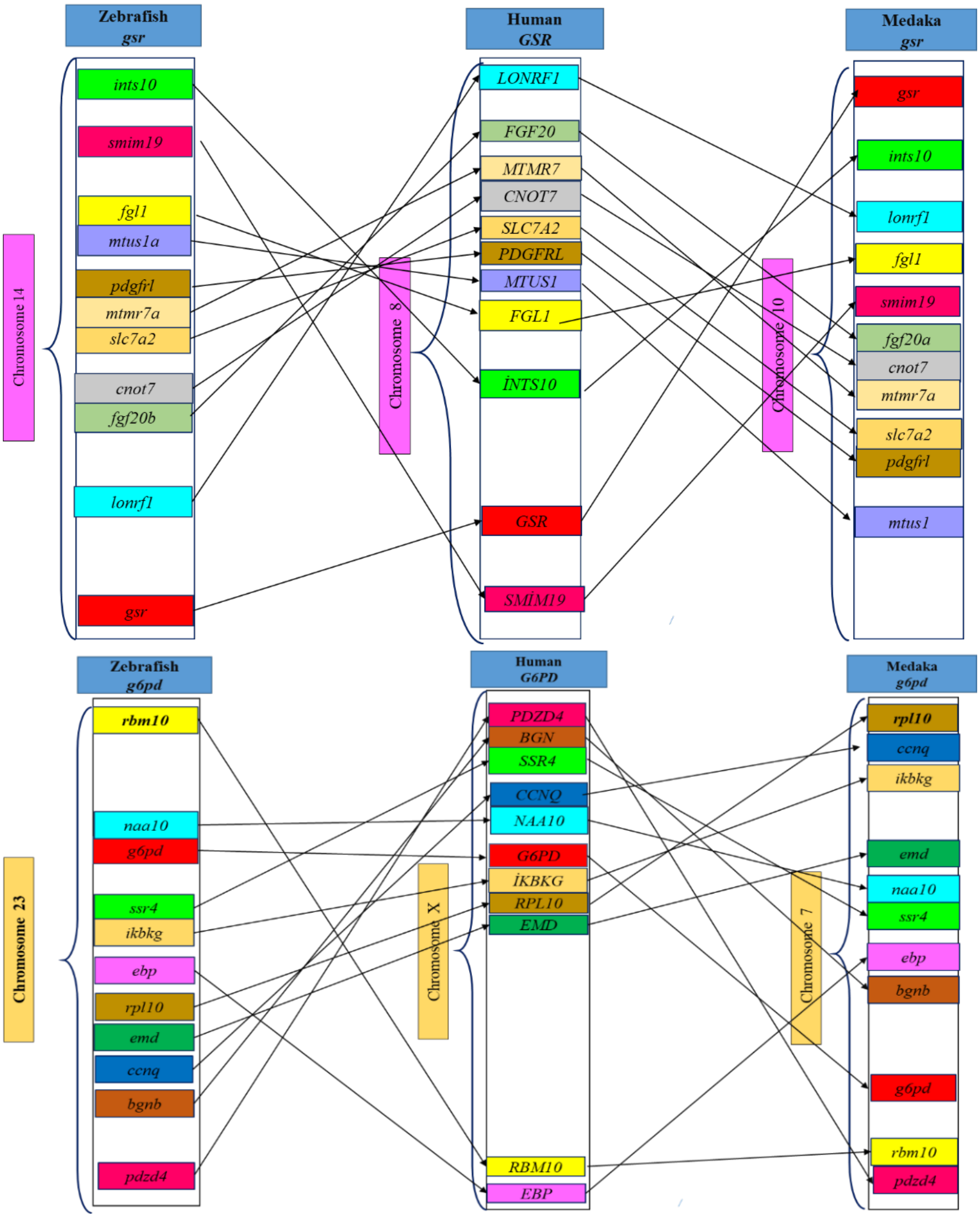


Figure 2. Identification of Conserved Genes of *gsr* and *g6pd* in zebrafish

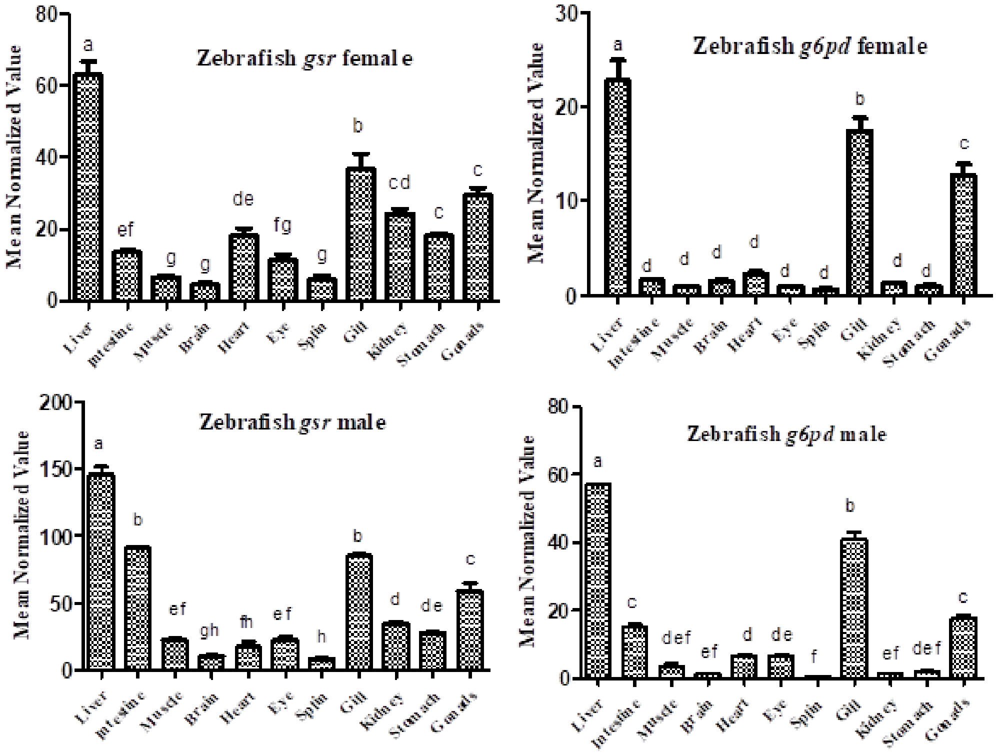


Figure 3. The tissue-specific distribution of zebrafish *gsr* and *g6pd* genes

Results

Bioinformatics Studies of gsr and g6pd Genes in Zebrafish

The characterization and identification of the *gsr* and *g6pd* enzyme genes in zebrafish through *in silico* analysis aims to provide basic data for the development of modern strategies to protect against the harmful effects of oxidative stress in both cultured fish and other vertebrates. The analysis revealed that the zebrafish *gsr* gene has 13 exons and 12 introns, while the *g6pd* gene has 14 exons and 13 introns, both with a highly conserved exon-intron organization (Table 3). Alignment analysis of the zebrafish Gsr/GSR and G6pd/G6PD sequences using CLUSTAL W (Thompson et al. 1994) showed that the polypeptide identity and similarity rates between zebrafish and its such as medaka, stickleback, goldfish, puffer fish, platyfish, mouse, and human were quite high (Table 4). The analysis also revealed that the zebrafish *gsr* gene shared the highest similarity and identity rates with the goldfish, while the *g6pd* gene had the highest similarity and identity rates with the medaka.

Tissue-Specific Transcription of gsr and g6pd Genes in Female and Male Zebrafish (Danio rerio)

In this study, while determining the tissue-specific distribution in male and female zebrafish, the transcription of the *gsr* and *g6pd* genes was detected using qPCR (Figure 3). For the *gsr* gene in female zebrafish, the tissue-specific distribution was determined as follows: liver 61.9±4.41; intestine 13.5±0.55; muscle 6.51±0.47; brain 4.56±0.46; heart 19.3±1.57; eye 10.23±1.45; spleen 6.55±0.91; gill 37±4.13; kidney 24.9±1.01; stomach 18±0.89; ovary 30.05±1.8. For the *gsr* gene in male zebrafish, the tissue-specific distribution was determined as follows: liver 145.4±6.03; intestine 91.1±0.31; muscle 22.6±0.88; brain 10.7±0.51; heart 17.5±3.60; eye 23.03±1.95; spleen 8.54±0.48; gill 85.2±0.89; kidney 34.9±1.39; stomach 27.7±1.18; testis 58.98±5.9 (Table 5). For the *g6pd* gene, the tissue-specific distribution in female zebrafish was determined as follows: liver 22.75±2.16; intestine 1.58±0.14; muscle 0.89±0.13; brain 1.50±0.17; heart 0.91±0.095; eye 0.91±0.095; spleen 0.65±0.091; gill 17.37±1.45; kidney 1.20±0.12; stomach 0.99±0.08; ovary 12.63±1.22. For the *g6pd* gene in male zebrafish, the tissue-specific distribution was determined as follows: liver 57±4.29; intestine 15.02±0.01; muscle 3.61±0.76; brain 1.44±0.20; heart 6.57±0.65; eye 6.37±0.78; spleen 0.55±0.091; gill 40.74±2.31; kidney 1.45±0.19; stomach 2.03±0.24; testis 17.91±0.82. While the mRNA transcription of liver, intestine, muscle, brain, eye, gill, kidney, stomach, and gonad tissues for the *g6pd* gene was found to be significantly higher ($P<0.05$) in males than in females, the differences between the other tissues were considered statistically insignificant (Table 6).

Table 4. Similarity-identity rates between *gsr* and *g6pd* gene sequences of zebrafish and other vertebrates' *gsr/GSR* and *g6pd/G6PD* gene sequences

```
                    10        20        30        40        50        60
            ....|....|....|....|....|....|....|....|....|....|....|....|
Zf Gsr 1    ------------------------------------------------------------
Gf Gsr 1    -------------------------------------------------MEILSPLARLR
St Gsr 1    ------------------------------------------------------------
Pf Gsr 1    ----------------------------------------------------MQLLKIRR
Me Gsr 1    ----------------------------------------------------MLLKKICR
Mo GSR 1    ------------------------MALLPRALGVGAAPSLRRAAR---------------
Fu Gsr 1    HLIFPGYTPLLQFIMTQQWLKFGPPTRASELRARPASASFLVMAEVILRTRVQLLFSSKQ
Hu GSR 1    ------------------------MALLPRALSAGAGPSWRRAARAFRGFLLLLPEPAAL

                    70        80        90       100       110       120
            ....|....|....|....|....|....|....|....|....|....|....|....|
Zf Gsr 1    --------------------MASGSVSRFDFLVVGGGSGGLAGARRAAELGATTAVIESH
Gf Gsr 12   ASFVTLGSSLSSSRRLFGRS...AT.T......I...................A......
St Gsr 1    ---------------MAS---.DPQTT.L....I.............S....SA......
Pf Gsr 9    LLCVSLRRHELVRRSMASNRASAAETT......I..................N.......
Me Gsr 9    LLPSVSLSFPRLRVLRRSSMASESDAT......I..................NA......
Mo GSR 21   --ALTCAMASPGEPQPPAP-----DT.S..Y..I........S.........RA..V...
Fu Gsr 61   RLFSAFCRQDVVRRSMASD-PS.TDIT......I.............S....SA......
Hu GSR 37   TRALSRAMACRQEPQPQGPPP.A.A.ASY.Y..I........S.........RA..V...

                   130       140       150       160       170       180
            ....|....|....|....|....|....|....|....|....|....|....|....|
Zf Gsr 41   RLGGTCVNVGCVPKKVMWNTSTHAEYLHDHEDYGFEGAKAHFSWQIIKHKRDAYVSRLNQ
Gf Gsr 72   K.........................................N..L..R...........
St Gsr 43   ...................AAV........S.....VESVR...EAL.A.....I.H..R
Pf Gsr 69   K..................AAV........S....ATE.V....ETL.A..........H
Me Gsr 69   K..................AAV........C.....TGSVR...EAL.A.....IAH..R
Mo GSR 75   K...................AV.S.FM...V....QSCEGK...HV..Q..........T
Fu Gsr 120  K..................AAV........S.....VGNVR...EAL.T.....I.H..R
Hu GSR 97   K...................AV.S.FM...A....PSCEGK.N.RV..E..........A

                   190       200       210       220       230       240
            ....|....|....|....|....|....|....|....|....|....|....|....|
Zf Gsr 101  IYRSNLEKGKIEFIHGYARFTDDPEPTVEVNGKKYTATHILISTGGHPSTVSEDDVPGSS
Gf Gsr 132  ...N..D.A...S........................P....A..........N....A.
St Gsr 103  ...N..D.A.VQN.Q.H....N........D.R....P....A...Q.TVL.DA.I..GN
Pf Gsr 129  ...N..D.A...T.Q.F...............R.L..P....A...Q..VL.DEE...A.
Me Gsr 129  ...N..D.A.VT..Q........A.............P........Q..VL.DEE...A.
Mo GSR 135  ..QN..T.SH..I.....T.A.G.R.........F..P....A...V.TVPH.SQI..A.
Fu Gsr 180  ...N..D.A..QT.Q.H....N...............P....A...Q..VL.DTE...A.
Hu GSR 157  ..QN..T.SH..I.R.H.A..S..K..I..S......P....A...M...PH.SQI..A.

                   250       260       270       280       290       300
            ....|....|....|....|....|....|....|....|....|....|....|....|
Zf Gsr 161  LGITSDGFFELESCPKRSVIVGAGYIAVEMAGILSTLGSKTSIIIRQGGVLRNFDALISS
Gf Gsr 192  ............................................................
St Gsr 163  ............TL...T........................M....S.......SFL.T
Pf Gsr 189  ............TL....................A.......LV...T........F..A
Me Gsr 189  ...N........TL............................L....T...........A
Mo GSR 195  .........Q..DL.S.............I.....A......LM..HDK......S....
Fu Gsr 240  .............L.....V......................L....T.......S...T
Hu GSR 217  .........Q..EL.G...................A......LM..HDK...S..SM..T
```

Table 4. (continued)

		310 320 330 340 350 360
		....|....|....|....|....|....|....|....|....|....|....|....|
Zf Gsr	221	NCTKELQNNGIDLRKNTQVKSVKKNGKGLSITLVTKDPDDKDSQEKFDTHUDVDCLLWAI
Gf Gsr	252	........H.......S..R....TDQ...V........E..A...Y...HE........
St Gsr	223	........S.V..W..S..T..R.TE...EV.V....QEK.NDE..TS..QE........
Pf Gsr	249	.............W..S.....S.TD...EV.I.....EK--ND..IS..EE.E......
Me Gsr	249	.....I.......W..S.....C.TE...EV.I......KT-ND..ISV.EE........
Mo GSR	255	...E..E.A.VEVL.F....E...TSS..ELQV..SV.GR.---PTTTM.P.........
Fu Gsr	300	........S....W..S..R..C.TD...EV.IA.R..ER.NEE..LR..QE........
Hu GSR	277	...E..E.A.VEVL.FS...E...TLS..EVSM..AV.GRL---PVMTM.P.........
		370 380 390 400 410 420
		....|....|....|....|....|....|....|....|....|....|....|....|
Zf Gsr	281	GREPNTAGLNLSQIGVKLDERGHIVVDEFQNTSRPGVYAVGDVCGRALLTP---------
Gf Gsr	312	...........RS........EQ.........T.A................VAIAAGRKL
St Gsr	283	..Q...S...VAAM.LEM..................I........K.....---------
Pf Gsr	307	..Q...S...IGSM.LDT......IA..........I........K.....VAIAAGRKL
Me Gsr	308	..Q.......IGAM..DT.D....I..D....T.S.I........K.....VAIAAGRKL
Mo GSR	312	..D..SK....NKV.IQT..K...L.......NVK..........K.....VAIAAGRKL
Fu Gsr	360	..Q..IT...IGHLN.DT..K.............A.I..............VAIAAGRKL
Hu GSR	334	..V...KD.S.NKL.IQT.DK...I.......NVK.I........K.....VAIAAGRKL
		430 440 450 460 470 480
		....|....|....|....|....|....|....|....|....|....|....|....|
Zf Gsr	331	-----------------------------------DEAVKTYGKDKVKVYTTSFTPMYYA
Gf Gsr	372	AHRLFEGKADSKISYDNIPTVVFSHPPIGTVGLTE...I..W...N..............
St Gsr	333	-----------------------------------E..IRSR..EN....K.......H.
Pf Gsr	367	AHRLFEGKKDSKLDYSSIPTVVFSHPPIGTVGLTEE....SH..EN..I.K.......H.
Me Gsr	368	AHRLFEGKKDSKLDYSCIPTVVFSHPPIGTVGLTEE.....K..EN..I.K.......H.
Mo GSR	372	AHRLFECKQDSKLDYDNIPTVVFSHPPIGTVGLTE....HK....N..I.S.A.....H.
Fu Gsr	420	AHRLFEGKKDSKLDYSTIPTVVFSHPPIGTVGLTEE...RSN..EN..I.K.......H.
Hu GSR	394	AHRLFEYKEDSKLDYNNIPTVVFSHPPIGTVGLTE...IHK..IEN..T.S.......H.
		490 500 510 520 530 540
		....|....|....|....|....|....|....|....|....|....|....|....|
Zf Gsr	357	ITTRKSQCIMKLVCAGENEKVVGLHMQGFGCDEMLQGMOVAVNMGATKADFDRTIAIHPT
Gf Gsr	432	................K...............................E...........
St Gsr	359	..S...........E.KE..........L............IK.........K.V.....
Pf Gsr	427	..S.R.P.......V.KE..........L............IK.........N.V.....
Me Gsr	428	..R...........V.KE..........L............IK.....E...K.V.....
Mo Gsr	432	V....TK.V..M...NKE.....I....I.............K.........N.V.....
Fu Gsr	480	..N.....V.....V.KE..........L.........S..IK.........K.V.....
Hu GSR	454	V.K..TK.V..M...NKE.....I....L.............K.........N.V.....

			Similarity (%)	Identity(%)
		....|....		
Zf Gsr	417	S-EELVTLR	100	100
Gf Gsr	492	.S.......	76	81
St Gsr	419	.S..F..M.	73	87
Pf Gsr	487	.S..F..M.	64	75
Me Gsr	488	.S..F..M-	64	73
Mo GSR	492	.S.......	58	68
Fu Gsr	540	.S..F..M.	58	67
Hu GSR	514	.S.......	54	66

Table 4. (continued)

```
                                                  10   20   30   40  50   60
              ....|....|....|....|....|....|....|....|....|....|....|....|
Zf G6pd  1    ----------------------------------MMGSRASADKMSLPLSRSEVFGQLRK
Me G6pd  1    -------------------------------------------MNR..........E...
Pf G6pd  1    --------------------------------------------.T..........E..Q
Gf G6pd  1    MLSLSAFDSAVYIQLSTKFSFYLYFLLCISCECDALHEII.KL.............E...
Fu G6pd  1    ----------------------------------------M.NIP---........E...
St G6pd  1    ----------------------------------------FGSSP.HQQRH.....E...
Hu G6PD  1    ------------------------------------------MAEQVA...TQ.C.I..E
Mo G6PD  1    ------------------------------------------MAEQVT...TQ.C.I..E

                      70        80        90       100       110       120
              ....|....|....|....|....|....|....|....|....|....|....|....|
Zf G6pd  27   ELHDDTAFHQSDVHIFIIMGASGDLAKKKIYPTLWWLFRDGLLPEQTYFVGMORSDLTVD
Me G6pd  18   ..Y..EE......................................S.F............
Pf G6pd  17   ..Y..EK......................................E..............
Gf G6pd  61   ...E.AE.....................................................
Fu G6pd  18   ...E.KE.......V........................................A....
St G6pd  21   ...EVEE....-A.V.............................................
Hu G6PD  19   ..FQGD......T....................I...........N.FI..Y...R...A
Mo G6PD  19   ..YQND....A.T....................I..........KE.FI..Y...Q....

                      130       140       150       160       170       180
              ....|....|....|....|....|....|....|....|....|....|....|....|
Zf G6pd  87   AIRIACMPYMKVVDNEAERLAAFFSRNSYISGKYVEESSFSDLNTHLLSLPGGAEANRLF
Me G6pd  78   ...TG.......A.T..D..SV............AD.....K..S.I......N......
Pf G6pd  77   ...T....F...TEM.....S...A.........A.DA...K..A.M.A....P......
Gf G6pd  121  ...A..L.....T---....T..............D.....N............G.....
Fu G6pd  78   ...TS....L..TET.SD..S...........N.TAGG...E..A.IM....ASD.....
St G6pd  80   ...T..T..L..T.KDT...S...K..T......TD.....K..S.MT.....PA.....
Hu G6PD  79   D..KQSE.FF.ATPE.KLK.ED..A....VA.Q.DDAA.YQR..S.MNA.HL.SQ.....
Mo G6PD  79   D.QKQSE.FF.ATPE.RPK.EE..T....VV.Q.DDPA.YKH..SYHUA.HQ.MQ..H..

                      190       200       210       220       230       240
              ....|....|....|....|....|....|....|....|....|....|....|....|
Zf G6pd  147  YLALPPSVYHDVTKNIKHQCMSTK--GWNRVIVEKPFGRDLQSSEELSSHLSSLFTEEQI
Me G6pd  138  ......T........L.L......--............H................A.D..
Pf G6pd  137  ......T..........QH.....--............H.........T......S.D..
Gf G6pd  178  ..................H.....--....I................T.........D..
Fu G6pd  138  ......TI..S..E....F...A.--............H.........T........D..
St G6pd  140  ......T..........DC...A.YR..T.........H..K......T........D..
Hu G6PD  139  ......T..EA.....HES...QI--....I.............DR..N.I....R.D..
Mo G6PD  139  ......T..EA.....QET...QT--.F..I.............NQ..N.I....R.D..

                      250       260       270       280       290       300
              ....|....|....|....|....|....|....|....|....|....|....|....|
Zf G6pd  205  YRIDHYLGKEMVQNLMVLRFGNRIFGPIWNRDSVACVVLTFKEPFGTQGRGGYFDDFGII
Me G6pd  196  ............................................................
Pf G6pd  195  ............................................................
Gf G6pd  236  ...............................................M............
Fu G6pd  196  ................................N...........................
St G6pd  200  .................................L..........................
Hu G6PD  197  ....................A...........NI...I.........E.......E....
Mo G6PD  197  .......D............A.........G.NI...I.........E.......E....
```

Table 4. (continued)

```
                          310       320       330       340       350       360
                    ....|....|....|....|....|....|....|....|....|....|....|....|
Zf G6pd     265 RDVMQNHLLQMLSLVAMEKPASTSSDDVRDEKVKVLKCIEPVTLSDVVLGQYVGDPDGEG
Me G6pd     256 ............C..........................A...M........M.N.....
Pf G6pd     255 ............C..........................T..SM..........N.E...
Gf G6pd     296 ............C.............................S.................

Fu G6pd     256 .......M....C..........N...............V.ASM............E...
St G6pd     260 ............C..........................T..SI............E...
Hu G6PD     257 ............C..........N...............SE.QANN........N.....
Mo G6PD     257 .....S......C........T.D.....N.......R.SE.ETDN.I......N.N...

                          370       380       390       400       410       420
                    ....|....|....|....|....|....|....|....|....|....|....|....|
Zf G6pd     325 EAKLGYLDDKTVPKGSTQATMOTAVLYVKNERWDGVPFILRCGKALNERKAEVRLQFTDV
Me G6pd     316 .........P..................H...............................
Pf G6pd     315 D........P..................H...............................
Gf G6pd     356 .............E..............................................
Fu G6pd     316 D........P.............V....H...............................
St G6pd     320 .........P...........T......H...............................
Hu G6PD     317 ..TK.....P...R...T....AV....E............................H..
Mo G6PD     317 ..AN.....P...R...T....A..................................R.I

                          430       440       450       460       470       480
                    ....|....|....|....|....|....|....|....|....|....|....|....|
Zf G6pd     385 PGDIFSSQCRRNELVVRVQPNEAIYAKMMSKKPGVYFSPEETELDLTYHSRYRDVKLPDA
Me G6pd     376 .....GN..Q......................................K...K.......
Pf G6pd     375 .....DNK.Q......................................K...K.......
Gf G6pd     416 .......H............................................K.......
Fu G6pd     376 .....RN..Y...........................T..........K...K.......
St G6pd     380 .....GN................V........................K...K.......
Hu G6PD     377 A....HQ..K.....I.......V.T...T....MF.N...S......GN..KN......
Mo G6PD     377 .....HQK.K.....I.M.....V.TT..T....MF.N...S......GNK.KN....G.

                          490       500       510       520       530       540
                    ....|....|....|....|....|....|....|....|....|....|....|....|
Zf G6pd     445 YERLILDVFCGSQMHFVRSDELREAWRIFTPLLHQIESEKTPPIKYKYGSRGPAEADELV
Me G6pd     436 ....................................DK..PK..P...............
Pf G6pd     435 ...............................I....DK..PK..P........S...D..
Gf G6pd     476 .....................................K......................
Fu G6pd     436 .....................................K..PK..P...............
St G6pd     440 ..................................H.DK..PK..P.I............A
Hu G6PD     437 .....................................L..PK..P.I......T.....M
Mo G6PD     437 ...........C......T.....G.........K..R..PQ.FP.V......T.....M

                          550
                    ....|....|....|....          Similarity (%)      Identitiy(%)
Zf G6pd     505 QKVGFRYEGTYKWVNPHKL                100                100
Me G6pd     496 .R.................                89                 93
Pf G6pd     495 KR.................                87                 93
Gf G6pd     536 K.................P                87                 89
Fu G6pd     496 KR...............R.                85                 91
St G6pd     500 K................R.                85                 89
Hu G6PD     497 KR...Q.............                74                 85
Mo G6PD     497 RR...Q.K....GTHK.--                69                 82
```

Note: * The dots in the figure represent the similarity between amino acid sequences, while the short dashes indicate the missing amino acids. Similarity rate refers to the percentage of nucleotides in the sequence that are identical or similar between the two species, while identity rate refers to the percentage of nucleotides that are identical. "Me" represents medaka (*Oryzias latipes*), "St" represents stickleback (*Gasterosteus aculeatus*), "Gf" represents goldfish (*Carassius auratus*), "Fu" represents fugu (*Fugu rubripes*), "Pf" represents platy fish (*Xiphophorus maculatus*), "Hu" represents human (*Homo sapiens*), and "Mo" represents mouse (*Mus musculus*) in the table.

Table 5. The differences in transcription of the *gsr* gene between genders in zebrafish

Tissue	Sex	N	Average±Std. Error	t	P
Liver	Female	6	61.49±4.41	-11.172	0.000**
	Male	6	145.4±6.03	-11.172	0.000**
Intestine	Female	6	13.5±0.55	-123.065	0.000**
	Male	6	91.1±0.31	-123.065	0.000**
Muscle	Female	6	6.51±0.47	-16.146	0.000**
	Male	6	22.6±0.88	-16.146	0.000**
Brain	Female	6	4.56±0.46	-8.948	0.000**
	Male	6	10.7±0.51	-8.948	0.000**
Heart	Female	6	19.3±1.57	0.458	0.657
	Male	6	17.5±3.60	0.458	0.661
Eye	Female	6	10.23±1.45	-5.267	0.000**
	Male	6	23±1.95	-5.267	0.000**
Spleen	Female	6	6.55±0.91	-1.936	0.082
	Male	6	8.54±0.48	-1.936	0.091
Gill	Female	6	37±4.13	-11.411	0.000**
	Male	6	85.2±0.89	-11.411	0.000**
Kidney	Female	6	24.9±1.01	-5.772	0.000**
	Male	6	34.9±1.39	-5.772	0.000**
Stomach	Female	6	18±0.89	-6.484	0.000**
	Male	6	27.7±1.18	-6.484	0.000**
Gonad	Female	6	30.05±1.8	-4.611	0.001**
	Male	6	58.98±5.9	-4.611	0.004**

Note: **: P<0.05

Discussion

Tissue-Specific Transcription of gsr and g6pd Genes in Female and Male Zebrafish (Danio rerio)

Glutathione reductase plays an important role among the biomarkers of oxidative stress (Puppel et al., 2015; Nandi et al., 2019). During the body's response to oxidative stress, *gsr* is responsible for maintaining the homeostasis of reduced glutathione, which is the most important substrate for the synthesis of bioproteins together with glutathione peroxidase, as well as the main antioxidants such as ascorbic acid and α-tocopherol (Szudrowicz et al., 2022). This study was conducted in zebrafish, which serves as a model organism in science, to perform detailed bioinformatic and molecular analyses of the *gsr* and *g6pd* enzyme genes, in order to better understand the molecular mechanism of oxidative stress damage in vertebrates, and to determine which gender and tissues these genes are dominant in. It has been determined that the *gsr* and *g6pd* enzyme genes are dominant in the liver tissue of both male and female fish. Therefore, we can say that the liver is the most suitable tissue for gene expression studies on stress-related diseases in the future, based on tissue-specific analyses. The gill tissue gene expressions are significantly (P<0.05) lower than liver tissue gene expressions, although it is the second tissue where the *gsr* and *g6pd* genes are dominant, and significantly (P<0.05) higher than other tissues. The *gsr* and *g6pd* mRNA transcription identified in the ovary and testis tissues are significantly (P<0.05) lower than the transcription of gill and liver tissues, but it is seen that the gonads have significantly (P<0.05) higher gene expression than other tissues. Therefore, the most dominant tissues in both *gsr* and *g6pd* genes are the liver, gill, and gonads in order. When the tissue-specific distribution differences between male and female fish were examined, it was seen that the gene expression of *gsr* and *g6pd* in males is significantly higher than in females in these three

Table 6. The differences in transcription of the *g6pd* gene between genders in zebrafish

Tissue	Sex	N	Average±Std. Error	t	P
Liver	Female	6	22.75±2.16	-7.126	0.000**
	Male	6	57±4.29	-7.126	0.000**
Intestine	Female	6	1.58±0.14	-13.116	0.000**
	Male	6	15.02±0.01	-13.116	0.000**
Muscle	Female	6	0.89±0.13	-3.521	0.006
	Male	6	3.6±0.76	-3.521	0.015
Brain	Female	6	1.50±0.17	0.189	0.854
	Male	6	1.44±0.20	0.189	0.854
Heart	Female	6	0.91±0.095	-8.603	0.000**
	Male	6	6.6±0.65	-8.603	0.000**
Eye	Female	6	0.91±0.095	-6.939	0.000**
	Male	6	6.4±0.78	-6.939	0.001**
Spleen	Female	6	0.65±0.091	0.742	0.475
	Male	6	0.55±0.092	0.742	0.475
Gill	Female	6	17.37±1.45	-8.561	0.000**
	Male	6	40.08±2.32	-8.561	0.000**
Kidney	Female	6	1.20±0.12	-1.096	0.299
	Male	6	1.45±0.19	-1.096	0.303
Stomach	Female	6	0.99±0.08	-4.163	0.002
	Male	6	2.03±0.24	-4.163	0.006
Gonad	Female	6	12.63±1.22	-3.585	0.005**
	Male	6	17.91±0.82	-3.585	0.005**

Note: **: P<0.05

tissues. The study discussed in the previous sections provides valuable information about the tissue-specific distribution of *gsr* and *g6pd* genes in zebrafish. The results show that the liver is the most suitable tissue for gene expression studies on stress-related diseases, as *gsr* and *g6pd* genes are dominant in this tissue for both male and female fish. This finding is consistent with previous studies that have shown that the liver plays a critical role in antioxidant defense mechanisms and is sensitive to oxidative stress. This finding suggests that liver, gill and gonads tissues may be a useful target for future studies on the effects of environmental stressors on fish health. The study also identified significant differences in gene expression between male and female fish in the liver, gill, and gonads, with male fish showing significantly higher levels of gene expression in these tissues. Furthermore, the significantly higher transcription values of the *gsr* and *g6pd* genes in male tissues, compared to females, suggest that males may experience more stress in fish, as in many other animals in nature, resulting in increased gene expression related to stress. Many environmental challenges can lead to the accumulation of ROS, which are fundamental cell signaling molecules in living organisms (Apel & Hirt, 2004; Schieber & Chandel, 2014). Under normal conditions, the balance of ROS in tissues can be disrupted by the presence of stress, which can lead to a decrease in male fertility (Dowling & Simmons, 2009). This can result in male fish exhibiting higher levels of gene expression related to oxidative stress compared to females, as a way of coping with the greater levels of stress they experience. In this study, the expression of *gsr* and *g6pd* were analyzed in liver, gill, and gonads tissues that serve as biochemical and molecular indicators of the antioxidant system, with the genes being found to be more highly expressed in males suggesting that males may be trying to cope with stress. Parallel to this study, Ozdemir & Bayır (2022) reported on transcriptional differences in the antioxidant enzyme gene *sod1* between male and female brown trout. Ozdemir & Bayır (2022) suggested that the higher expression of antioxidant enzyme genes in males may be related to hypotheses about the role of antioxidants in mating performance, which is based on the male's efforts to attract females, known as sexual ornamentation (Blount, 2004; Catoni et al., 2008). This finding highlights the importance of considering sex-specific differences in gene expression in future studies on oxidative stress in fish. Further research is needed to determine how these gene expression patterns relate to fish health and the effects of environmental stressors on fish populations.

Bioinformatics Studies of gsr and g6pd Genes in Zebrafish

The identification and characterization of the *gsr* and *g6pd* genes in zebrafish provide valuable information on the evolution and function of these genes across different species. This information can be used to develop modern strategies to protect against the harmful effects of oxidative stress in both cultured fish and other vertebrates. The synteny designed to identify conserved genes between zebrafish, medaka, and humans suggests that the zebrafish *gsr* and *g6pd* genes are the result of teleost whole genome duplication (TWGD). Zebrafish genome mapping studies (Barbazuk et al., 2000; Postlethwait et al., 2000) and phylogenetic analyses of zebrafish genes (Meyer & Schartl, 1999; Taylor et al., 2001) also support the hypothesis that an early genome duplication event occurred in ray-finned fish (Taylor et al., 2003). Taylor et al. (2001) estimated that the fish-specific duplication event occurred more than 300 million years ago. However, it is impossible to determine the exact ages of zebrafish gene copies because the third codon positions used to estimate their ages have reached saturation (Taylor et al., 2003). Previous studies have reported that teleost fish have two copies of many genes that other vertebrates have only one (Postlethwait et al., 1998; Meyer & Schartl, 1999; Braasch & Postlethwait, 2012). However, this study found that the zebrafish genome contains only one copy of the *gsr* and *g6pd* genes, and it is believed that the reason for their presence as single copies is due to functional redundancy, which is a common occurrence in duplicated genes (Glasauer & Neuhauss, 2014). Functional redundancy occurs when one copy of a duplicated gene maintains the original function, while the other copy may acquire new functions or undergo functional divergence (Glasauer & Neuhauss, 2014). In the case of the *gsr* and *g6pd* genes, it is possible that the single copies in zebrafish have retained the original function of their duplicated counterparts, while the duplicates may have undergone functional divergence or been lost in the course of evolution. Further studies are needed to investigate the functional significance of the single copies of the *gsr* and *g6pd* genes in zebrafish and their potential roles in protecting against oxidative stress.

Conclusion

In conclusion, this study provides important information on the bioinformatics and tissue-specific distribution of *gsr* and *g6pd* genes in zebrafish. The results show that the liver is the dominant tissue for both genes in both female and male zebrafish. The study also reveals sex differences in the expression of these genes, with higher levels of *gsr* and *g6pd* transcripts found in various tissues of male zebrafish compared to female fish. *In silico* analyses demonstrate that the *gsr* gene of zebrafish has high similarity and identity ratios with goldfish and stickleback, while the *g6pd* gene shows the highest similarity and identity ratios with medaka fish and platy fish. These findings provide a foundation for further molecular studies of *gsr* and *g6pd* genes in zebrafish and related species, and could contribute to a better understanding of their roles in physiological and pathological processes.

Acknowledgements

The present research was financially supported by Atatürk University Scientific Research Project (FYL-2021-955).

Compliance With Ethical Standards

Authors' Contributions

BNU: Literature review, Drafting, Writing, Laboratory, Data analysis and management experiments

MB: Conceptualization, Drafting, Writing, Review, Editing, Supervision

Both authors have reviewed and approved the final version of the manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

The research adhered to all relevant international, national, and institutional guidelines for the ethical care and use of animals.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

Apel, K., & Hirt, H. (2004). Reactive oxygen species: metabolism, oxidative stress, and signal transduction. *Annual Review of Plant Biology*, *55*, 373-399. https://doi.org/10.1146/annurev.arplant.55.031903.141701

Barbazuk, W. B., Korf, I., Kadavi, C., Heyen, J., Tate, S., Wun, E., Bedel, J. A., Pherson, M. C., & Johnson, S. L. (2000). The syntenic relationship of the zebrafish and human genomes. *Genome Research*, *10*(9), 1351-1358. https://doi.org/10.1101/gr.144700

Bayır, M., & Arslan, G. (2021). Bioinformatics of Nile tilapia (*Oreochromis niloticus*) lymphocyte cytosolic protein 1 (*lcp1*) gene Nil tilapia (*Oreochromis niloticus*) lenfosit sitosolik protein 1 (*lcp1*). *Ege Journal of Fisheries and Aquatic Sciences*, *38*(1), 63-68. https://doi.org/10.12714/egejfas.38.1.07

Bayır, M., Arslan, G., & Oğuzhan Yıldız, P. (2020). Characterization, identification and phylogeny of the creatine kinase (*ckma*) gene in medaka (*Oryzias latipes*). *Marine Science and Technology Bulletin*, *9*(1), 15-22. https://doi.org/10.33714/masteb.660220

Blount, J. D. (2004). Carotenoids and life-history evolution in animals. *Archives of Biochemistry and Biophysics*, *430*(1), 10-15. https://doi.org/10.1016/j.abb.2004.03.039

Braasch, I., & Postlethwait, J. H. (2012). Polyploidy in fish and the teleost genome duplication. In Soltis, P., & Soltis, D. (Eds.), *Polyploidy and Genome Evolution* (pp. 341-383). Springer. https://doi.org/10.1007/978-3-642-31442-1_17

Catoni, C., Peters, A., & Schaefer, H. M. (2008). Life history trade-offs are influenced by the diversity, availability and interactions of dietary antioxidants. *Animal Behaviour*, *76*(4), 1107-1119. https://doi.org/10.1016/j.anbehav.2008.05.027

Collins, F. S., Patrinos, A., Jordan, E., Chakravarti, A., Gesteland, R., & Walters, L. (1998). New goals for the U.S. human genome project: 1998-2003. *Science*, *282*, 682-689. https://doi.org/10.1126/science.282.5389.682

Dowling, D. K., & Simmons, L. W. (2009). Reactive oxygen species as universal constraints in life-history evolution. *Proceedings of the Royal Society B: Biological Sciences*, *276*(1663), 1737-1745. https://doi.org/10.1098/rspb.2008.1791

Espinosa-Diez, C., Miguel, V., Mennerich, D., Kietzmann, T., Sánchez-Pérez, P., Cadenas, S., & Lamas, S. (2015). Antioxidant responses and cellular adjustments to oxidative stress. *Redox Biology*, *6*, 183-197. https://doi.org/10.1016/j.redox.2015.07.008

García-Meilán, I., Tort, L., & Khansari, A. R. (2022). Rainbow trout integrated response after recovery from short-term acute hypoxia. *Frontiers in Physiology*, *21*(13), 1021927. https://doi.org/10.3389/fphys.2022.1021927

Glasauer, S. M., & Neuhauss, S. C. (2014). Whole-genome duplication in teleost fishes and its evolutionary consequences. *Molecular Genetics and Genomics*, *289*(6), 1045-1060. https://doi.org/10.1007/s00438-014-0889

Gromiha, M. M. (2010). *Protein Bioinformatics: From Sequence to Function*. Academic Press.

Hill, G. E. (2014). The evolution of ornaments and armaments. In Yasukawa, K. (Ed.), Animal Behavior: How and Why Animals Do the Things They Do, 2. Volume 2: Function and Evolution (pp. 145-172). Praeger.

Kari, G., Rodeck, U., & Dicker, A. P. (2007). Zebrafish: an emerging model system for human disease and drug discovery. *Clinical Pharmacology & Therapeutics*, *82*(1), 70-80. https://doi.org/10.1038/sj.clpt.6100230

Kumar, S., Dudley, J., Nei, M., & Tamura, K. (2008). MEGA: A biologist-centric software for evolutionary analysis of DNA and protein sequences. *Briefings in Bioinformatics*, *9*(4), 299-306. https://doi.org/10.1093/bib/bbn017

Li, C., Wei, M., Ge, Y., Zhao, J., Chen, Y., Hou, J., Cheng, Y., Chen, J., & Li, J. (2020). The role of glucose-6-phosphate dehydrogenase in reactive oxygen species metabolism in apple exocarp induced by acibenzolar-S-methyl, *Food Chemistry*, *308*, 125663. https://doi.org/10.1016/j.foodchem.2019.125663

Meyer, A., & Schartl, M. (1999). Gene and genome duplications in vertebrates: the one-to-four (-to-eight in fish) rule and the evolution of novel gene functions. *Current Opinion in Cell Biology*, *11*(6), 699-704. https://doi.org/10.1016/S0955-0674(99)00039-3

Nandi, A., Yan, L. J., Jana, C. K., & Das, N. (2019). Role of catalase in oxidative stress- and age- diseases. *Oxidative Medicine and Cellular Longevity*, *2019*, 9613090. https://doi.org/10.1155/2019/9613090

Osman, A. (2012). Biomarkers in associated degenerative Nile Tilapia *Oreochromis niloticus niloticus* (Linnaeus, 1758) to assess the impacts of River Nile pollution: Bioaccumulation, biochemical and tissues biomarkers, *Journal of Environmental Protection*, *3*(8A), 966-977. https://doi.org/10.4236/jep.2012.328112

Ozdemir, E., & Bayır, M. (2022). Molecular cloning and characterization of Cu-Zn superoxide dismutase (sod1) gene in brown trout and its expression in response to acute aquaculture stressors. *Animal Biotechnology*, *2022*, 1–11. https://doi.org/10.1080/10495398.2022.2061505

Parmar, M. B., Venkatachalam, A. B., & Wright, J. M. (2012). The evolutionary relationship of the transcriptionally active fabp11a (intronless) and fabp11b genes of medaka with fabp11 genes of other teleost fishes. *The FEBS Journal*, *279*(13), 2310-2321. https://doi.org/10.1111/j.1742-4658.2012.08611.x

Postlethwait, J. H., Woods, I. G., Ngo-Hazelett, P., Yan, Y. L., Kelly, P. D., Chu, F., Huang, H., Hill-Force, A., & Talbot, W. S. (2000). Zebrafish comparative genomics and the origins of vertebrate chromosomes. *Genome Research*, *10*(12), 1890-1902. https://doi.org/10.1101/gr.164800

Postlethwait, J. H., Yan, Y. L., Gates, M. A., Horne, S., Amores, A., Brownlie, A., Donovan, A., Egan, E. S., Force, A., Gong, Z., Goutel, C., Fritz, A., Kelsh, R., Knapik, E., Liao, E., Paw, B., Ransom, D., Singer, A., Thomson, M., Abduljabbar, T. S., Yelick, P., Beier, D., Joly, J. S., Larhammar, D., Rosa, F., Westerfield, M., Zon, L. I., Johnson, S. L., & Talbot, W. S. (1998). Vertebrate genome evolution and the zebrafish gene map. *Nature Genetics*, *18*(4), 345-349. https://doi.org/10.1038/ng0498-345

Puppel, K., Kapusta, A., & Kuczynska, B. (2015). The etiology of oxidative stress in the various species of animals, a review. *Journal of the Science of Food and Agriculture*, *95*(11), 2179-2184. https://doi.org/10.1002/jsfa.7015

Schieber, M., & Chandel, N. S. (2014). ROS function in redox signaling and oxidative stress. *Current Biology*, *24*(10), R453-R462. https://doi.org/10.1016/j.cub.2014.03.034

Szudrowicz, H., Kamaszewski, M., Adamski, A., Skrobisz, M., Frankowska-Łukawska, J., Wójcik, M., Bochenek, J., Kawalski, K., Martynow, J., & Bujarski, P. (2022). The effects of seven-day exposure to silver nanoparticles on fertility and homeostasis of zebrafish (*Danio rerio*). *International Journal of Molecular Sciences*, *23*(19), 11239. https://doi.org/10.3390/ijms231911239

Taylor, J. S., Braasch, I., Frickey, T., Meyer, A., & Van de Peer, Y. (2001). Genome duplication, a trait shared by 22000 species of ray-finned fish. *Genome Research*, *11*(12), 240-250. https://doi.org/10.1101/gr.194001

Taylor, J. S., Van de Peer, Y., & Meyer, A. (2003). Genome duplication, divergent resolution and speciation. *Trends in Genetics*, *19*(5), 259-266. https://doi.org/10.1016/S0168-9525(03)00080-6

Thompson, J. D., Higgins, D. G., & Gibson, T. J. (1994). CLUSTAL W: Improving the sensitivity of progressive multiple sequence alignment through sequence weighting, position-specific gap penalties and weight matrix choice. *Nucleic Acids Research*, *22*(22), 4673-4680. https://doi.org/10.1093/nar/22.22.4673

Torstensen, B. E., Nanton, D. A., Olsvik, P. A., Sundvold, H., & Stubhaug, I., (2009). Gene expression of fatty acid-binding proteins, fatty acid transport proteins (cd36 and FATP) and ß-oxidation-related genes in Atlantic salmon (*Salmo salar* L.) fed fish oil or vegetable oil. *Aquaculture Nutrition*, *15*(4), 440–451. https://doi.org/10.1111/j.1365- 2095.2008.00609.x

Traverso, N., Ricciarelli, R., Nitti, M., Marengo, B., Furfaro, A. L., Pronzato, M. A., & Marinari, U. M. (2013). Role of glutathione in cancer progression and chemoresistance. *Oxidative Medicine and Cellular Longevity*, *2013*, 972913. https://doi.org/10.1155/2013/972913

Veldman, M. & Lin, S. (2008). Zebrafish as a developmental model organism for pediatric research. Pediatric Research, *64*, 470-476. https://doi.org/10.1203/PDR.0b013e318186e609

Wolff, J. N., Ladoukakis, E. D., Enríquez, J. A., & Dowling, D. K. (2014). Mitonuclear interactions: evolutionary consequences over multiple biological scales. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*(1646), 20130443. https://doi.org/10.1098/rstb.2013.0443

Xu, D., Li, L., & Li, C. (2020). Glutathione reductase gene in zebrafish: Characterization and expression analysis under heavy metal exposure. *International Journal of Molecular Sciences*, *21*(17), 6143. https://doi.org/10.3390/ijms21176143

Zorov, D. B., Juhaszova, M., & Sollott, S. J. (2014). Mitochondrial reactive oxygen species (ROS) and ROS-induced ROS release. *Physiological Reviews*, *94*(3), 909-950. https://doi.org/10.1016/j.bbabio.2006.04.029

Mar. Sci. Tech. Bull. (2023) 12(3): 370-379
e–ISSN: 2147–9666
info@masteb.com

dergipark.org.tr/en/pub/masteb
www.masteb.com
DOI: 10.33714/masteb.1338476

Marine Science and Technology Bulletin

PRENSIP
https://prensip.gen.tr/

RESEARCH ARTICLE

A study on safe navigation towards intelligent shipping considering sea conditions

Gökhan Budak[1*]

[1] *İzmir Katip Çelebi University, Faculty of Naval Architecture and Maritime, Department of Shipbuilding and Ocean Engineering, İzmir, Türkiye*

ARTICLE INFO

Article History:
Received: 06.08.2023
Received in revised form: 25.08.2023
Accepted: 27.08.2023
Available online: 28.09.2023

Keywords:
Ship maneuvering
Safe navigation
Regular head waves
Path following

ABSTRACT

A mathematical model is created to obtain safe navigation for ships in regular head waves in this study. To validate the suggested model, firstly, the added resistances are calculated for two different ships using empirical formulas in the mathematical model. Secondly, the turning test simulations are performed for calm water and in waves with various wave amplitudes. After these validation studies, the path following simulation of the ship to the target destinations is performed in both waves and calm water for the determined course. It is assumed that regular head waves affect the ship as an external disturbance. The wavelengths and wave amplitudes are changed systematically to understand their effect during the path following simulations. When the ratio of wavelength to ship length, λ/L_{pp}, is nearly 1.0, the path following simulation times increase. Moreover, when the value of wave amplitude increases, so does the simulation time.

Please cite this paper as follows:

Budak, G. (2023). A study on safe navigation towards intelligent shipping considering sea conditions. *Marine Science and Technology Bulletin*, *12*(3), 370-379. https://doi.org/10.33714/masteb.1338476

Introduction

Automatic control systems have been seen frequently in all fields of science. Nowadays, road and rail vehicles have been equipped with autonomous systems in all aspects, thanks to the technological developments. Moreover, there is a remarkable interest in autonomous shipping due to positive feedbacks obtained from applications in train and car industries. In this context, the similar expectations for autonomous ships reveal with the promises of autonomous applications in shipping to provide operational, economic, and ecological sustainability. The main promise of autonomous ships is safe navigation for all components in shipping. For example, human decisions can be risky since there are too many variables in some situations such as collision risk and bad weather condition. However, it can be safer when a critical decision given by the onboard intelligent systems analyzing all changing parameters. On the other hand, these systems are important not only for safe navigation, but also for economic and sustainable operations (Akbar et al., 2021; Kurt & Aymelek, 2022; Kafalı & Aksu,

* Corresponding author
E-mail address: gokhan.budak@ikc.edu.tr (G. Budak)

2022). Although it is thought that the transition to autonomous shipping is its infant age, there is an opportunity to operate ships under control with autonomous systems thanks to obtained positive outputs from sea trials. This study proposes a mathematical model including a basic intelligent control system to ensure safe navigation in regular head wave by avoiding possible collision risk.

The previous studies in the literature aimed to safely finish the ship's movement considering environmental conditions, reducing fuel consumption, or shortening the ship's berthing time at the port. The intelligent controller systems, such as PID (Proportional Integral Derivative), fuzzy logic, and neural networks etc., are commonly performed by researchers to achieve these goals. Safe navigation on a created course is one of the main aims of the previous studies in the literature. For instance, Moreira et al. (2007) proposed a control system for path following application based on LOS (light of sight) guidance. In their research, the proposed system was verified for the Esso Osaka and the simulations were performed for different desired geometrical paths. In another study, Zaccone & Martelli (2020) studied on a collision avoidance system based on Rapidly Exploring Random Tree (RRT*) algorithm for surface vessel navigation. Additionally, Mohamed-Seghir et al. (2021) developed an intelligent system based on fuzzy logic to determine a ship route in the event of the collision risks and reduce energy consumption. In a similar study, Chen et al. (2021) investigated a smart control system based on fuzzy sets for unmanned surface vessel to avoid the collision. This investigation applied both the fixed obstacles and incoming ships' encounter situations. Zhou et al. (2021) used the traditional PID as a control system for collision avoidance and path following simulations. Moreover, there are studies in the literature including more than one control system among the proposed methods for both path following and collision avoidance. For example, He et al. (2021) used not only fuzzy but also PID controller to determine the optimal route to avoid the collision. The different mathematical models to avoid the collision are proposed by the researchers (Degre & Lefevre, 1981; Fossen, 2002). Many control systems based on various algorithms can be found in the literature. Tsou & Hsueh (2010) proposed a mathematical model including avoidance collision system based on Art Colony Optimization Algorithm. Lyu & Yin (2017) introduced a trajectory planning algorithm modified artificial potential field to navigate safely. Perera et al. (2010) presented a collision-avoidance system that used a Bayesian Network decision-making process to avoid collision with multiple ships. The algorithm based on neural network is one of them which is applied on collision avoidance simulations (Praczyk, 2015; Wang & Fu, 2020; Suo et al., 2020). Other worth-to-mention proposed algorithms to solve the same problem were explained in the studies (Liu et al., 2020; Zhao et al., 2021). All these mentioned mathematical models, including different control algorithms and/or numerical approaches, show that safe navigation is an interesting topic for researchers.

The forces and moments that the ship will be exposed to due to external disturbances will also affect the movements of the ship. For instance, the studies that analyze the calculation of wave-induced forces and moments as well as how these forces and moments affect ships are extremely popular. Among these studies, Beji (2020) formulated the waves and currents forces acting on a body. Xie et al. (2020) numerically calculated the turning circle tests under the effect of waves with varying wavelengths for two different ships. Similarly, Fang et al. (2005) simulated the turning test of a ship under the effect of waves. In another study, Jin et al. (2021) performed turning circle test simulations with the URANS (Unsteady Reynolds-Averaged Navier–Stokes) equations based on CFD (Computational Fluid Dynamics). In another study, the added resistance of a model ship with the constant forward velocity in waves was calculated using URANS equations (Ozdemir & Barlas, 2017). Furthermore, Park et al. (2016) studied on added resistance induced head waves for different draft value of ship. The effects of external disturbances such as current and wind, as well as wave-induced forces, have been studied in the literature (Szelangiewicz et al., 2014; Yasukawa & Sakuno, 2019). Besides these studies, a comprehensive review including studies of investigating the effects of external disturbances on ship motions and maneuvering was presented by Hirdaris et al. (2014).

In this study, the control system, which is one of the intelligent transportation systems that should be on an autonomous ship, has been added to the mathematical model. Thus, the ship can reach the target area by avoiding collision in regular head waves thanks to this control system. To validate the proposed mathematical model, firstly, the added resistances are calculated for the KVLCC2 ship to validate the regular wave forces, and then these results are compared with the other studies in the literature. Secondly, the turning circle test simulations for the Esso Osaka ship having limited studies comparison to the KVLCC2 ship are performed in regular head waves having different wave amplitudes. Finally, a random course with fixed obstacles is determined for the Esso Osaka to perform the simulations. These simulations are carried out both in regular head waves and calm water to understand the effects of the waves using the mathematical model. Moreover, it is discussed whether the ship could reach the target coordinates and create a safe route automatically to avoid collisions on the determined course.

Material and Method

Maneuvering Model

The MMG (Maneuvering Modeling Group) model was added to the literature by Ogawa & Kasai (1978). In this maneuvering model, the forces and the moment acting on a ship are calculated separately based on the hull, propeller, rudder, and external forces. The MMG model is widely preferred to obtain information about ship maneuvering (Yasukawa & Yoshimura, 2015; Aksu & Köse, 2017). In this study, regular head wave is assumed as an external force.

The mathematical model is created based on the MMG model to calculate all these forces and moments. The equations for surge, sway and yaw motions may be written in Eq. 1.

$$(m + m_x)\dot{u} - (m + m_y)vr - mx_G r^2 = X$$

$$(m + m_y)\dot{v} + (m + m_x)ur + mx_G\dot{r} = Y$$

$$(I_{zz} + mx_G^2 + J_{zz})\dot{r} + mx_G(\dot{v} + ur) = N \qquad (1)$$

where m, ship mass; m_x and m_y, the added masses; I_{zz} the mass moment of inertia; J_{zz}, the added mass moment of inertia; u and v the velocity components of ship velocity; r, angular velocity of ship, and x_G the distance between origin and the gravity center of the ship.

The fixed and moving coordinates of ship are described for the mathematical model and other relevant quantities are shown in Figure 1.

The total forces and moment can be expressed as the sum of the hull, propeller, rudder, and wave forces and moment for this study.

The hydrodynamic forces and moment for ship hull are calculated with Eq. 2.

$$X_H = -R_0 + X_{vv}v^2 + X_{vr}vr + X_{rr}r^2 + X_{vvvv}v^4$$

$$Y_H = Y_v v + Y_r r + Y_{vvv}v^3 + Y_{vvr}v^2 r + Y_{vrr}vr^2 + Y_{rrr}r^3$$

$$N_H = N_v v + N_r r + N_{vvv}v^3 + N_{vvr}v^2 r + N_{vrr}vr^2 + N_{rrr}r^3 \qquad (2)$$

While calculating the propeller-induced force on x-direction, Eq. 3 may be written depending on thrust deduction factor (t) and propeller thrust (T). The force on y-direction Y_P and the moment N_P are accepted as zero.

$$X_P = (1 - t)T \qquad (3)$$

Eq. 4 expresses rudder-induced forces and moment. The forces and moment depending on the changing rudder angle can be calculated using this equation. The expression of the rudder normal force is $F_N = (1/2)\rho A_R {U_R}^2 f_\alpha \sin\alpha_R$.

$$X_R = -(1 - t_R)F_N sin\delta$$

$$Y_R = -(1 - a_H)F_N cos\delta$$

$$N_R = -(x_R + a_H x_H)F_N cos\delta \qquad (4)$$

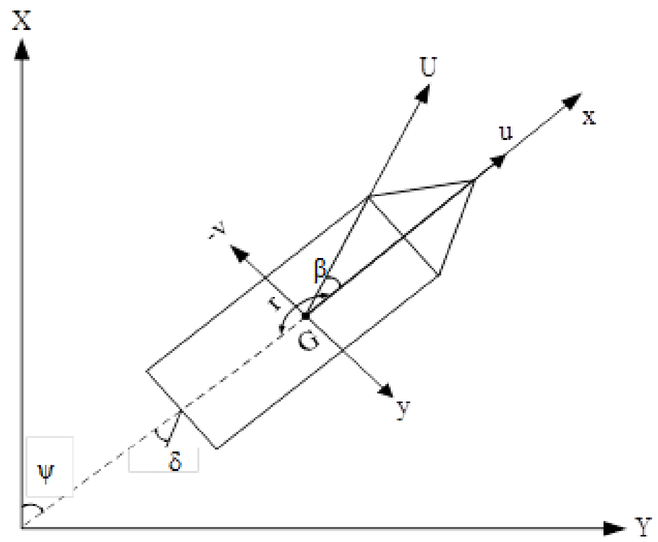


Figure 1. Fixed and ship coordinates

The added resistance values can be obtained by using experimental methods (Lee et al., 2013) numerical calculations (Sadat-Hosseini et al., 2013; Çakıcı et al., 2017), and empirical formulas. Since the fastest one among them is the empirical formulas, it is implemented for this study. The empirical formulas to calculate the total added resistance due to the regular head waves given in Eq. 5 is chosen from the studies in the literature. More details information about these empirical formulas can be seen in the studies of (Tsujimoto et al., 2008; Liu & Papanikolaou, 2016; Liu et al., 2020; Lang & Mao, 2020).

$$R_{AW} = R_{AWR} + R_{AWM} \qquad (5)$$

The first part of the total added resistance (R_{AWR}) will be calculated using Eq. 6, and Eq. 7 may be used to calculate the second part of the total resistance (R_{AWM}).

$$R_{AWR} = \frac{2.25}{2}\rho g \zeta_a^2 \alpha_T sin^2 E \left(1 + 5\sqrt{\frac{L_{pp}}{\lambda}} Fn\right)\left(\frac{0.87}{C_B}\right)^{1+4\sqrt{Fn}} \quad (6)$$

where ρ, is the density; g, gravity acceleration; ζ_a, the incident wave amplitude; L_{pp}, length between perpendiculars; λ, the wavelength; Fn, Froude number; C_B, block coefficient; $E = \text{atan}\,(\frac{B}{2L_E})$, waterline entrance angle; L_E waterline entrance length.

$$R_{AWM} = 4\rho g \zeta_a^2 \frac{B^2}{L_{pp}} \bar{\omega}^{b_1} exp\left[\frac{b_1}{d_1}(1 - \bar{\omega}^{d_1})\right] a_1 a_2 a_3 \quad (7)$$

where the parameters $\bar{\omega}$, b_1, d_1, a_1, a_2, a_3 can be calculated using empirical formulas are given by Liu & Papanikolaou (2017).

The dimensionless wave induced force and moment can be calculated using Eq. 8 (Li & Zhang, 2022). The dimensionless force coefficient $Y_W{}'$ is multiplied by $(1/2)\rho L^2 U^2$ to make dimensional. Similarly, the dimensionless moment coefficient $N_W{}'$ is multiplied by $(1/2)\rho L^3 U^2$.

$$Y_W' = -2aL\frac{\sin(b)\sin(c)}{b}s(t)$$

$$N_W' = ak\left(B^2 \sin(b)\frac{c\cos(c) - \sin(c)}{c^2} - L^2 \sin(c)\frac{b\cos(b) - \sin(b)}{b^2}\right)\xi(t) \quad (8)$$

where the parameters can be express as $a = \rho g(1 - e^{kT})/k^2$, $b = (kL\,cos(\chi))/2$, $c = (kB\,sin(\chi))/2$, $k = \frac{2\pi}{\lambda}$, χ is the wave direction.

Controller

In the simulated application, the classical PD controller given Eq. 9 and proposed algorithm are used as the control system to obtain the ship route and to avoid collision. The controller gains, K_P and K_D, have been determined with Matlab-PID Tuner. When the ship encounters any obstacle while following the determined course, Eq. 11 and Eq. 12 are used, otherwise Eq. 10 is used to calculate the desired ship heading angle.

$$\delta(t) = K_p e(t) + K_d \frac{de(t)}{dt} \quad (9)$$

where $\delta(t)$, the rudder angle; $e(t)$, the error.

The calculation of the ship's heading angle differs depending on whether there is an obstacle between any two points on the determined course. If there is no obstacle between the determined coordinates on the course, the desired ship heading angle ψ_d is calculated for the target coordinates. The ship has been no sooner arrived the target coordinates than the desired heading angle has been calculated automatically for the next target coordinates. The changing of desired ship heading depends on the coordinates of ship (x_{sp}, y_{sp}) and the destination point (x_{dp}, y_{dp}).

$$\psi_d = atan\left(\frac{y_{dp} - y_{sp}}{x_{dp} - x_{sp}}\right) \quad (10)$$

If there is an obstacle on the course, the ship will maneuver to avoid the collision risk. To avoid the collision, the obstacle coordinates and the maximum length of obstacle should be entered into the mathematical model as data, initially. The safe coordinates are determined thanks to the mathematical model according to the size and distance of the obstacle. The required heading angle to reach the target virtual coordinates is accepted as the reference angle for each virtual coordinate and the needed angle is commanded to the rudder. The ship continues to follow the course thanks to the controller system since the commanded rudder angle for the next target coordinates on the course has been changed. The following chart given in Figure 2 explains safe navigation in the mathematical model according to the position of the obstacles.

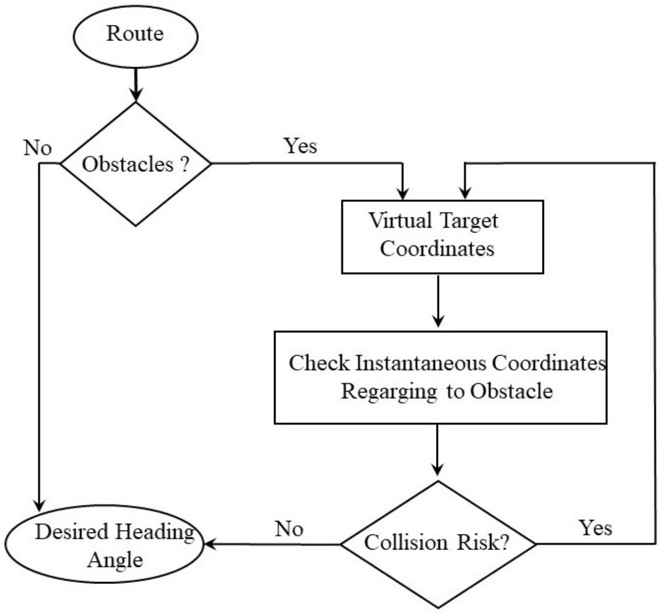


Figure 2. Flow diagram

If the ship encounters an obstacle on the determined course, the ship may follow the route without collision by assistance of the virtual target coordinates. Meanwhile, these virtual coordinates are used to obtain a safe route.

$$SY_{pe1} = Y_{obs} - y_{sp}$$

$$SX_{pe1} = X_{obs} - x_{sp}$$

$$S\psi_{pe1} = \text{atan}\left(\frac{SY_{pe1}}{SX_{pe1}}\right) \quad (11)$$

where X_{obs}, Y_{obs} are the coordinates of the obstacle.

$$SY_{pe2} = Y_{obs} + D + D * \cos\left(\left(\frac{\pi}{2}\right) - S\psi_{pe1}\right)$$

$$SX_{pe2} = X_{obs} + D * \sin(S\psi_{pe1})$$

$$S\psi_{pe2} = \text{atan}\left(\frac{SY_{pe2}}{SX_{pe2}}\right) \quad (12)$$

D is value of the maximum safe zone length. The maneuvering characteristics are the remarkable parameters to determine the virtual coordinates 1 since the ship has enough length to maneuver before the safe zone. The part of the algorithm for avoiding the collision is shown in Eq. 11 and Eq. 12. Briefly, the virtual coordinates 1, SX_{pe1} and SY_{pe1}, the difference between the coordinates of obstacles, and the ship, are calculated at each time step until a certain distance obtained from the safe zone calculated for the ship's maneuvering ability. When the ship reaches virtual coordinates 1; the ship maneuver to the virtual coordinates 2, given in Eq. 12, to avoid the collision. When the ship reaches virtual coordinates 2, the rudder angle is changed for the target coordinates. Other detailed information can be seen in Budak (2023).

Results and Discussion

Simulation Study

In the scope of this study, three different simulations are performed using the mathematical model. Firstly, the added resistances depending on various wavelength are calculated for KVLCC2 at Fn=0.142 for validation purpose. Since the lack of experimental data or numerical calculations for Esso Osaka ship in regular head wave, the simulation results are only compared with numerical calculations for KVLCC2. Secondly, after validating the mathematical model for regular head wave, the simulations are enlarged for turning tests of the Esso Osaka ship. These turning test simulations are performed for different wave amplitudes and the obtained results for turning trajectories of the Esso Osaka ship are evaluated under same wavelength (λ/L_{pp}=1.0) of regular head waves. Lastly, the path following simulations are carried out for determined course in regular head waves.

The basic dimensions, seen in Table 1, and the required maneuvering derivatives in MMG model for these ships can be seen in the studies of (Kobayashi et al., 2002; Abdel-latif et al., 2013; Yasukawa & Yoshimura, 2015).

Table 1. Main sizes of the ships

	KVLCC2	Esso Osaka
L_{pp} (m)	320	325
B (m)	58	53
T (m)	20.8	22.05
C_B (-)	0.81	0.831
U (knot)	15.5	10

Validation Study

The added resistance values of KVLCC2 ship, which act depending on the variation of wave amplitudes at different wavelength, are shown in Figure 3. Since there are many studies for the KVLCC2 ship, the added resistance values obtained from mathematical model are compared with other results in the literature. It is obviously seen in Figure 3 that a ship has highest added resistance when the ratio λ/L_{pp} is nearly 1.0. When this ratio is considered as the peak, if this ratio increases or decreases, the added resistance value of ship decreases. However, if the ratio is less than approximately 0.5, the added resistance increases again.

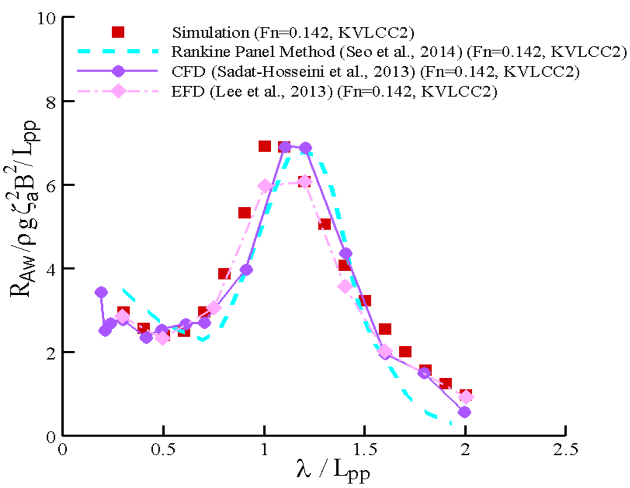


Figure 3. Added resistance for KVLCC2 ship

The values of Esso Osaka's added resistance for various wavelengths are obtained from the validated mathematical model. Figure 4 shows these obtained values in regular head waves. Just like the obtained added resistance values for KVLCC2, the orientations of the added resistance graphs in Figure 4 for the Esso Osaka ship are similar.

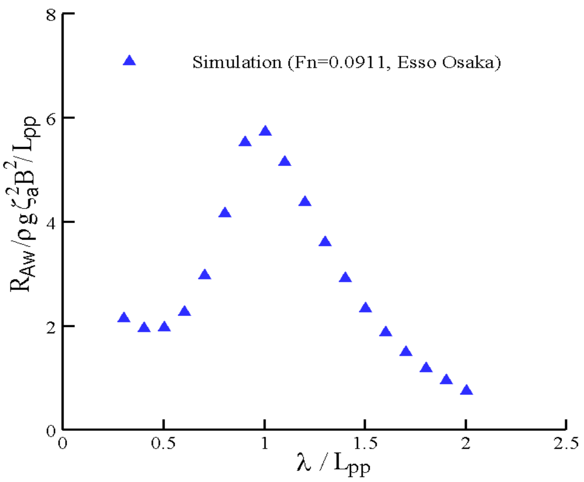


Figure 4. Added resistance for Esso Osaka ship

The Simulation of Turning Tests

The turning circle results for the Esso Osaka is obtained using the mathematical model. The turning circle simulation by assuming calm water are validated previous study (Budak, 2023) and the trial data are shown in Figure 5 for the Esso Osaka ship. Additionally, the turning tests given in Figure 5 are performed in regular head waves for Esso Osaka ship. In these simulations, the ratio (λ/L_{pp}) is equal to 1.0 and constant, however the values of the wave amplitudes are assumed as 0.5 m, 1.0 m, and 1.5 m. Although the ratio is equal to 1.0 in these simulations, as the wave amplitude increases, the added resistance of the ship increases, and the ship follows an elliptic rotation.

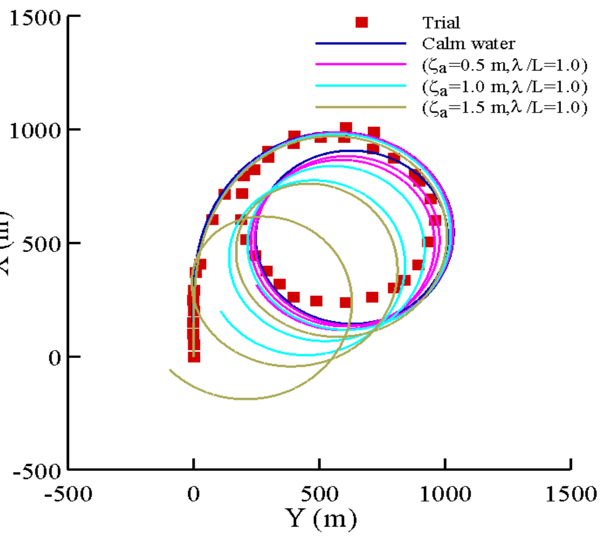


Figure 5. The comparison of obtained turning circle results

Simulation Cases

A course with fixed obstacles in some locations is determined for performing path following simulation. The ship velocity is assumed to be U=5.144 m/s. The mentioned mathematical model is used to obtain routes for two cases, calm water, and regular head waves. As the results of simulations, the ship can reach all randomly determined coordinates on the course for both cases. As shown in Figure 6, when the ship encounters an obstacle on her route, the ship modifies her route automatically to avoid the collisions and reaches the determined target destination safely. The oscillations in the fields of target coordinates shown in the Figure 6 are quite normal considering the obtained maneuvering characteristics of Esso Osaka ship. From this point of view, it can be understood that these oscillations in some fields where obstacles exist on the course are seen acceptable for Esso Osaka ship during the simulation. Moreover, the algorithm used to obtain a safe route achieves the purpose of this study as seen in Figure 6.

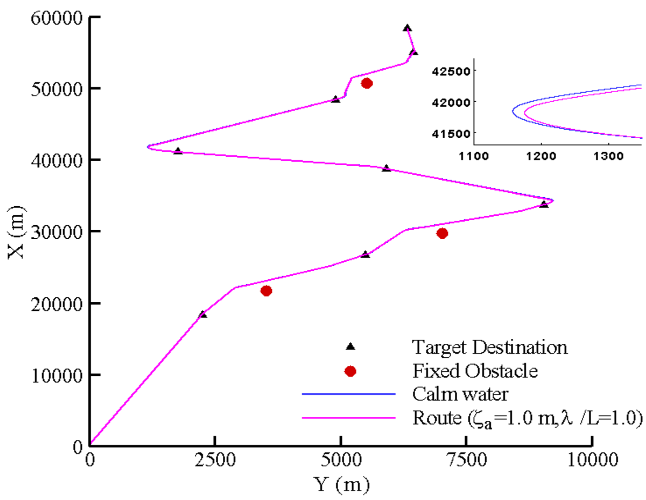


Figure 6. Path following simulations with avoidance collision

In the simulations, both different wavelengths and different wave amplitudes are considered. The path following simulation durations for determined course depend on the values of the wave amplitude and wavelength. However, in each simulation, it is concluded that the ship could reach the targeted destinations safely. Although more simulations with various wave amplitude and wavelength are performed using mathematical model, the path following simulations for regular head waves, determined as ζ_a=1.0 m in wave amplitude and λ/L_{pp}=1.0 in ratio, and for calm water are shown in Figure 6 to show the differences clearly. However, the heading angle changings of Esso Osaka during the other simulations are shown in Figure 7 to see the simulation times shown in Table 2. In all path following simulations, the angle of the regular waves acting on the initial ship position is 180°. However, it is emphasized that the acting angle of the regular waves to the ship changes since the ship maneuvers to reach the target coordinates, and the calculations are performed to calculate according to the changing angle of the wave in each time interval during the simulations. Various path following simulations are performed by changing the wavelength and amplitude values to determine the effects of the regular head waves.

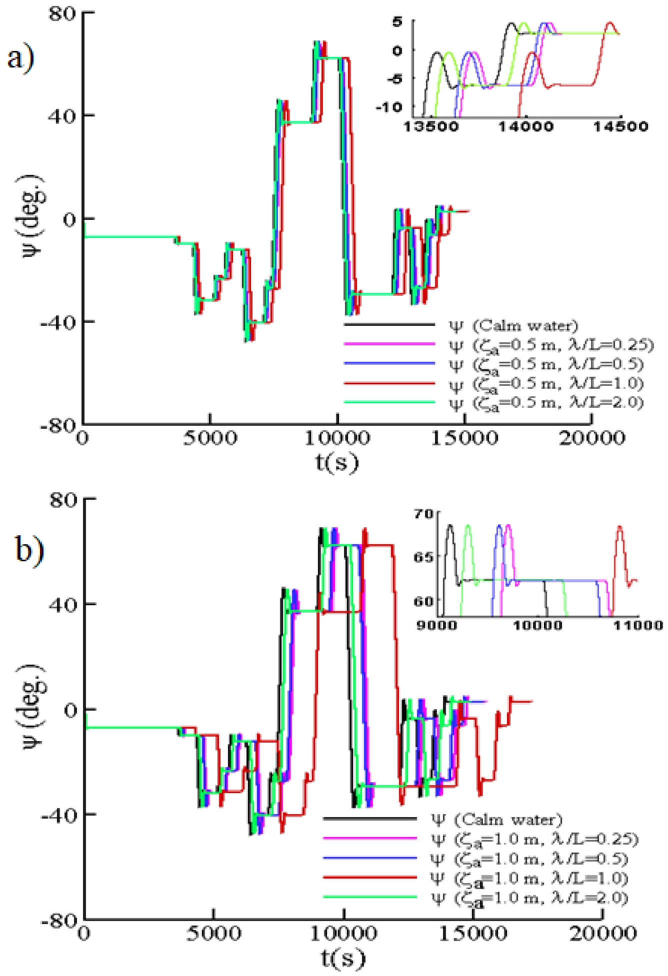


Figure 7. The heading angle for various wavelengths and amplitudes during the simulations, a) for ζ_a=0.5 m and b) for ζ_a=1.0 m

The simulation times shown in Table 2 for path following simulations with various wavelengths and amplitudes. Considering the added resistance values obtained for the Esso Osaka ship in Figure 4, it is said that the highest added resistance occurs when the ratio nearly λ/L_{pp}=1.0. Therefore, in regular head waves with $\lambda \sim L_{pp}$, the added resistance value is higher for that ship, so ship velocity decreases even more than the others, and so the simulation time increases. In other words, the added resistance value at λ/L_{pp} ~ 0.25 has higher than at λ/L_{pp} ~ 0.5. For this reason, the simulation time at λ/L_{pp} ~ 0.25 is expected to be longer than the simulation time at λ/L_{pp} ~ 0.5. Moreover, since the ship needs to perform extra maneuvers to reach the target coordinates along the determined course, the simulation time increases. When the ratio λ/L_{pp}=1.0 and ζ_a=0.5 are selected, the simulation time is 251.33 min. However, if the ratio λ/L_{pp}=1.0 and ζ_a=1.0 are selected, the simulation time is 277.57 min. In another words, the simulation time for λ/L_{pp}=1.0 and ζ_a=0.5 increases about 3.3% compared to the calm water while this increasing ratio is nearly 14% for λ/L_{pp}=1.0 and ζ_a=1.0.

Table 2. The simulation times

$\frac{\lambda}{L}=$	$\zeta_a = 0.5\,m$ Time (min.)	$\zeta_a = 1.0\,m$ Time (min.)
0.25	246.7	257.16
0.5	246.19	255.07
1.0	251.33	277.57
2.0	244.18	246.60
Calm water		243.40

Conclusion

A mathematical model including a maneuvering model and a control system is created within the scope of this article. The mathematical model is proposed to ensure that the ship can reach the desired coordinates by determining an automatic safe route. For this purpose, the maneuvering model and PD (Proportional Derivative) controller are combined to create the mathematical model. The added resistances for KVLCC2 ship are calculated in regular head waves with different wavelengths and compared to other studies in the literature for validation simulations. If the results are examined, while the highest value of added resistance for the KVLCC2 ship in regular head waves is when the wavelength to ship length ratio is nearly 1.0 (λ/L_{pp} ~1.0), the lowest value is when the ratio is nearly 2.0 (λ/L_{pp} ~2.0). The obtained added resistance results are compatible with the other studies in the literature. Similarly, the added resistance simulations are performed for Esso Osaka ship due to the chosen for path following simulations. Additionally, the turning tests are simulated for Esso Osaka in calm water, and regular head waves. Similarly, the path following simulations in regular head waves are performed not only in calm water but also in regular head waves with various wave amplitudes and wavelengths. In conclusion, considering the result of performed path following simulations, the time of simulation has been recorded as the longest when the ratio of λ/L_{pp} is ~1.0. However, if λ/L_{pp} is the farther from the mentioned ratio (λ/L_{pp} ~1.0), the simulation time decreases until λ/L_{pp} is nearly 0.5. Moreover, in the case that λ/L_{pp} is less than ~0.5, the simulation time commences to increase. As expected, the simulation time varies according to the added resistance value. When the added resistance value is high, the simulation time is longer, and when it is low, the simulation time is shorter. Furthermore, simulation results using mathematical model are shown that a ship in regular head waves may reach the target coordinates safely even if the ship encounters an obstacle on the determined course. In future studies, the other control systems named velocity controller, berthing controller, etc. can be added to the mathematical model to create an autonomous ship, thus the ship may be used more effectively for maritime transportation because of having an intelligent system.

Compliance With Ethical Standards

Conflict of Interest

The author declares that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Data Availability Statement

All data generated or analyzed during this study are included in this published article.

References

Abdel-latif, S., Abdel-geliel, M. & Zakzouk E. E. (2013). Simulation of ship maneuvering behavior based on the modular mathematical model. *International Conference on Aerospace Sciences and Aviation Technology, 15(Aerospace Sciences & Aviation Technology)*, Egypt, pp. 1-14. https://doi.org/10.21608/asat.2013.22111

Akbar, A., Aasen, A., Msakni, M. K., Fagerholt, K., Lindstad, E. & Meisel, F. (2021). An economic analysis of introducing autonomous ships in a short-sea liner shipping network. *International Transactions in Operational Research*, *28*(4), 1740-1764. https://doi.org/10.1111/itor.12788

Aksu, E., & Köse, E. (2017). Evaluation of mathematical models for tankers' maneuvering motions. *Journal of ETA Maritime Science*, *5*(1), 95-109. https://dx.doi.org/10.5505/jems.2017.52523

Beji, S. (2020). Formulation of wave and current forces acting on a body and resistance of ships. *Ocean Engineering*, *218*, 108121. https://doi.org/10.1016/j.oceaneng.2020.108121

Budak, G. (2023). The effect of controller selection in collision avoidance system on fuel consumption for unmanned surface vessel: a case study. *Ships and Offshore Structures*, *18*(2), 315-323. https://doi.org/10.1080/17445302.2022.2157131

Çakıcı, F., Kahramanoglu, E., & Alkan, A. D. (2017). Numerical prediction of vertical ship motions and added resistance. *Transactions of the Royal Institution of Naval Architects Part A: International Journal of Maritime Engineering*, *159*(Part A4), 393-402. https://doi.org/10.3940/rina.ijme.2017.a4.450

Chen, Y. Y., Ellis-Tiew, M. Z., Chen, W. C., & Wang, C. Z. (2021). Fuzzy risk evaluation and collision avoidance control of unmanned surface vessels. *Applied Sciences*, *11*(14), 6338. https://doi.org/10.3390/app11146338

Degre, T., & Lefevre, X. (1981). A collision avoidance system. *Journal of Navigation*, *34*(2), 294-302. https://doi.org/10.1017/S0373463300021408

Fang, M. -C., Luo, J. -H., & Lee, M. -L. (2005). A nonlinear mathematical model for ship turning circle simulation in waves. *Journal of Ship Research*, *49*(2), 69-79. https://doi.org/10.5957/jsr.2005.49.2.69

Fossen, T. (2002). *Marine Control Systems: Guidance, Navigation and Control of Ships, Rigs and Underwater Vehicles*. Marine Cybernetics.

He, Y., Li, Z., Mou, J., Hu, W., Li, L., & Wang, B. (2021). Collision-avoidance path planning for multi-ship encounters considering ship manoeuvrability and COLREGs. *Transportation Safety and Environment*, *3*(2), 1-11. https://doi.org/10.1093/tse/tdab004

Hirdaris, S., Bai, W., Dessi, D., Ergin, A., Gu, X., Hermundstad, O., Huijsmans, R., Iijima, K., Nielsen, U., Parunov, J., Fonseca, N., Papanikolaou, A., Argyriadis, K., & Incecik, A. (2014). Loads for use in the design of ships and offshore structures. *Ocean Engineering*, *78*, 131–174. https://doi.org/10.1016/j.oceaneng.2013.09.012

Jin, Y., Yiew, L., Zheng, Y., Magee, A., Duffy, J., & Chai, S. (2021). Dynamic manoeuvres of KCS with CFD free-running computation and system-based modelling. *Ocean Engineering*, *241*, 110043. https://doi.org/10.1016/j.oceaneng.2021.110043

Kafalı, M., & Aksu, E. (2022). A multi-objective optimization model for determining the performance of a sailboat. *Journal of ETA Maritime Science*, *10*(3), 177-184. https://doi.org/10.4274/jems.2022.24392

Kobayashi, H., Blok, J., Barr, R., Kim, Y. S., & Nowicki, J. (2002). Specialist committee on Esso Osaka: Final report and recommendations to the 23rd ITTC. *23rd International Towing Tank Conference*, pp. 8-14.

Kurt, I., & Aymelek, M. (2022). Operational and economic advantages of autonomous ships and their perceived impacts on port operations. *Maritime Economics & Logistics* *24*(2), 302-326. https://doi.org/10.1057/s41278-022-00213-1

Lang, X., & Mao, W. (2020). A semi-empirical model for ship speed loss prediction at head sea and its validation by full-scale measurements. *Ocean Engineering*, *209*, 107494. https://doi.org/10.1016/j.oceaneng.2020.107494

Lee, J. H., Seo, M. G., Park, D. M., Yang, K. K., Kim, K. H., & Kim, Y. (2013). Study on the effects of hull form on added resistance. *Proceedings of the 12th International Symposium on Practical Design of Ships and Other Floating Structures*. Korea, pp. 329-337.

Li, G., & Zhang, X. (2022). Research on the influence of wind, waves, and tidal current on ship turning ability based on Norrbin Model. *Ocean Engineering*, *259*, 111875. https://doi.org/10.1016/j.oceaneng.2022.111875

Liu, L., Zhang, L., Zhang, S., & Cao, S. (2020) Multi-UUV cooperative dynamic maneuver decision-making algorithm using intuitionistic fuzzy game theory. *Complexity*, *2020*, 2815258. https://doi.org/10.1155/2020/2815258

Liu, S., & Papanikolaou, A. (2016). Fast approach to the estimation of the added resistance of ships in head waves. *Ocean Engineering*, *112*, 211-225. https://doi.org/10.1016/j.oceaneng.2015.12.022

Liu, S., & Papanikolaou, A. (2017). Approximation of the added resistance of ships with small draft or in ballast condition by empirical formula. *Proceedings of the IMechE Part M: Journal of Engineering for the Maritime Environment*, *223*(1), 27-40. https://doi.org/10.1177/1475090217710099

Lyu, H. G., & Yin, Y. (2017). Ship's trajectory planning for collision avoidance at sea based on modified artificial potential field. *2nd International Conference on Robotics and Automation Engineering*, (Icrae) Shanghai, pp. 351-357.

Mohamed-Seghir, M., Kula, K., & Kouzou, A. (2021). Artificial intelligence-based methods for decision support to avoid collisions at sea. *Electronics*, *19*(10), 2360. https://doi.org/10.3390/electronics10192360

Moreira, L., Fossen, T. I., & Soares, C. G. (2007) Path following control system for a tanker ship model. *Ocean Engineering*, *34*, (14,15), 2074-2085. https://doi.org/10.1016/j.oceaneng.2007.02.005

Ogawa, A., & Kasai, H. (1978). On the mathematical model of maneuvering motion of ships. *International Shipbuild Progress*, *25*, 306–319.

Ozdemir, Y., & Barlas, B. (2017). Numerical study of ship motions and added resistance in regular incident waves of KVLCC2 model. *International Journal of Naval Architecture and Ocean Engineering*, *9*, 149-159. https://doi.org/10.1016/j.ijnaoe.2016.09.001

Park, D. -M. Kim, Y., Seo, M. -G., & Lee, J. (2016). Study on added resistance of a tanker in head waves at different drafts. *Ocean Engineering*, *111*, 569-581. https://doi.org/10.1016/j.oceaneng.2015.11.026

Perera, L. P., Carvalho, J. P., & Soares, C. G. (2010). Bayesian network based sequential collision avoidance action execution for an ocean navigational system. *IFAC Proceedings*, *43*(20), 266-271.

Praczyk, T. (2015). Neural anti-collision system for autonomous surface vehicle. *Neurocomputing*, *149*, 559–572. https://doi.org/10.1016/j.neucom.2014.08.018

Sadat-Hosseini, H., Wu, P., Carrica, P., Kim, H., Toda, Y., & Stern, F. (2013). CFD verification and validation of added resistance and motions of KVLCC2 with fixed and free surge in short and long head waves. *Ocean Engineering*, *59*, 240–273. https://doi.org/10.1016/j.oceaneng.2012.12.016

Suo, Y., Chen, W., Claramunt, C., & Yang, S. (2020). A ship trajectory prediction framework based on a recurrent neural network. *Sensors*, *20*, 5133. https://doi.org/10.3390/s20185133

Szelangiewicz, T., Wiśniewski, B., & Żelazny, K. (2014). The influence of wind, wave and loading condition on total resistance and speed of the vessel. *Polish Maritime Research, 21*(3), 61-67. https://doi.org/10.2478/pomr-2014-0031

Tsou, M. C., & Hsueh, C. K. (2010). The study of ship collision avoidance route planning by ant colony algorithm. *Journal of Marine Science and Technology*, *18*(5), 746-756. https://doi.org/10.51400/2709-6998.1929

Tsujimoto, M., Shibata, K., & Kuroda, M. (2008). A practical correction method for added resistance in waves. *Journal of the Japan Society of Naval Architects and Ocean Engineers*, *8*, 177-184. https://doi.org/10.2534/jjasnaoe.8.177

Wang, C., & Fu, Y. (2020). Ship trajectory prediction based on attention in bidirectional recurrent neural networks. *5th International Conference on Information Science, Computer Technology and Transportation (ISCTT)*, Shenyang, China, pp. 529–533.

Xie, Z., Falzarano, J. M., & Wang, H. (2020). A framework of numerically evaluating a maneuvering vessel in waves. *Journal of Marine Science and Engineering*, *8*(6), 392. https://doi.org/10.3390/jmse8060392

Yasukawa, H., & Sakuno, R. (2019). Application of the mmg method for the prediction of steady sailing condition and course stability of a ship under external disturbances. *Journal of Marine Science and Technology*, *25*, 196–220. https://doi.org/10.1007/s00773-019-00641-4

Yasukawa, H., & Yoshimura, Y. (2015). Introduction of mmg standard method for ship maneuvering predictions. *Journal of Marine Science and Technology*, *20*, 37–52. https://doi.org/10.1007/s00773-014-0293-y

Zaccone, R., & Martelli, M. (2020). A collision avoidance algorithm for ship guidance applications. *Journal of Marine Engineering & Technology*, *19*, 62-75. https://doi.org/10.1080/20464177.2019.1685836

Zhao, W., Wang, Y., Zhang, Z., & Wang, H. (2021). Multicriteria ship route planning method based on improved particle swarm optimization–genetic algorithm. *Journal of Marine Science and Engineering*, *9*(4), 357. https://doi.org/10.3390/jmse9040357

Zhou, Z., Zhang, Y., & Wang, S. A. (2021). Coordination system between decision making and controlling for autonomous collision avoidance of large intelligent ships. *Journal of Marine Science and Engineering*, *9*(11), 1202. https://doi.org/10.3390/jmse9111202

Mar. Sci. Tech. Bull. (2023) 12(3): 380-401
e–ISSN: 2147–9666
info@masteb.com

dergipark.org.tr/en/pub/masteb
www.masteb.com
DOI: 10.33714/masteb.1324266

Marine Science and Technology Bulletin

PRENSİP
https://prensip.gen.tr/

RESEARCH ARTICLE

Optimizing shipbuilding production project scheduling under resource constraints using genetic algorithms and fuzzy sets

Ercan Akan[1*] • Güler Alkan[2]

[1] *Iskenderun Technical University, Barbaros Hayrettin Naval Architecture and Maritime Faculty, Department of Maritime Transportation Management Engineering, Hatay, Türkiye*

[2] *Mersin University, Faculty of Maritime, Department of Maritime Transportation Management Engineering, Mersin, Türkiye*

ARTICLE INFO

Article History:
Received: 07.07.2023
Received in revised form: 26.08.2023
Accepted: 30.08.2023
Available online: 28.09.2023

Keywords:
Shipbuilding production
Project management (PM)
Resource constraint project scheduling problem (RCPSP)
Genetic algorithms (GA)
Fuzzy sets (FS)

ABSTRACT

This study explores the application of Genetic Algorithms (GA) in optimizing shipbuilding production processes in the presence of uncertain environments. The research addresses two key aspects: firstly, the integration of GA RCPSP (Resource-Constrained Project Scheduling Problem) with techniques for managing uncertainty in shipbuilding production; and secondly, the analysis of Pareto optimal solutions generated by GA to achieve optimal scheduling in the shipbuilding context. The proposed framework aims to minimize project completion time and maximize resource utilization by incorporating probabilistic models, scenario analysis to handle uncertainties. Furthermore, the study focuses on evaluating the trade-offs between project completion time, resource allocation, and cost through the analysis of Pareto optimal solutions, using visualization techniques and sensitivity analyses to support decision-making processes. The findings contribute to enhancing shipbuilding production by providing a comprehensive approach for effectively managing uncertainty, improving resource allocation, and reducing project duration through the integration of GA RCPSP and uncertainty management techniques.

Please cite this paper as follows:

Akan, E., & Alkan, G. (2023). Optimizing shipbuilding production project scheduling under resource constraints using genetic algorithms and fuzzy sets. *Marine Science and Technology Bulletin*, *12*(3), 380-401. https://doi.org/10.33714/masteb.1324266

Introduction

The shipbuilding industry, which is estimated to reach a global shipbuilding market value of $145.67 billion in 2023 (Statista, 2023), is one of the capital-intensive and heavy industries that creates substantial employment opportunities and makes a significant contribution to the global economy. In recent years, the global supply of merchant ships has been dominated by China, the Republic of Korea and Japan, which together have a 94% market share in the shipbuilding industry

* Corresponding author
E-mail address: ercan.akan@iste.edu.tr (E. Akan)

(UNCTAD, 2022). The shipbuilding industry is a highly complicated sector with a multifaceted value chain encompassing the design, construction, and installation of diverse vessels (Lee et al., 2020). The production process within a shipyard represents one of the most intricate manufacturing systems (Okubo & Mitsuyuki, 2022). In the shipbuilding industry, competitiveness is multifaceted, encompassing various dimensions, including shipbuilding expenses, delivery timelines, ship quality, after sales services, and financing terms (Ecorys, 2009; Jiang & Strandenes, 2012). Shipbuilding is characterized by a complex production system with intricate work and organizational structures, extended lead times, and diverse resource requirements (Liu et al., 2011). The modern shipbuilding industry continually faces new challenges and market demands, necessitating ongoing improvements in the shipbuilding process to enhance fabrication efficiency amidst numerous uncertainties on the factory floor. Consequently, shipyards are compelled to continuously develop and implement novel production technologies and methodologies to effectively schedule the complex shipbuilding process (Hadžić, 2019).

The shipbuilding industry, which operates under an Engineering-to-Order (ETO) production mode, is a representative example of a project-based industry. Shipbuilding projects possess distinct characteristics such as complex product structures, multiple manufacturing stages, long production cycles, tight deadlines, jobbing work, concurrent execution of multiple projects, frequent modifications in engineering designs, and so on (Mao et al., 2020). Effective production planning plays a crucial role as it directly impacts construction costs and project duration. Moreover, given the limited time available for comparing multiple plans, production resource constraints must be taken into account (Okubo & Mitsuyuki, 2022). The shipbuilding production is a complex and lengthy process, which demands careful planning and timely decision-making. Characteristic of an intermittent process like shipbuilding is a large number of working activities of different duration (Ljubenkov et al., 2008). With the rapid development of technology, it has been affecting in ship production process (Mao et al., 2020). The primary challenge in shipbuilding processes lies in enhancing productivity at shipyards by developing new production technologies and effectively managing them (Lee et al., 2020). Labor plays a critical role in shipbuilding industry productivity, making it difficult to estimate workloads and schedules while considering worker allocation. Given the characteristics of the ETO industry, design and scheduling changes frequently occur during production. Furthermore, managing long-term production plans poses challenges. Process managers oversee the control of each task according to predefined schedules, making it difficult to negotiate and coordinate with other processes and increasing the possibility of making inefficient decisions (Goo et al., 2019). In a multi-project environment, all construction tasks are consolidated into an overall shipyard-level plan that analyzes available capabilities and resources over the planning horizon. Since all ships are built using shared resources in a competitive manner, it is necessary to plan the aggregate utilization of resources across all projects in order to create a reliable master schedule for each production stage and the entire project (Liu et al., 2011). In a distributed manufacturing environment, accomplishing such a complex shipbuilding project requires cross-enterprise cooperation. Multi-project parallelism and distributed manufacturing introduce numerous project coordination tasks. The complexity of shipbuilding projects and the extensive coordination required exponentially increase the difficulty of project control (Mao et al., 2020). For most shipbuilding enterprises, project execution is generally inefficient, as evidenced by poor coordination, underutilization of resources, cost overruns, and project delays, all of which have a significant impact on the enterprise's reputation within the industry. The root cause of these performance issues is the lack of effective project scheduling methods that align with the characteristics of current shipbuilding projects involving distributed manufacturing, collaborative decision-making, and dynamic scheduling (Mao et al., 2020). To ensure competitiveness and sustainability, shipyards must continuously monitor and enhance productivity, efficiency, and quality while reducing overall production costs (Rubeša et al., 2023).

Shipbuilding production is a complex process that requires careful planning and timely decision-making. It involves numerous working activities of varying durations, following an intermittent process. In a multi-project environment, all building tasks are consolidated into an overall shipyard-level plan. This plan analyzes available capabilities and resources over the planning horizon. However, coordinating multiple projects and managing distributed manufacturing poses significant challenges. It exponentially increases the difficulty of controlling the shipbuilding project due to its inherent complexity and extensive coordination requirements. Hence, it is imperative to employ efficient project planning and scheduling techniques in order to enhance the optimization of resource utilization, encompassing resource allocation and comprehensive resource utilization strategies. Given the finite resources available to enterprises for their production endeavors, meticulous planning of both temporal and quantitative aspects of project resources becomes indispensable. Shipbuilding faces the RCPSP, which involves optimizing the allocation of limited resources within a project's time constraints. This complex challenge requires efficient management of manpower, materials, and equipment to ensure timely completion of ship construction, addressing the industry's unique operational requirements. Additionally, GAs, a metaheuristic inspired by natural evolution and used to solve complex optimization problems, are used for RCPSPs because they can handle multiple constraints simultaneously, explore and exploit the solution space, utilize a population-based approach, and iteratively improve solutions. These algorithms are well-suited for optimizing complex scheduling problems by considering task dependencies, resource availability, and limits. GAs generate and evaluate a population of potential solutions, selecting and combining individuals through genetic operations like crossover and mutation. This iterative process continues until a termination criterion is met, aiming to find an optimal or near-optimal solution in a large search space. By representing project schedules as chromosomes and using genetic operations, GAs explore various combinations to find efficient project schedules that balance resource allocation, task dependencies, and project objectives (Akan, 2017; Han et al., 2017; Hu et al., 2019; Jeong et al., 2018; Mao et al., 2020). Furthermore, precisely estimating the duration of activities in terms of project management in the ship production process can be challenging due to the unique nature of each order. In such cases, fuzzy set theory effectively handles uncertainty and provides more accurate modeling of real-world problems compared to deterministic methods by addressing uncertainty and vagueness, using approximate knowledge (Kahraman & Kaya, 2010). Zadeh's (1965) development of fuzzy set theory introduced membership functions, assigning degrees of membership within the interval [0,1] to elements therefore, thanks to the membership functions of fuzzy sets being defined for project duration in scheduling, it becomes possible to provide a wider range of feasible cluster solutions for projects operating in uncertain environments (Akan & Bayar, 2022). Therefore, effective project planning and scheduling, along with the utilization of artificial intelligence techniques such as GAs and fuzzy set theory, can significantly contribute to overcoming the challenges of shipbuilding production and optimizing resource allocation in this complex and resource-intensive industry. Additionally, the aim of this study is to comprehensively explore the integration of genetic algorithm into shipbuilding production processes under uncertainty, providing actionable insights for efficient resource utilization and timely project completion. By addressing the two research questions, the article strives to bridge the gap between theoretical concepts and practical implementation, providing insights into the adaptation of GA to real-world shipbuilding scenarios. With the motivation to investigate and provide valuable insights into the following research questions:

(RQ1) How can the application of GA RCPSP be applied to the shipbuilding production process in the presence of an uncertain environment?

(RQ2) How can the analysis of Pareto optimal solutions be performed using the set generated by the Genetic Algorithm for the GA RCPSP in the context of the shipbuilding production process?

Furthermore, a shipbuilding process consists respectively of the stages of shipowner's decision, design and contracting, engineering and approval, material procurement, fabrication and assembly, outfitting and installation, testing and trials, certification and documentation, delivery and commissioning, and post-delivery support (Kim et al., 2005; Özyiğit, 2006). The manufacturing phase is prone to minor variations, primarily characterized by pivotal procedures such as block erection, prioritized block assembly, exterior assembly, and painting (Park et al., 2002) nevertheless, the manufacturing phase may vary due to different production arrangements adopted by shipyards based on ship type and outsourcing decisions (Stopford, 2009). Therefore, the application of this study focuses on the following stages of ship production process such as plate cutting and assembly of components, surface cleaning and grinding operations of plates, preparation of profiles, preparation of cut single-piece plates, surface preparation, and bending operations, assembly of small groups and pre-fabrication, panel manufacturing, component panel manufacturing, grouped panel production, block production, block assembly on the slipway, and launching the steel ship into the sea.

Additionally, the rest of the research is structured as follows: Section 2 provides a comprehensive literature review. In Section 3, the methodology is presented in detail. Section 4 demonstrates the application of the study method to perform. The final section encompasses the discussion of the findings, drawing conclusions based on the results obtained, and providing suggestions for future research endeavors.

Literature Review

This section considers the application of the GA RCPSP within fuzzy environment in the context of the shipbuilding industry.

The studies in regard to the use of RCPSP: Kolisch (1995) introduced ProGen, an algorithm for solving RCPSP. The algorithm was utilized to solve the problem using the priority rule method. To enable comparison with other researchers, Kolisch & Spracher (1996) developed the PSPLib Project Scheduling Library. Özdamar & Ulusoy (1996) proposed an iterative scheduling algorithm that improved project duration through forward/backward planning transitions obtained from Local Constraint-Based Analysis. This algorithm demonstrated an average project duration deviation of 1%. Boctor (1996) explored the multi-mode RCPSP, generating 21 heuristic methods to solve it. Sprecher & Drexl (1998) devised a branch and bound algorithm and a parallel scheduling algorithm for solving the multi-mode RCPSP. Reyck & Herroelen (1998) developed a branch and bound algorithm for the RCPSP, incorporating minimum and maximum delays between activities as activity precedence constraints. Schirmer (1998) evaluated a case-based approach for the RCPSP by comparing it with other algorithms using PSPLib data. Hartmann & Kolisch (2000) proposed a simulated annealing-based method within the X-Pass approach for solving RCPSP. Brucker & Knust (2000) introduced a new lower bound for the RCPSP, minimizing workforce utilization in the RCPSP through constraint propagation and linear programming. Abbasi et al. (2006) presented a simulated annealing algorithm based on time maximization to minimize workforce utilization and enhance scheduling reliability in the RCPSP. Shadrokh & Kianfar (2007) aimed to minimize the cost of resource capacity and project completion time by addressing the resource investment problem within the RCPSP category. Homberger (2007) proposed a multi-agent approach and a restart evolution method for the Resource-Constrained Multi-Project Scheduling problem. Adhau et al. (2012) developed a negotiation-based multi-agent method utilizing an auction approach to prevent resource intersections and generate optimal solution sets. Adhau et al. (2013) excluded resource transportation cost and time from their solution to facilitate comparison with previous methods. Furthermore, recent studies provide novel methods and algorithms, RCPSP. Etgar et al. (2018) achieved near-optimal solutions for multi-release work plans using clustering-based techniques. Chand et al. (2018) proposed genetic programming-based hyper-heuristics, while Muñoz et al. (2018) showcased the effectiveness of the Bienstock-Zuckerberg algorithm for project scheduling problems. Zhu et al. (2019) introduced a discrete oppositional multi-verse optimization algorithm for the multi-skill RCPSP, demonstrating superior performance. Servranckx & Vanhoucke (2019) focused on RCPSP with alternative subgraphs, highlighting the benefits of using a set of schedules. Vanhoucke & Coelho (2019) presented a solution algorithm for RCPSP with activity splitting and setup times. Tesch (2020) proposed event-based mixed-integer programming formulations for RCPSP, while Shariatmadari & Nahavandi (2020) enhanced schedule robustness using resource buffers. Wang et al. (2020) integrated information and data flow for RCPSP in construction scheduling. Guo et al. (2021) introduced a decision tree approach leveraging project indicators and predictions to identify the best priority rule. Asadujjaman et al. (2021) proposed a hybrid immune genetic algorithm for net present value-based RCPSP, outperforming existing methods. Saad et al. (2021) presented a quantum-inspired genetic algorithm that surpassed other evolutionary algorithms for RCPSP. Van Eynde & Vanhoucke (2022) developed a theoretical framework for assessing instance complexity, while Zhou et al. (2022) introduced a hybrid approach for multi-objective scheduling problems. Akhbari (2022) proposed a mathematical model integrating multiple modes. Xu & Bai (2023) presented an algorithm using a hybrid genetic algorithm and sensitivity analysis to analyze the impact of dynamic resource disruptions on project makespan. Zhang et al. (2023) developed a specific RCPSP model for water conservancy project scheduling, combining priority rule-based heuristics and hybrid genetic algorithms. Issa et al. (2023) proposed a heuristic method for reassessing scheduling interruption categories in RCPSP, providing decision choices to optimize project makespan. Akan (2023) analyzed the maritime logistics operation process by applying RCPSP approach in the "to-be" process stage in terms of business process management perspective.

The studies in regard to the use of GA-RCPSP: Sprecher et al. (1995) addressed semi-active, active, and non-delay scheduling without precedence relations. Hartmann (1998) incorporated problem-specific knowledge through permutation-based encoding, priority-based assignment, and rule-based priority scheme. Hartmann (2001) extended the concept of problem representation importance by incorporating two local searches. Alcaraz & Maroto (2001) utilized crossover techniques and a two-point passage. Hartmann (2002) aimed to minimize resource imbalances and achieve optimal results quickly. Toklu (2002) directly operated on the scheduling problem for the RCPSP. Kim et al. (2003) developed a hybrid GA with a fuzzy logic controller. Hindi et al. (2002) incorporated a crossover strategy related to the maintenance of order. Coelho & Tavares (2003) introduced a new crossover operator and activity representation. Valls et al. (2004) developed a hybrid GA with a peak passage operator. Tseng & Chen (2006) proposed a hybrid metaheuristic model combining Ant Colony Optimization, GA, and Local Search strategies. Ranjbar & Kianfar (2007) incorporated a resource utilization ratio and a local search method. Franco et al. (2007) minimized resource consumption using object-oriented programming and two-point crossover. Valls et al. (2008) introduced a hybrid GA with a local improvement operator. Goncalves et al. (2008) addressed the multi-project RCPSP. Chang et al. (2008) enhanced the decision support capability of the GA. Van Peteghem & Vanhoucke (2008, 2010) used two populations to minimize activity completion time and improve mode selection. Montoya-Torres et al. (2009) suggested a multi-string object-oriented GA model. Tseng & Chen (2009) proposed a two-phase genetic local search algorithm. Magalhaes-Mendes (2011) introduced a two-level GA. Khanzadi et al. (2011) presented a GA for large-scale projects. Palencia & Delgadillo (2012) applied a GA approach to a bus assembly line. Ponz-Tienda et al. (2012) demonstrated the effectiveness of an adaptive GA. Afshar-Nadjafi et al. (2013) integrated intelligent local search into the GA and organized sub-activities based on resource usage, employing a unified approach within each set. Devikamalam & Jane (2013) optimized resource allocation and reduced costs. Kim (2013) utilized an elitist GA. Tasan & Gen (2013) employed a fuzzy logic control-based automatic adjustment strategy. Huang et al. (2013) developed formulas to estimate completion time and minimize cost in project scheduling with fuzzy activity durations, along with constructing different fuzzy models and analyzing GAs. Aziz (2013) focused on minimizing project duration and maximizing net present value. Cheng et al. (2014) used a fuzzy clustering method and Differential Evolution algorithm. Sawant (2016) developed a GA to minimize resource usage. Zhang et al. (2008) also addressed resource usage minimization. Furthermore, in recent years, the GA RCPSP method has been widely used in many fields (e.g., García-Nieves et al., 2018; Muritiba et al., 2018; Chand et al. 2019; Zamani, 2019; Chaleshtarti et al., 2020; Liu et al., 2020; Snauwaert & Vanhoucke, 2021; Zaman et al., 2021; Aramesh et al., 2022; Hua et al., 2022; Myszkowski & Laszczyk, 2022; Coelho & Vanhoucke, 2023; Xu & Bai, 2023; Zhang et al., 2023).

The studies in regard to the use of fuzzy sets in project scheduling: Hapke & Slowinski (1996) proposed a fuzzy scheduling procedure for RCPSPs using fuzzy duration parameters and generating prioritized fuzzy orders. Bhaskar et al. (2011) introduced a parallel scheduling scheme based on priority rules for fuzzy activity durations in RCPSP. Long & Ohsato (2008) presented the fuzzy critical chain method for project scheduling. Çebi & Otay (2015) suggested a multi-objective linear programming model for minimizing project duration and cost in fuzzy project scheduling. Knyazeva et al. (2015) proposed a fuzzy heuristic priority algorithm for the fuzzy-constrained project scheduling problem in RCPSP. Birjandi et al. (2019) presented a hybrid fuzzy approach, FPND, combining PSO, BPSO, and GA, to minimize project end cost in the fuzzy RCPSP-MR problem, showcasing its effectiveness through comparisons and numerical examples.

The studies in regard to the production planning in shipbuilding: Cho & Chung (1996) introduced the part assembly chart, a semantic network representation system that utilized case-based and rule-based logic for ship block assembly planning. This system incorporated structural and geometric information, as well as cutting, bending, and welding operations. Lee et al. (1997) conducted research on ship production planning and scheduling, incorporating various disciplines such as operations management, artificial intelligence, and information technology. Their work focused on reducing scheduling time, selecting optimal schedules through simulation, and transferring technology from academia to industry. Kim et al. (2002) proposed a Constraint Satisfaction Problem-based algorithm to minimize unplanned blocks and balance workload in block assembly scheduling. Hiekata et al. (2010) introduced a method to improve design quality in ship production processes using statistical analysis and process ontology. Park & Seo (2010) developed GA-based approaches to solve storage location assignment problems in shipbuilding. Cha & Roh (2010) focused on process planning simulation models, particularly the simulation core. Soong et al. (2011) investigated ship production management strategies using various business tools and key performance indicators. Formentini & Romano (2011) proposed an information transfer model based on Value Analysis for multi-project environments. Yuguang et al. (2016) developed a real-time shipment and block assembly system for effective production control. Hwang et al. (2014) developed an intelligent simulation model for shipbuilding production planning and decision-making. In Joo & Kim (2014) presented a GA-based scheduling model for timely delivery of ship blocks. Park et al. (2014)

integrated process mining and data envelopment analysis for performance evaluation in ship block production processes. Kwon & Lee (2015) formulated a spatial scheduling problem for large assembly blocks in shipyard assembly lines. Back et al. (2016) defined a shipyard production simulation data model using an iterative procedure. Yuguang et al. (2016) developed a discrete particle swarm optimization algorithm for ship production assembly lines. Wang et al. (2016) proposed an integer programming model for ship block production considering uncertain factors. Dong et al. (2016) developed a flexible two-stage queue model for optimal cost-effectiveness in ship maintenance and construction. Mei et al. (2016) created an impact factor system for evaluating production processes in flexible intermediate product manufacturing. Furthermore, Hu et al. (2019) developed a guided local search algorithm for the 2D-RCPSP, Yang & Liu (2018) introduced a hybrid algorithm for fuzzy blocking flow shop scheduling, and Zhong (2017) proposed an improved genetic algorithm for multi-objective hull assembly line balancing. Li et al. (2021) integrated job scheduling, workshop layout, and transportation tasks for green manufacturing in marine crankshaft production using a genetic algorithm. Mao et al. (2020) presented an agent-based framework for collaborative planning and scheduling in shipbuilding projects. Other studies focused on improving time estimation precision (Li et al., 2019), shipbuilding block assembly line scheduling (Cho et al., 2022), and large-scale shipyard scheduling problems (Han et al., 2017). Jeong et al. (2018) proposed efficient spatial arrangement planning for shipyards, while Ge & Wang (2021) addressed block spatial scheduling optimization and scheduling strategies for irregular curved blocks. These studies collectively advance optimization techniques in shipbuilding, covering scheduling, resource utilization, spatial arrangement, and time estimation.

Accordingly, the contribution of this study is that the utilization of a GA approach to address the RCPSP in the context of shipbuilding, considering a fuzzy environment has not been studied in the existing academic literature.

Methodology

Resource Constraint Project Scheduling Problem

The RCPSP is a method that evaluates the activities of a project using limited resources without violating precedence relationships, aiming for the most suitable or optimal solution among mathematical methods. The RCPSP is a type of problem that is frequently studied in the literature and generates solutions using different methods. Due to the presence of two different constraints, activity priorities and resource constraints, it is considered more challenging than other problems. The RCPSP falls into the problem class classified as NP (Non-Polynomial) - Hard in the Strong Sense (Blazewicz et al., 1983) in the literature. Resources are the elements used for the realization of a project. The types of resources expressed in projects are as follows: Renewable resources have limited availability but do not deplete with usage. They can be reused after an activity. Non-renewable resources are limited and deplete with usage. When project duration and resource usage are constrained, they are doubly constrained. Non-renewable resources can be discrete if divisible into units, or continuous if indivisible. During the execution of activities that constitute projects, there is a relationship between the resources assigned and used for these activities. Usually, it is expressed as a Time-Cost Trade-Off, where it is expected that increasing the use of a resource in an activity will lead to a decrease in the activity duration. Due to the continuous and discrete nature of resource utilization, it is referred to as a continuous and discrete function of cost-time. In the case of discreteness, it is expressed as a mode corresponding to the cost-time pair. Project scheduling problems with multiple modes are also referred to as multi-modal problems. Another type of interaction is when the activity duration is fixed, but the resources can have different usages, which is called Resource-Resource Trade-Off. RCPSP models are examined in two categories as the Single-Mode RCPSP assumes fixed and unchanged project activity durations and assigned resource quantities, while the Multi-Mode RCPSP allows for variable and not fixed activity durations and assigned resource quantities. The RCPSP with multiple projects can be formulated in Eq. (1-5) as follows (Kolisch & Spracher, 1996; Ulusoy, 2002; Satıç, 2014; Akan, 2017).

$$min\ Z = \frac{\sum_{t=EFT_{jq}}^{LFT_{jq}} tX_{qjt}}{Q} \tag{1}$$

$$\sum_{t=EFT_j}^{LFT_j} X_{jt} = 1, j = 0, 1, \dots, n+1 \tag{2}$$

$$\sum_{t=EFT_i}^{LFT_i} tX_{imt} \leq \sum_{t=EFT_j}^{LFT_j} (t - d_j) X_{jt}, j = 1, \dots, n+1 \text{ and } i \in P_j \tag{3}$$

$$\sum_{j=1}^{j} k_{jr} \sum_{r=t}^{t+d_j-1} X_{jt} \leq K_r, r \in R, t = 1, \dots, r \tag{4}$$

$$X_{jt} = \begin{cases} 1, & if\ the\ activity\ j\ is\ finished\ at\ the\ end\ of\ the\ period\ t \\ 0, & for\ other\ situations, \end{cases} \tag{5}$$

where;

t the time index $t = 1, \dots, T$

j the activity index $j = 1, \dots, J$

R the set of renewable resources

d_j the duration of activity j^{th}

P_j the set of the predecessors of the activity j^{th}

EFT_j the earliest finish time of activity j^{th}

LFT_j the latest finish time of activity j^{th}

k_{jr} the amount of resource usage per unit time from resource r for activityj^{th}

K_r the unit time upper limit of resource utilization for renewable resource r

M_j the mode number of the activity j^{th}

q the project index $q = 1, \dots, Q$

Eq. (1) aims to minimize the objective function and project delays. Eq. (2) requires the scheduling of each activity j^{th}. Eq. (3) represents the constraint that activity j^{th} can start only when its dependent activities, X_{it}, i and P_j are completed. Eq. (4) represents the constraint that ensures the precedence relationship between activity $j^{th}$and its predecessor activity i^{th} is satisfied. Eq. (5) defines the resource constraint per unit of time for each activity, where the variable X_{jt} is defined within the time interval $\{EFT_j, LFT_j\}$.

In essence, the presence of multiple projects does not fundamentally differ from having a single project in the context under consideration. The decision variables and constraints remain unchanged for both single and multiple projects. However, the objectives of the projects may differ. For instance, while one project may solely aim to minimize project duration, another project may seek to minimize both duration and cost simultaneously. When addressing multiple projects, two approaches can be adopted: treating each project as an independent entity with its distinct start and finish nodes, or merging them into a unified project for evaluation. The integration of all projects allows for the creation of a single start and finish node. In this particular study, the two projects were integrated into a unified project, necessitating adjustments to the activity and resource relationships accordingly.

Genetic Algorithm (GA)

The GA technique, developed by Holland (1975) and further enhanced by Goldberg (1989), is an intuitive method inspired by the Theory of Evolution. It models the processes of inheritance, including crossover, mutation, and selection, to transmit inherited information to subsequent generations. GAs offer broad applicability and provide accurate, convenient, and efficient solutions for various problems GAs aim to address complex problems in various domains and fall under the category of metaheuristic techniques (Haupt & Haupt, 2004). One such application is RCPSPs. GAs consist of key elements: chromosome populations, fitness-based selection, crossover for generating new generations, and random mutations. GAs utilize fitness functions to evaluate chromosome quality. GAs differ from traditional optimization methods in several aspects. GAs utilize probabilistic rules, objective functions, sets of points for solution search, and parameter codes instead of direct manipulation. Haupt & Haupt (2004) classify GAs as metaheuristic techniques, primarily employed for addressing complex problems. With its advantages GAs demonstrate versatility in handling both continuous and discrete variables, operating without derivative information, exploring solutions concurrently with large samples, adapting well to problems with many variables, being suitable for parallel computing, overcoming local optima in complex solution variables, providing a list of optimal variable solutions, encoding variables for optimization, and working with numerical, experimental, or analytical functions. However, GAs may not be the best approach for every problem. Traditional methods may suffice for simple problems. Consider using GAs for large populations or when past experience indicates their efficacy (Goldberg, 1989). GA concepts possess the following characteristics (Coley, 1999; Mitchell, 1999; Haupt & Haupt, 2004):

- Gen represents a section of the solution in GAs, which corresponds to a project activity in RCPSP.
- Chromosome encodes a solution in GAs. It represents a scheduling solution in RCPSP, using random key, activity list, or other methods.
- Population is the number of solutions being searched simultaneously. A larger population increases the chances of finding the optimal solution, but population size should be adjusted to prevent excessive solution time.
- Generation is the process of producing solutions through successive iterations.
- Fitness Function evaluates solutions to recognize the desired solution. It can be a combination of objectives for problems with multiple goals.
- Selection chooses chromosomes for the next generation based on fitness functions.
- Crossover modifies chromosome programming from one generation to another, creating more qualified individuals.

- Mutation creates a new solution by making slight changes to existing information. Mutation can occur after crossover or independently and includes operations like reversal, displacement, insertion, and reciprocal exchange.

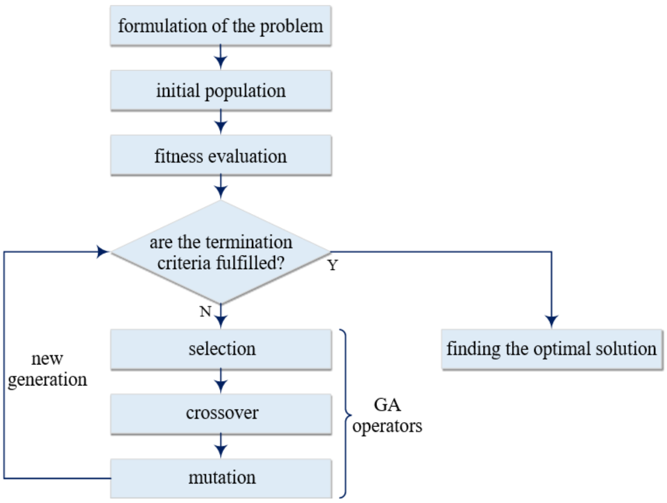


Figure 1. GA diagram

Generally, the operational principles of a standard GA can be summarized in Figure 1 as follows (Coley, 1999; Mitchell, 1999; Haupt & Haupt, 2004).

- Generating a solution population by encoding possible solutions. The population size is determined considering the complexity and depth of the problem.
- Evaluating the fitness of each chromosome in the population using a fitness function. The evolution process involves determining the quality of chromosomes through this function, which is problem-specific and critical to the success of the GA.
- Creating a new population by applying crossover and mutation operators to selected chromosomes. Crossover promotes diversity, while mutation influences individual solutions.
- Updating the population by replacing old chromosomes with newly generated ones, maintaining a fixed population size.
- Assessing the success of the population by calculating the fitness values of the new chromosomes.
- Iterating the process to produce improved generations within a specified time frame.
- Eventually, the solution is obtained by identifying the best individuals in the population during the generation computation.

Defuzzification Method in Fuzzy Sets

The trapezoidal fuzzy numbers defined as $\tilde{A} = (a, b, c, d)$ in fuzzy sets $A \in F(R)$, Wang (2009) proposed the widely used a centroid defuzzification method in computed by Eq. (6), which is based on trapezoidal numbers in fuzzy sets.

$$\tilde{X}_0(\tilde{A}) = \frac{1}{3}\left[a + b + c + d - \frac{dc-ab}{(d+c)-(a+b)}\right] \quad (6)$$

Application

In this study, the ship block construction problem in the shipyard was solved using a GA in a fuzzy duration environment with the RCPSP method. Subsequently, a solution set consisting of 32 solutions was generated based on 8 different scenarios within the framework of the shipyard's gradually decreasing 4 capacities. The solutions in this set were evaluated using the Pareto optimal curve method to find the solutions for the optimal shipyard capacity-project completion time. In addition, infeasible and unimplementable solutions were also searched and evaluated within the solution set in Figure 2. Accordingly, the solution steps were as follows:

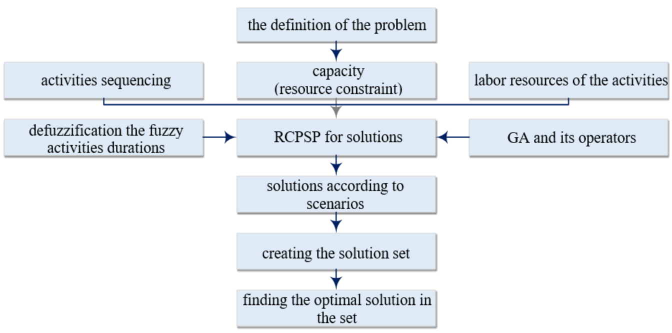


Figure 2. Proposed methodology follows

Since the problem is solved based on the RCPSP methodology, the objective function is specifically defined as RCPSP.

The block construction plans for ships A and B are available, and they were prepared according to the plans provided. The gradually decreasing shipyard capacity values are listed in Table 1. Additionally, Appendices includes the activity list, resource workforce values, activity precedence relationships indicating the activity sequencing, and information about which workstation the activities will be processed for the block construction of ships A and B also, they present the fuzzy trapezoidal duration assigned to the project activities. These data are also required for solving the RCPSP.

In Table 1, the capacity, resource supply, and constraints of workstations in the shipyard are allocated. Capacity1 represents the actual capacity of the shipyard for the work stations as WS 02, WS 04, WS 05, WS 09 and WS 12. Capacity 2 is obtained by reducing Capacity 1 by 75 workers, Capacity 3 is obtained by reducing Capacity 2 by reducing 75 workers, and Capacity 4 is obtained by reducing Capacity 3 by an additional 75 workers.

Since the problem is solved using a GA in the resource-constrained project scheduling framework, deterministic processing with durations is necessary. Due to the fuzzy duration representation of activity durations, the fuzzy durations of activities are transformed into deterministic durations through defuzzification considering the membership function of fuzzy trapezoidal numbers with known weights. Appendices provide the fuzzy trapezoidal durations of the block construction activities for ships A and B and their corresponding defuzzified values.

Table 1. The capacity, resource supply, and constraints of workstations in the shipyard

Work Station (WS)	**Resource (workforce)**	**Capacity 1 *(person/day)***	**Capacity 2 *(person/day)***	**Capacity 3 *(person/day)***	**Capacity 4 *(person/day)***
WS 02 (Cutting)	Resource 1 (Cutting workforce)	10	10	10	10
WS 04 (Prefabrication)	Resource 2 (Prefabrication Workforce)	115	100	85	70
WS 05 (Panel Production)	Resource 3 (Panel Production Workforce)	115	100	85	70
WS 09 (Block Production)	Resource 4 (Block Production Workforce)	270	240	210	180
WS 12 (Slipway)	Resource 5 (Slipway Workforce)	135	120	105	90
Total		645	570	495	420

Table 2. The solution scenarios of the problem

Scenario	**Description**	**Capacity 1**	**Capacity 2**	**Capacity 3**	**Capacity 4**
A	Normal project programming	*A1*	*A2*	*A3*	*A4*
B	20% workforce increase for WS 04 (Prefabrication) and WS 05 (Panel Production)	*B1*	*B2*	*B3*	*B4*
C	3 workers (12%) increase in critical activities 295 and 297	*C1*	*C2*	*C3*	*C4*
D	3 workers (12%) increase in critical activities 274, 299, 300 and 301	*D1*	*D2*	*D3*	*D4*
E	3 workers (12%) increase in critical activities 274, 295, 297, 299, 300 and 301	*E1*	*E2*	*E3*	*E4*
F	5 workers (20%) increase in critical activities 295 and 297	*F1*	*F2*	*F3*	*F4*
G	5 workers (20%) increase in critical activities 274, 299, 300 and 301	*G1*	*G2*	*G3*	*G4*
H	5 workers (20%) increase in critical activities 274, 295, 297, 299, 300 and 301	*H1*	*H2*	*H3*	*H4*

With all the necessary data provided, the solution sets are generated using the GA in the RCPSP. In this study, the GA, which is a metaheuristic method, is employed for solving the RCPSP. Therefore, the mutation rate, selection rate, crossover, population size, and generation parameter values of the GAs are determined, and the problem-solving process starts with these parameter values. Multiple solutions were generated for each solution with different GA parameter values, and the solutions with the best local values were included in the solution set. The assumptions in line with the structure of the GA RCPSP can be stated as follows:

- Activity durations are deterministic, converting fuzzy durations into precise values
- The amount of resources used per unit of time in activities is constant.
- A resource assigned to an activity cannot be used by another activity until the completion of that activity.
- There are no breaks or discontinuities between the start and finish of activities.
- The defined activities cannot be canceled and must be completed.
- The resources used for the execution of activities are considered as renewable resources.
- Subsequent activities cannot start before the completion of preceding activities.
- RCPSP literature can be classified into groups aiming to minimize project duration, project cost, or achieve a multi-objective optimal solution considering time and cost.
- *Initialization of the Initial Population*: Activities were assigned randomly within a given period based solely on their priority constraints. The scheduling period used was the longest completion time of the project. Start times were sorted in descending order based on the activity constraints, creating the initial activity sequence.
- *Chromosome Structure*: Chromosomes were constructed using the activity list design method. Genes in the chromosome represented the starting order of activities. Activity starts and finish times were determined based on the activity sequence and resource capacities.
- *Generation of the Initial Population*: The initial population was randomly generated according to the activity priority rule. Serial scheduling was employed to order the project's activities.
- *Fitness Function*: The fitness function evaluated the chromosomes based on the project's duration.
- The objective was to minimize the project's duration while considering all resource constraints.
- *Crossover Operation*: Single-point sequential crossover method was used.
- *Mutation Operation*: Single-point mutation operator was applied with varying mutation parameters.
- *Selection Operation*: Elitist selection mechanism was employed to choose the best individuals for the next generation.
- *Termination of the Algorithm*: The algorithm stopped after reaching a specified generation count.
- *Software Solution*: The Genetic Algorithm Project Scheduler (Satıç, 2014) was used to compute the RCPSP.

Based on these 8 different scenarios, a solution set consisting of 32 solutions, representing the shipyard's capacity-project completion time combinations, is generated. In this study, various solution scenarios were generated for ship block construction, considering the problem scenarios. Solutions were then produced based on these scenarios. These scenarios are classified as follows. The solution set for these scenarios is presented in Table 2.

In the context of a ship block construction project where a GA-based resource-constrained project scheduling method is applied in a fuzzy time environment, the solutions obtained based on different project capacities are provided in Table 3. When evaluating the project completion times in the solution set, the following observations can be made:

- *Normal Project Completion Time:* The project's normal completion time, without any resource constraints, is 462 days.
- *Scenario A:* Normal Project Scheduling: In this scenario, the project completion time remains the same at 462 days for the capacities of shipyard numbers 1, 2, and 3. Despite a gradual decrease in the shipyard's capacity, there is no increase in the project completion time. However, for the solution based on the capacity of shipyard number 4, the project completion time increases by 20 days to 482 days.
- *Scenario B:* 20% Workforce Increase for WS 04 and WS 05: In this scenario, the project completion time remains the same at 461 days for the capacities of shipyard numbers 1, 2, and 3. There is no increase in the project completion time despite the gradual decrease in the shipyard's capacity. Furthermore, with the increase in workforce, the project duration is reduced by 1 day. However, for the solution based on the capacity of shipyard number 4, the project completion time increases by 11 days to 473 days.
- *Scenario C:* 3-Person (12%) Increase for Activities 295 and 297: In this scenario, the project completion time remains the same at 445 days for the capacities of shipyard numbers 1, 2, and 3. Despite the decrease in the

shipyard's capacity, there is no increase in the project completion time. By increasing the resources for activities 295 and 297, the project completion time is reduced by 17 days. However, for the solution based on the capacity of shipyard number 4, the project completion time decreases by 6 days to 456 days.

- *Scenario D:* 3-Person (12%) Increase for Activities 274, 299, 300, and 301: In this scenario, the project completion time decreases by 17 days to 445 days for the capacity of shipyard number 1, by 14 days to 448 days for the capacity of shipyard number 2, by 13 days to 449 days for the capacity of shipyard number 3, and increases by 11 days to 473 days for the capacity of shipyard number 4.
- *Scenario E:* 3-Person (12%) Increase for Activities 274, 295, 297, 299, 300, and 301: In this scenario, the project completion time decreases by 30 days to 432 days for the capacities of shipyard numbers 1 and 2, by 29 days to 433 days for the capacity of shipyard number 3, and increases by 7 days to 469 days for the capacity of shipyard number 4.
- *Scenario F:* 5-Person (15%) Increase for Activities 295 and 297: In this scenario, the project completion time decreases by 26 days to 436 days for the capacities of shipyard numbers 1, 2, and 3, and decreases by 6 days to 456 days for the capacity of shipyard number 4.
- *Scenario G:* 5-Person (15%) Increase for Activities 274, 299, 300, and 301: In this scenario, the project completion time decreases by 21 days to 441 days for the capacities of shipyard numbers 1 and 2, by 19
- *Scenario H:* 5-Person (15%) Increase for Activities 274, 295, 297, 299, 300, and 301: In this scenario, the project completion time decreases by 47 days to 415 days for the capacity of shipyard number 1, decreases by 43 days to 419 days for the capacity of shipyard number 2, decreases by 41 days to 421 days for the capacity of shipyard number 3, and decreases by 13 days to 449 days for the capacity of shipyard number 4.

According to the results of the project computation in Table 3:

- For *Capacity 1*, which is 645 persons/day; the project completion duration is 462 days for *A1*, 461 days for *B1*, 445 days for *C1*, 445 days for *D1*, 432 days for *E1*, 436 days for *F1*, 441 days for *G1* and 415 days for *H1*.
- For *Capacity 2*, which is 570 persons/day; the project completion duration is 462 days for *A2*, 461 days for *B2*, 445 days for *C2*, 448 days for *D2*, 432 days for *E2*, 436 days for *F2*, 441 days for *G2* and 419 days for *H2*.
- For *Capacity 3*, which is 495 persons/day; the project completion duration is 462 days for *A3*, 461 days for *B3*, 445 days for *C3*, 449 days for *D3*, 433 days for *E3*, 436 days for *F3*, 443 days for *G3* and 421 days for *H3*.
- For *Capacity 4*, which is 420 person/day; the project completion duration is 482 days for *A4*, 473 days for *B4*, 456 days for *C4*, 473 days for *D4*, 469 days for *E4*, 456 days for *F4*, 471 days for *G4* and 449 days for *H4*.

The Pareto optimal curve method is applied to the solution set to identify optimal solutions and infeasible solutions, which are then interpreted. After 32 different scenarios consisting of shipyard capacity and project completion times were computed by proposed methodology, a convex solution set of Pareto optimality is obtained as shown in Figure 2. Accordingly, solutions within the region that does not lie on the convex Pareto curve are observed not to be optimal solutions.

Table 3. The comparison of project completion durations

Scenario	**Capacity 1**	**Capacity 2**	**Capacity 3**	**Capacity 4**
	645 persons/day	***570 persons/day***	***495 persons/day***	***420 persons/day***
An	462 days	462 days	462 days	482 days
Bn	461 days	461 days	461 days	473 days
Cn	445 days	445 days	445 days	456 days
Dn	445 days	448 days	449 days	473 days
En	432 days	432 days	433 days	469 days
Fn	436 days	436 days	436 days	456 days
Gn	441 days	441 days	443 days	471 days
Hn	415 days	419 days	421 days	449 days

Note: $n=(1, \ldots, 4), n \in N$

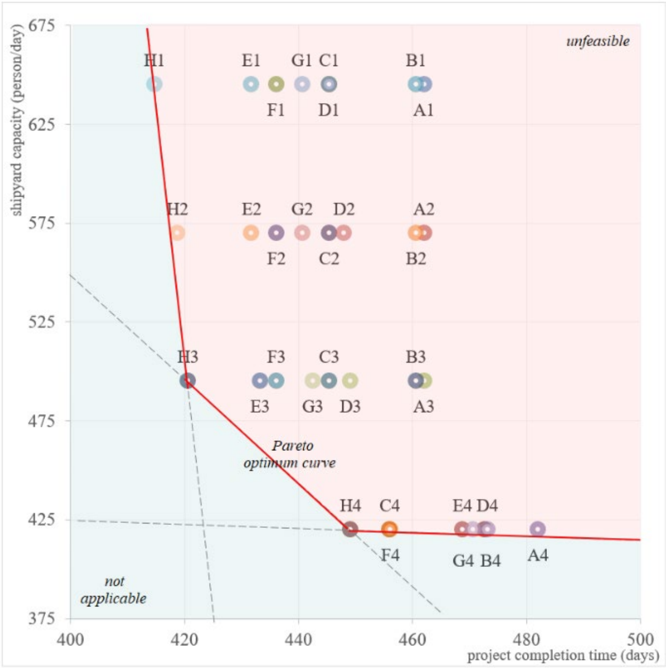


Figure 2. The Pareto optimal curve and the capacity-time solution set

The solutions located on the Pareto optimal curve are represented by *H1*, *H3*, *H4*, and *F4*. Therefore, the optimal solution should be sought within this boundary. Upon examining these solutions: Scenario *H1* is the solution with the shortest duration and the highest capacity supply. Scenario *H3* is one of the optimal solutions. Scenario *H4* is one of the optimal solutions. Scenario *F4* is the solution with the longest duration and the lowest capacity supply. Furthermore, comparing *H3* and *H4*, in *H3*, the project completion time is 421 days with a shipyard capacity of 495 persons/day, whereas in *H4*, the project completion time is 449 days with a shipyard capacity of 420 persons/day. Although the solutions within the space that is not on the convex Pareto curve are not optimal solutions, their preference or prioritization will be evaluated by the shipyard. On the other Project delays lead to increased costs, while early completion yields cost savings. As the resources allocated from the shipyard capacity decrease, the gains in cost increase up to a certain threshold. Scenarios *A4*, *B4*, *D4*, *E4*, and *G4* of the shipyard do not exhibit value gains but rather result in losses. Scenarios *A1*, *A2*, and *A3* do not yield any gains or losses. Other solutions show gains. The largest value loss occurs in scenario *A4* with shipyard capacity number 4, whereas the greatest value gain is observed in scenario *H1* with shipyard capacity 1.

Results and Discussion

This study addresses the RCPSP in the context of block construction of ships in shipyards, aiming to optimize capacity utilization. The RCPSP becomes particularly important in competitive environments or situations with limited resources. The problem objectives in RCPSP include minimizing costs, minimizing project duration, and optimizing the trade-off between costs and time.

The flow time values are the same for all jobs at workstation WS 02 in the entire capacity of the shipyard. This is because the station operates at full capacity and there is no idle workforce available. Additionally, this station has the shortest processing time among all production workstations. On the other hand, workstation WS 09 has the highest flow time value among the production workstations, which is proportional to the decrease in its capacity. Furthermore, when the shipyard's capacity decreases, this workstation still has the highest flow time value, and the job flow at this workstation becomes intermittent when the shipyard operates at capacity 4. Considering the block construction times of both ships and the conditions at their workstations, the flow time of *ship B*, which is being constructed, is longer than that of *ship A*. When evaluating the solution set based on the makespan (total project completion time), both projects are expected to be completed within 462 days under normal conditions. However, solutions that exceed this duration result in longer makespan values. The project completion times range from a maximum of 482 days to a minimum of 415 days. Therefore, a decrease in the shipyard's capacity leads to longer project durations. While projects can be completed within the normal or shorter time frame for shipyard capacities 1, 2, and 3, the makespan, or total project completion time, increases for capacity 4. This pattern is observed in other solution alternatives as well. When the project's completion time exceeds the normal completion time, the lateness values in this solution set become greater than zero, resulting in tardiness. An increase in tardiness is observed as the resource constraint decreases. Among the solutions in the solution set, the solution obtained with the shipyard's capacity 4 shows the highest tardiness value. For other solution scenarios, the tardiness values are lower. In contrast, no tardiness occurs for capacities 1, 2, and 3, and the lateness values are smaller than zero due to projects being completed earlier than the normal completion time. The solution set includes projects with completion times reduced to 415 days, and the solution with the smallest earliness value is generated by *H1*. Solutions *C4*, *F4*, and *H4* show earliness values for capacity 4 and for other capacities, which means the projects are completed earlier. All solutions in the solution set aim to minimize the completion time for the due dates of the projects. For capacities 1, 2, and 3, the completion time occurs earlier than the project's total completion time. However, for capacity 4, the completion time is later than the project's total completion time with a certain tardiness value. In the block construction process, for delayed projects, especially in capacity 4 of the shipyard, the critical ratio can be used to prioritize the completion of preferred projects or projects that need to be completed early in order to prevent delays in project delivery. However, in this study, the completion time of *ship B* is later than that of *ship A*, so such a delivery priority is disregarded. For solutions in capacities 1, 2, and 3 of the shipyard, the resource histogram shows similar values for the makespan, which is the normal completion time of the project. However, in capacity 4 of the shipyard, as the workforce supply provided by the shipyard decreases, the resource distribution changes, resulting in an increase in the makespan of the project. Therefore, the resource distribution chart shows a spread towards the completion time of the project.

In the literature, GA RCPSP method has been widely used in many fields (e.g., Muritiba et al., 2018; Chand et al. 2019; Liu et al., 2020; Zaman et al., 2021; Hua et al., 2022; Zhang et al., 2023) however, neither GA RCPSP nor RCPSP in fuzzy environment has been proposed as a methodology for the shipbuilding except for the study of Akan (2017), but there is a study that proposes a project scheduling problem with spatial resource constraints (Hu et al., 2019) for RCPSP methodology in shipbuilding. . On the other hand, RCPSP are widely applied in many fields with integrating extension methods such as branch and bound (Bianco & Caramia, 2012), fuzzy mixed integer nonlinear programming (MILP), and GA and particle swarm optimization (PSO) (Birjandi & Mousavi, 2019), ant colony optimization (ACO) (Dridi et al., 2019), fuzzy clustering chaotic-based differential evolution (Cheng et al., 2014), genetic programming based hyper-heuristic (Chand et al., 2018), memetic algorithm (Rahman et al., 2022), hybrid simulation and optimization (Wang et al., 2020), multi-agent-based cooperative (Li et al., 2021), exact linear programming binary formulation (García-Nieves et al., 2019), Improvement of the critical chain method (Tian et al., 2020), nondominated sorting genetic algorithm II (NSGA-II) (Laszczyk & Myszkowski, 2019), and column generation (Changchun et al., 2018).

In production planning and management, scheduling operations play a crucial role. Finding the best schedule can be challenging, depending on the project environment, performance criteria, and process constraints. GAs are a viable method for addressing RCPSPs, which belong to the *np-hard in the strong sense* class. While intuitive approaches don't guarantee optimal solutions, metaheuristic methods like GAs have shown better results. These problems offer combinatorial solutions, and GAs provide efficient and effective solutions. GAs use genetic operators, including crossover, mutation, and selection, to create the solution set. The mutation rate, ranging from 0% to 100%, influences the best solution time, with rates of 50% to 70% yielding optimal results. Selection operators prioritize the project completion time, typically with selection rates of 10% to 20% for the best local value. The population rate, representing the global solution set, is usually set between 100 and 200. As the population size increases, the solution space grows, resulting in longer solution times. The number of generations affects the algorithm's runtime and the quality of the best local solution. Generally, 1,000 to 2,000 generations are preferred, with 1,000 generations often leading to the best solutions. GAs search for solutions within a population rather than a single set. Mutated and selected new generations maintain the problem objectives, and the final generation with improved solution sets achieves the best result. Traditional methods for resource-constrained project scheduling, such as first come first served, fail to consider future resource requirements. In contrast, GAs prioritize critical activities and schedule remaining activities randomly, adhering to priority rules and project-wide constraints. The scheduling process generates a population of solutions, which is then refined using genetic operators until the desired number of generations is reached. GAs require computer resources even for simple projects. The algorithm's design involves methods, encoding, creation, population initialization, genetic operators (crossover, mutation, selection), and a fitness function. Genetic parameters, including population size, generation count, mutation rate, and project activity count, impact the algorithm's runtime.

In terms of practical implications, shipbuilding projects often face uncertainties such as unexpected delays, material shortages, or workforce fluctuations. This means that shipbuilders can plan and allocate resources more effectively, taking into account potential disruptions, and thereby improving the overall project success rate. On the analysis side, stakeholders can visually understand the impact of different scheduling decisions and the trade-offs involved. In addition, shipbuilding production efficiency is improved by optimizing the allocation of resources and tasks, resulting in reduced project completion times while maintaining effective resource utilization. This optimization is critical due to the limited and expensive resources in shipbuilding. GAs can be used to optimize allocation, ensuring that the right resources are assigned to tasks at the right time. This minimizes waste and idle time, ultimately resulting in cost savings. These actions have a significant financial impact, leading to a faster return on investment and improved overall business performance.

Conclusion

This study optimizes ship production processes through the RCPSP, focusing on cost minimization, project duration reduction, and optimal cost-time optimization. Utilizing GA and fuzzy set theory, it enhances project planning for efficient resource allocation in competitive, resource-intensive shipbuilding. The framework integrates probabilistic models and scenario analysis to optimize project completion time and resource utilization.

The study's major contributions to the literature can be summarized as follows:

i) The solution of GA RCPSP method in fuzzy environment was carried out.

ii) The analysis of Pareto optimal solutions was carried out.

iii) The application of this study has been carried out in shipbuilding industry.

Overall, it was observed that the utilization of a GA approach to address the RCPSP in the context of shipbuilding, considering a fuzzy environment can be applied to ship production plan during the shipbuilding process. With this study, GA RCPSP with fuzzy environment in shipbuilding process planning can be a contribution for the literature of the shipbuilding process.

The main limitation of this study is that the method GA RCPSP can be designed different aspects to optimize alternative solutions with GA designed architecture. Regarding future research, the problem can be applied by different designed GA RCPSP methodologies or alternative metaheuristic RCPSP solutions methods or other methods. The focus will be on the development of methods for the parallel inclusion of fuzzy numbers in the model. A shipyard will engage in holistic planning by considering all shipbuilding projects within the shipyard's production planning process.

Acknowledgements

This article was prepared based on the doctoral thesis entitled "Model of Ship Production Management in Shipyard: A Case Study in Marmara Region" completed by the first author in the "Maritime Transportation Management Engineering" PhD Program at Institute of Graduate Studies in Science, İstanbul University.

Compliance With Ethical Standards

Authors' Contributions

EA: Manuscript design, Drafting, Writing, Data analysis.
GA: Manuscript design, Drafting, Writing, Data analysis.
Both authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Data Availability Statement

All data generated or analyzed during this study are included in this published article and its supplementary information files.

Supplementary Materials

Supplementary data to this article can be found online at https://doi.org/10.33714/masteb.1324266

References

Abbasi, B., Shadrokh, S., & Arkat, J. (2006). Bi-objective resource-constrained project scheduling with robustness and makespan criteria. *Applied mathematics and Computation*, *180*(1), 146-152. https://doi.org/10.1016/j.amc.2005.11.160

Adhau, S., Mittal, M. L., & Mittal, A. (2012). A multi-agent system for distributed multi-project scheduling: An auction-based negotiation approach. *Engineering Applications of Artificial Intelligence*, *25*(8), 1738-1751. https://doi.org/10.1016/j.engappai.2011.12.003

Adhau, S., Mittal, M. L., & Mittal, A. (2013). A multi-agent system for decentralized multi-project scheduling with resource transfers. *International Journal of Production Economics*, *146*(2), 646-661. https://doi.org/10.1016/j.ijpe.2013.08.013

Afshar-Nadjafi, B., Rahimi, A., & Karimi, H. (2013). A genetic algorithm for mode identity and the resource constrained project scheduling problem. *Scientia Iranica*, *20*(3), 824-831. https://doi.org/10.1016/j.scient.2012.11.011

Akan, E., & Bayar, S. (2022). Interval type-2 fuzzy program evaluation and review technique for project management in shipbuilding, *Ships and Offshore Structures*, *17*(8), 1872-1890, https://doi.org/10.1080/17445302.2021.1950350

Akan, E. (2023). A holistic analysis of maritime logistics process in fuzzy environment in terms of business process management. *Business Process Management Journal*, *29*(4), 1116-1158. https://doi.org/10.1108/BPMJ-08-2022-0368

Akan, E., (2017). *Tersanelerde Gemi Üretim Yönetimi Modeli: Marmara Bölgesinde Bir Uygulama*. [PhD Thesis. İstanbul University].

Akhbari, M. (2022). Integration of multi-mode resource-constrained project scheduling under bonus-penalty policies with material ordering under quantity discount scheme for minimizing project cost. *Scientia Iranica*, *29*(1), 427-446. https://doi.org/10.24200/sci.2020.54286.3680

Alcaraz, J., & Maroto, C. (2001). A robust genetic algorithm for resource allocation in project scheduling. *Annals of operations Research*, *102*, 83-109. https://doi.org/10.1023/A:1010949931021

Aramesh, S., Aickelin, U., & Akbarzadeh Khorshidi, H. (2022). A hybrid projection method for resource-constrained project scheduling problem under uncertainty. *Neural Computing and Applications*, *34*(17), 14557-14576. https://doi.org/10.1007/s00521-022-07321-2

Asadujjaman, M., Rahman, H. F., Chakrabortty, R. K., & Ryan, M. J. (2021). An immune genetic algorithm for solving NPV-based resource constrained project scheduling problem. *IEEE Access*, *9*, 26177-26195. https://doi.org/10.1109/ACCESS.2021.3057366

Aziz, R. F. (2013). Optimizing strategy software for repetitive construction projects within multi-mode resources. *Alexandria Engineering Journal*, *52*(3), 373-385. https://doi.org/10.1016/j.aej.2013.04.002

Back, M. G., Lee, D. K., Shin, J. G., & Woo, J. H. (2016). A study for production simulation model generation system based on data model at a shipyard. *International Journal of Naval Architecture and Ocean Engineering*, *8*, 496e510. https://doi.org/10.1016/j.ijnaoe.2016.05.005

Bhaskar, T., Pal, M. N., & Pal, A. K. (2011). A heuristic method for RCPSP with fuzzy activity times. *European Journal of Operational Research*, *208*(1), 57-66. https://doi.org/10.1016/j.ejor.2010.07.021

Bianco, L., & Caramia, M. (2012). An exact algorithm to minimize the makespan in project scheduling with scarce resources and generalized precedence relations. *European Journal of Operational Research*, *219*(1), 73-85. https://doi.org/10.1016/j.ejor.2011.12.019.

Birjandi, A., & Mousavi, S. M. (2019). Fuzzy resource-constrained project scheduling with multiple routes: A heuristic solution. *Automation in Construction*, *100*, 84-102. https://doi.org/10.1016/j.autcon.2018.11.029

Birjandi, A., Mousavi, S. M., Hajirezaie, M., & Vahdani, B. (2019). A new weighted mixed integer nonlinear model and FPND solution algorithm for RCPSP with multi-route work packages under fuzzy uncertainty. *Journal of Intelligent & Fuzzy Systems*, *37*(1), 737-751. https://doi.org/10.3233/JIFS-181293

Blazewicz, J., Lenstra, J. K., & Rinnooy Kan, A. H. G. (1983). Scheduling subject to resource constraints: Classification and complexity. *Discrete Applied Mathematics*, *5*, 11-22. https://doi.org/10.1016/0166-218X(83)90012-4

Boctor, F. F. (1996). A new and efficient heuristic for scheduling projects with resource restrictions and multiple execution modes. *European Journal of Operational Research*, *90*(2), 349-361. https://doi.org/10.1016/0377-2217(95)00359-2

Brucker, P., & Knust, S. (2000). A linear programming and constraint propagation-based lower bound for the RCPSP. *European Journal of Operational Research*, *127*(2), 355-362. https://doi.org/10.1016/S0377-2217(99)00489-0

Çebi, F., & Otay, İ. (2015). A fuzzy multi-objective model for solving project network problem with bonus and incremental penalty cost. *Computers & Industrial Engineering*, *82*, 143-150. https://doi.org/10.1016/j.cie.2015.01.007

Cha, J. H., & Roh, M. I. (2010). Combined discrete event and discrete time simulation framework and its application to the block erection process in shipbuilding. *Advances in Engineering Software*, *41*, 656-665.

Chaleshtarti, A. S., Shadrokh, S., Khakifirooz, M., Fathi, M., & Pardalos, P. M. (2020). A hybrid genetic and Lagrangian relaxation algorithm for resource-constrained project scheduling under nonrenewable resources. *Applied Soft Computing*, *94*, 106482. https://doi.org/10.1016/j.asoc.2020.106482

Chand, S., Huynh, Q., Singh, H., Ray, T., & Wagner, M. (2018). On the use of genetic programming to evolve priority rules for resource constrained project scheduling problems. *Information Sciences*, *432*, 146-163. https://doi.org/10.1016/j.ins.2017.12.013

Chand, S., Singh, H., & Ray, T. (2019). Evolving heuristics for the resource constrained project scheduling problem with dynamic resource disruptions. *Swarm and Evolutionary Computation*, *44*, 897-912. https://doi.org/10.1016/j.swevo.2018.09.007

Chang, C. K., Jiang, H. Y., Di, Y., Zhu, D., & Ge, Y. (2008). Time-line based model for software project scheduling with genetic algorithms. *Information and Software Technology*, *50*(11), 1142-1154. https://doi.org/10.1016/j.infsof.2008.03.002

Changchun, L., Xi, X., Canrong, Z., Qiang, W., & Li, Z. (2018). A column generation based distributed scheduling algorithm for multi-mode resource constrained project scheduling problem. *Computers & Industrial Engineering*. *125*, 258-278. https://doi.org/10.1016/j.cie.2018.08.036

Cheng, M. Y., Tran, D. H., & Wu, Y. W. (2014). Using a fuzzy clustering chaotic-based differential evolution with serial method to solve resource-constrained project scheduling problems. *Automation in Construction*, *37*, 88-97. https://doi.org/10.1016/j.autcon.2013.10.002

Cho, K. K., & Chung, D. S. (1996). An automatic process-planning system for block assembly in shipbuilding. *ClRP Annals*, *45*(1), 41-46. https://doi.org/10.1016/S0007-8506(07)63013-3

Cho, Y. I., Nam, S. H., Cho, K. Y., Yoon, H. C., & Woo, J. H. (2022). Minimize makespan of permutation flowshop using pointer network. *Journal of Computational Design and Engineering*, *9*(1), 51-67. https://doi.org/10.1093/jcde/qwab068

Coelho, J., & Tavares. L. (2003). *Comparative analysis of meta–heuristics for the resource constrained project scheduling problem*. Technical report, Department of Civil Engineering, Instituto Superior Tecnico, Portugal.

Coelho, J., & Vanhoucke, M. (2023). New resource-constrained project scheduling instances for testing (meta-) heuristic scheduling algorithms. *Computers & Operations Research*, *153*, 106165. https://doi.org/10.1016/j.cor.2023.106165

Coley, D. A. (1999). *An introduction to Genetic Algorithms for Scientists and Engineers*. World Scientific.

Devikamalam, J., & Jane Helena, H. (2013). Resource scheduling of construction projects using genetic algorithm, *International Journal of Advanced Engineering Technology*, *4*(3), 113-119.

Dong, F., Deglise-Hawkinson, J. R., Van Oyen, M. P., & Singer, D. J. (2016). Dynamic control of a closed two-stage queueing network for outfitting process in shipbuilding. *Computers & Operations Research*, *72*, 1-11. https://doi.org/10.1016/j.cor.2015.05.002

Dridi, O., Krichen, S., & Guitouni, A. (2014). A multiobjective hybrid ant colony optimization approach applied to the assignment and scheduling problem. *International Transactions in Operational Research*, *21*(6), 935-953. https://doi.org/10.1111/itor.12071

Ecorys. (2009). *Study on competitiveness of the European shipbuilding industry: Within the framework contract of sectoral competitiveness studies* – ENTR/06/054. Final report.

Etgar, R., Gelbard, R., & Cohen, Y. (2018). Feature assignment in multi-release work plan: accelerating optimization using gene clustering. *Computers & Industrial Engineering*, *118*, 123-137. https://doi.org/10.1016/j.cie.2018.02.036

Formentini, M., & Romano, P. (2011). Using value analysis to support knowledge transfer in the multi-project setting. *International. Journal of Production Economics*, *131*, 545–560. https://doi.org/10.1016/j.ijpe.2011.01.023

Franco, E. D., Zurita, F. L. Z., & Delgadillo, G. M. (2007). A genetic algorithm for the resource constrained project scheduling problem (RCPSP). *Revista Investigación & Desarrollo*, 7(1), 39-50.

García-Nieves, J. D., Ponz-Tienda, J. L., Ospina-Alvarado, A., & Bonilla-Palacios, M. (2019). Multipurpose linear programming optimization model for repetitive activities scheduling in construction projects. *Automation in Construction*, *105*, 102799. https://doi.org/10.1016/j.autcon.2019.03.020

García-Nieves, J. D., Ponz-Tienda, J. L., Salcedo-Bernal, A., & Pellicer, E. (2018). The multimode resource-constrained project scheduling problem for repetitive activities in construction projects. *Computer-Aided Civil and Infrastructure Engineering*, *33*(8), 655-671. https://doi.org/10.1111/mice.12356

Ge, Y., & Wang, A. (2021). Spatial scheduling for irregularly shaped blocks in shipbuilding. *Computers & Industrial Engineering*, *152*, 106985. https://doi.org/10.1016/j.cie.2020.106985

Goldberg, D. A. (1989). *Genetic Algorithms in search optimization and machine learning*. Addison-Wesley Publishing.

Goncalves, J. F., Mendes, J. J. M., & Resende, M. G. C. (2008). A genetic algorithm for the resource constrained multi-project scheduling problem. *European Journal of Operational Research*, *189*, 1171–1190. https://doi.org/10.1016/j.ejor.2006.06.074

Goo, B., Chung, H., & Han, S. (2019). Layered discrete event system specification for a ship production scheduling model. *Simulation Modelling Practice and Theory*, *96*, 101934. https://doi.org/10.1016/j.simpat.2019.101934

Guo, W., Vanhoucke, M., Coelho, J., & Luo, J. (2021). Automatic detection of the best performing priority rule for the resource-constrained project scheduling problem. *Expert Systems with Applications*, *167*, 114116. https://doi.org/10.1016/j.eswa.2020.114116

Hadžić, N. (2019). Analytical solution of the serial Bernoulli production line steady-state performance and its application in the shipbuilding process. *International Journal of Production Research*, *57*(4), 1052-1065. https://doi.org/10.1080/00207543.2018.1500042

Han, D., Yang, B., Li, J., Sun, M., Zhou, Q., & Wang, J. (2017). A three-layer parallel computing system for shipbuilding project scheduling optimization. *Advances in Mechanical Engineering*, *9*(10), 1687814017723297. https://doi.org/10.1177/1687814017723297

Hapke, M., & Slowinski, R. (1996). Fuzzy priority heuristics for project scheduling. *Fuzzy sets and systems*, *83*(3), 291-299. https://doi.org/10.1016/0165-0114(95)00338-X

Hartmann, S. (1998). A competitive genetic algorithm for resource-constrained project scheduling. *Naval Research Logistics (NRL)*, *45*(7), 733-750. https://doi.org/10.1002/(SICI)1520-6750(199810)45:7%3C733::AID-NAV5%3E3.0.CO;2-C

Hartmann, S. (2001). Project scheduling with multiple modes: a genetic algorithm. *Annals of Operations Research*, *102*(1-4), 111-135. https://doi.org/10.1023/A:1010902015091

Hartmann, S. (2002). A self-adapting genetic algorithm for project scheduling under resource constraints. *Naval Research Logistics (NRL)*, 49(5) 433-448. https://doi.org/10.1002/nav.10029

Hartmann, S., & Kolisch, R. (2000). Experimental evaluation of state-of-the-art heuristics for the resource-constrained project scheduling problem. *European Journal of Operational Research*, *127*(2), 394-407. https://doi.org/10.1016/S0377-2217(99)00485-3

Haupt, R. L., & Haupt, S. E. (2004). *Pratical genetic algorithms.* 2nd ed. Wiley-Interscience Publication.

Hiekata, K., Yamato, H., & Tsujimoto, S. (2010). Ontology based knowledge extraction for shipyard fabrication workshop reports. *Expert Systems with Applications*, *37*, 7380-7386. https://doi.org/10.1016/j.eswa.2010.04.031

Hindi, K. S., Yang, H., & Fleszar, K. (2002). An evolutionary algorithm for resource-constrained project scheduling. *IEEE Transactions on Evolutionary Computation*, *6*, 512-518. https://doi.org/10.1109/TEVC.2002.804914

Holland, J. H. (1975). Adaptation in natural and artificial systems. The MIT Press.

Homberger, J. (2007). A multi-agent system for the decentralized resource-constrained multi-project scheduling problem. *International Transactions in Operational Research*, *14*(6), 565-589. https://doi.org/10.1111/j.1475-3995.2007.00614.x

Hu, S., Zhang, Z., Wang, S., Kao, Y., & Ito, T. (2019). A project scheduling problem with spatial resource constraints and a corresponding guided local search algorithm. *Journal of the Operational Research Society*, *70*(8), 1349–1361. https://doi.org/10.1080/01605682.2018.1489340

Hua, Z., Liu, Z., Yang, L., & Yang, L. (2022). Improved genetic algorithm based on time windows decomposition for solving resource-constrained project scheduling problem. *Automation in Construction*, *142*, 104503. https://doi.org/10.1016/j.autcon.2022.104503

Huang, W., Oh, S. K., & Pedrycz, W. (2013). A fuzzy time-dependent project scheduling problem. *Information Sciences*, *246*, 100-114. https://doi.org/10.1016/j.ins.2013.05.026

Hwang, I. H., Kim, Y., Lee, D. G., & Shin, J. G. (2014). Automation of block assignment planning using a diagram-based scenario modeling method. *International Journal of Naval Architect Ocean Engineering*, *6*, 162-174. https://doi.org/10.2478/IJNAOE-2013-0170

Issa, S. B., Patterson, R. A., & Tu, Y. (2023). Solving resource-constrained project scheduling problems under different activity assumptions. *Computers & Industrial Engineering*, *180*, 109170. https://doi.org/10.1016/j.cie.2023.109170

Jeong, Y. K., Ju, S., Shen, H., Lee, D. K., Shin, J. G., & Ryu, C. (2018). An analysis of shipyard spatial arrangement planning problems and a spatial arrangement algorithm considering free space and unplaced block. *The International Journal of Advanced Manufacturing Technology*, *95*, 4307-4325. https://doi.org/10.1007/s00170-017-1525-1

Jiang, L., & Strandenes, S. P. (2012). Assessing the cost competitiveness of China's shipbuilding industry. *Maritime Economics & Logistics*, *14*, 480-497. https://doi.org/10.1057/mel.2012.17

Joo, C. M., & Kim, B. S. (2014). Block transportation scheduling under delivery restriction in shipyard using meta-heuristic algorithms. *Expert Systems with Applications*, *41*, 2851-2858. https://doi.org/10.1016/j.eswa.2013.10.020

Kahraman, C., & Kaya, I. (2010). A fuzzy multicriteria methodology for selection among energy alternatives. *Expert Systems with Applications*, *37*(9), 6270–6281. https://doi.org/10.1016/j.eswa.2010.02.095

Khanzadi, M., Soufipour, R., & Rostami, M. (2011). A new improved genetic algorithm approach and a competitive heuristic method for large-scale multiple resource-constrained project-scheduling problems. *International Journal of Industrial Engineering Computations*, *2*(4), 737-748. https://doi.org/10.5267/j.ijiec.2011.06.009

Kim, H., Kang, J., & Park, S. (2002). Scheduling of shipyard block assembly process using constraint satisfaction problem. *Asia Pacific Management Review*, *7*(1), 119-138.

Kim, H., Lee, S. S., Park, J. H., & Lee, J. G. (2005). A model for a simulation-based shipbuilding system in a shipyard manufacturing process. *International Journal of Computer Integrated Manufacturing*, *18*(6), 427-441. https://doi.org/10.1080/09511920500064789

Kim, J. L. (2013). Genetic algorithm stopping criteria for optimization of construction resource scheduling problems. *Construction Management and Economics*, *31*(1), 3-19. https://doi.org/10.1080/01446193.2012.697181

Kim, K. W., Gen, M., & Yamazaki, G. (2003). Hybrid genetic algorithm with fuzzy logic for resource-constrained project scheduling. *Applied Soft Computing*, *2*(3), 174-188. https://doi.org/10.1016/S1568-4946(02)00065-0

Knyazeva, M., Bozhenyuk, A., & Rozenberg, I. (2015). Resource-constrained project scheduling approach under fuzzy conditions. *Procedia Computer Science*, *77*, 56-64. https://doi.org/10.1016/j.procs.2015.12.359

Kolisch, R., & Spracher A. (1996). PSPLIB - A project scheduling problem library. *European Journal of Operational Research*, *96*, 205-216. https://doi.org/10.1016/S0377-2217(96)00170-1

Kolisch, R. (1995). *Project scheduling under resource constraints*. Springer.

Kwon, B., & Lee, G. M. (2015). Spatial scheduling for large assembly blocks in shipbuilding. *Computers & Industrial Engineering*, *89*, 203–212. https://doi.org/10.1016/j.cie.2015.04.036

Laszczyk, M., & Myszkowski, P. B. (2019). Improved selection in evolutionary multi–objective optimization of multi–skill resource–constrained project scheduling problem. *Information Sciences*, *481*, 412-431. https://doi.org/10.1016/j.ins.2019.01.002

Lee, J. K., Lee, K. J., Park, H. K., Hong, J. S., & Lee, J. S. (1997). Developing scheduling systems for Daewoo Shipbuilding: DAS project. *European Journal of Operational Research*, *97*, 380-395. https://doi.org/10.1016/S0377-2217(96)00205-6

Lee, Y. G., Ju, S., & Woo, J. H. (2020). Simulation-based planning system for shipbuilding. *International Journal of Computer Integrated Manufacturing*, *33*(6), 626-641. https://doi.org/10.1080/0951192X.2020.1775304

Li, H., Duan, J., & Zhang, Q. (2021a). Multi-objective integrated scheduling optimization of semi-combined marine crankshaft structure production workshop for green manufacturing. *Transactions of the Institute of Measurement and Control*, *43*(3), 579-596. https://doi.org/10.1177/0142331220945917

Li, F., Xu, Z., & Li, H. (2021b). A multi-agent based cooperative approach to decentralized multi-project scheduling and resource allocation. *Computers & Industrial Engineering*, *151*, 106961. https://doi.org/10.1016/j.cie.2020.106961

Li, J., Sun, M., Han, D., Wang, J., Mao, X., & Wu, X. (2019). A knowledge discovery and reuse method for time estimation in ship block manufacturing planning using DEA. *Advanced Engineering Informatics*, *39*, 25-40. https://doi.org/10.1016/j.aei.2018.11.005

Liu, J., Liu, Y., Shi, Y., & Li, J. (2020). Solving resource-constrained project scheduling problem via genetic algorithm. *Journal of Computing in Civil Engineering*, *34*(2), 04019055. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000874

Liu, Z., Chua, D. K. H., & Yeoh, K. W. (2011). Aggregate production planning for shipbuilding with variation-inventory trade-offs. *International Journal of Production Research*, *49*(20), 6249-6272. https://doi.org/10.1080/00207543.2010.527388

Ljubenkov, B., Dukic, G., & Kuzmanic, M. (2008). Simulation methods in shipbuilding process design. *Strojniski Vestnik*, *54*(2), 131-139.

Long, L. D., & Ohsato, A. (2008). Fuzzy critical chain method for project scheduling under resource constraints and uncertainty. *International Journal of Project Management*, *26*(6), 688-698. https://doi.org/10.1016/j.ijproman.2007.09.012

Magalhaes-Mendes, J. (2011). A two-level genetic algorithm for the multi-mode resource-constrained project scheduling problem. *International Journal of Systems Applications, Engineering & Development*, *3*(5), 271-278.

Mao, X., Li, J., Guo, H., & Wu, X. (2020). Research on collaborative planning and symmetric scheduling for parallel shipbuilding projects in the open distributed manufacturing environment. *Symmetry*, *12*(1), 161. https://doi.org/10.3390/sym12010161

Mei, Y., Ye, J., & Zeng, Z. (2016). Entropy-weighted ANP fuzzy comprehensive evaluation of interim product production schemes in one-of-a-kind production. *Computers & Industrial Engineering*, *100*, 144-152. https://doi.org/10.1016/j.cie.2016.08.016

Mitchell, M. (1999). *An introduction to genetic algorithms.* 5th ed. MIT Press.

Montoya-Torres, J. R., Gutierrez-Franco, E., & Pirachicán-Mayorga, C. P. (2009). Project scheduling with limited resources using a genetic algorithm. *International Journal of Project Management*, *28*, 619–628. https://doi.org/10.1016/j.ijproman.2009.10.003

Muñoz, G., Espinoza, D., Goycoolea, M., Moreno, E., Queyranne, M., & Letelier, O. R. (2018). A study of the Bienstock–Zuckerberg algorithm: applications in mining and resource constrained project scheduling. *Computational Optimization and Applications*, *69*, 501-534. https://doi.org/10.1007/s10589-017-9946-1

Muritiba, A. E. F., Rodrigues, C. D., & da Costa, F. A. (2018). A path-relinking algorithm for the multi-mode resource-constrained project scheduling problem. *Computers & Operations Research*, *92*, 145-154. https://doi.org/10.1016/j.cor.2018.01.001

Myszkowski, P. B., & Laszczyk, M. (2022). Investigation of benchmark dataset for many-objective multi-skill resource constrained project scheduling problem. *Applied Soft Computing*, *127*, 109253. https://doi.org/10.1016/j.asoc.2022.109253

Okubo, Y., & Mitsuyuki, T. (2022). Ship production planning using shipbuilding system modeling and discrete time process simulation. *Journal of Marine Science and Engineering*, *10*(2), 176. https://doi.org/10.3390/jmse10020176

Özyiğit, İ., 2006, *Gemi İnşaatında Planlama ve Üretim Kademeleri* [MSc Thesis. Yıldız Teknik University].

Palencia, A. E. R., & Delgadillo, G. E. M. (2012). A computer application for a bus body assembly line using Genetic Algorithms, *International Journal Production Economics*, *140*(1), 431-438. https://doi.org/10.1016/j.ijpe.2012.06.026

Park, C., & Seo, J. (2010). Comparing heuristic algorithms of the planar storage location assignment problem. *Transportation Research Part E: Logistics and Transportation Review*, *46*, 171–185. https://doi.org/10.1016/j.tre.2009.07.004

Park, C., Chung, K. H., Park, J. C., Cho, K. K., Baek, T. H., & Son, E. I. (2002). A spatial scheduling application at the block paint shop in shipbuilding: The HYPOS project. *Production Planning & Control*, *13*(4), 342-354. https://doi.org/10.1080/095372802760108309

Park, J., Lee, D., & Zhu, J. (2014). An integrated approach for ship block manufacturing process performance evaluation: Case from a Korean shipbuilding company. *International. Journal of Production Economics*, *156*, 214–222. https://doi.org/10.1016/j.ijpe.2014.06.012

Ponz-Tienda, J. L., Yepes, V., Pellicer, E., & Moreno-Flores, J. (2012). The resource leveling problem with multiple resources using an adaptive genetic algorithm. *Automation in Construction*, *29*, 161–172. https://doi.org/10.1016/j.autcon.2012.10.003

Rahman, H. F., Servranckx, T., Chakrabortty, R. K., Vanhoucke, M., & El Sawah, S. (2022). Manufacturing project scheduling considering human factors to minimize total cost and carbon footprints. *Applied Soft Computing*, *131*, 109764. https://doi.org/10.1016/j.asoc.2022.109764

Ranjbar, M. R., & Kianfar, F. (2007). Solving the discrete time/resource trade-off problem in project scheduling with genetic algorithms. *Applied Mathematics and Computation*, *191*, 451–456. https://doi.org/10.1016/j.amc.2007.02.109

Reyck, B., & Herroelen, W. (1998). A branch-and-bound procedure for the resource-constrained project scheduling problem with generalized precedence relations. *European Journal of Operational Research*, *111*, 152-174.

Rubeša, R., Hadjina, M., Matulja, T., & Bolf, D. (2023). The shipyard technological level evaluation methodology. *Brodogradnja: Teorija i praksa brodogradnje i pomorske tehnike*, *74*(3), 91-106. https://doi.org/10.1016/S0377-2217(97)00305-6

Saad, H. M., Chakrabortty, R. K., Elsayed, S., & Ryan, M. J. (2021). Quantum-inspired genetic algorithm for resource-constrained project-scheduling. *IEEE Access*, *9*, 38488-38502. https://doi.org/10.1109/ACCESS.2021.3062790

Satıç, U. (2014). *Çok kaynak kısıtlı projelerin sezgisel yöntemlerle çizelgelenmesi.* [MSc Thesis. Yıldız Teknik University].

Sawant, V. C. (2016). Genetic algorithm for resource constrained project scheduling. *International Journal of Science and Research*, *5*(6), 733-750 https://doi.org/10.1002/(SICI)1520-6750(199810)45:7%3C733::AID-NAV5%3E3.0.CO;2-C

Schirmer, A. (1998). Case-based reasoning and improved adaptive search for project scheduling. *Naval Research Logistics*. *47*, 201-222. https://doi.org/10.1002/(SICI)1520-6750(200004)47:3%3C201::AID-NAV2%3E3.0.CO;2-L

Servranckx, T., & Vanhoucke, M. (2019). Strategies for project scheduling with alternative subgraphs under uncertainty: similar and dissimilar sets of schedules. *European Journal of Operational Research*, *279*(1), 38-53. https://doi.org/10.1016/j.ejor.2019.05.023

Shadrokh, S., & Kianfar, F. (2007). A genetic algorithm for resource investment project scheduling problem, tardiness permitted with penalty. *European Journal of Operational Research*, *181*(1), 86-101. https://doi.org/10.1016/j.ejor.2006.03.056

Shariatmadari, M., & Nahavandi, N. (2020). A new resource buffer insertion approach for proactive resource investment problem. *Computers & Industrial Engineering*, *146*, 106582. https://doi.org/10.1016/j.cie.2020.106582

Snauwaert, J., & Vanhoucke, M. (2021). A new algorithm for resource-constrained project scheduling with breadth and depth of skills. *European Journal of Operational Research*, *292*(1), 43-59. https://doi.org/10.1016/j.ejor.2020.10.032

Soong, Y. J., Woo, J. H., & Shin., J. G. (2011). Research on systematization and advancement of shipbuilding production management for flexible and agile response for high value offshore platform. *International Journal of Naval Architect Ocean Engineering*, *3*, 181~192. https://doi.org/10.2478/IJNAOE-2013-0061

Sprecher, A., & Drexl, A. (1998). Multi-mode resource-constrained project scheduling by a simple, general and powerful sequencing algorithm. *European Journal of Operational Research*, *107*(2), 431-450. https://doi.org/10.1016/S0377-2217(97)00348-2

Sprecher, A., Kolisch, R., & Drexl, A. (1995). Semi-active, active, and non-delay schedules for the resource-constrained project scheduling problem. *European Journal of Operational Research*, *80*, 94-102. https://doi.org/10.1016/0377-2217(93)E0294-8

Statista. (2023). *Size of the global shipbuilding market in 2020 and 2021, with a forecast through 2030*. Retrieved on July 1, 2023, from https://www.statista.com/statistics/1102252/size-of-the-global-shipbuilding-market/

Stopford, M. (2009). *Maritime economics*. Routledge.

Tasan, S. O., & Gen, M. (2013). An integrated selection and scheduling for disjunctive network problems. *Computers & Industrial Engineering*, *65*(1), 65-76. https://doi.org/10.1016/j.cie.2011.12.022

Tesch, A. (2020). A polyhedral study of event-based models for the resource-constrained project scheduling problem. *Journal of Scheduling*, *23*(2), 233-251. https://doi.org/10.1007/s10951-020-00647-6

Tian, M., Liu, R. J., & Zhang, G. J. (2020). Solving the resource-constrained multi-project scheduling problem with an improved critical chain method. *Journal of the Operational Research Society*, *71*(8), 1243-1258. https://doi.org/10.1080/01605682.2019.1609883

Toklu, Y. C. (2002). Application of genetic algorithms to construction scheduling with or without resource constraints. *Canadian Journal of Civil Engineering*, *29*, 421-429. https://doi.org/10.1139/l02-034

Tseng, L. Y., & Chen, S. C. (2006). A hybrid metaheuristic for the resource-constrained project scheduling problem. *European Journal of Operational Research*, *175*(2), 707-721. https://doi.org/10.1016/j.ejor.2005.06.014

Tseng, L. Y., & Chen, S. C. (2009). Two-phase genetic local search algorithm for the multimode resource-constrained project scheduling problem. *IEEE Transactions on Evolutionary Computation*, *13*(4), 848-857. https://doi.org/10.1109/TEVC.2008.2011991

Ulusoy, G., & Özdamar, L. (1996). A framework for an interactive project scheduling system under limited resources. *European Journal of Operational Research*, *90*(2), 362-375. https://doi.org/10.1016/0377-2217(95)00360-6

Ulusoy, G. (2002). Proje planlamada kaynak kısıtlı çizelgeleme. In M. Köksalan, & N. Erkip (Eds.), *Yöneylem Araştırması – Halim Doğrusöz'e Armağan* (pp. 89-128). ODTÜ Basım.

UNCTAD. (2022). *Review of Maritime Transport 2022*. United Nations Publications.

Valls, V., Ballestin, F., & Quintanilla, M. S. (2004). Justification and RCPSP: A technique that pays. *European Journal of Operational Research*, *165*(2), 375-386. https://doi.org/10.1016/j.ejor.2004.04.008

Valls, V., Ballestin, F., & Quintanilla, S. (2008). A hybrid genetic algorithm for the resource-constrained project scheduling problem. *European Journal of Operational Research*, *185*(2), 495-508. https://doi.org/10.1016/j.ejor.2006.12.033

Van Eynde, R., & Vanhoucke, M. (2022). A theoretical framework for instance complexity of the resource-constrained project scheduling problem. *Mathematics of Operations Research*, *47*(4), 3156-3183. https://doi.org/10.1287/moor.2021.1237

Van Peteghem, V., & Vanhoucke, M. (2008). *A genetic algorithm for the multi-mode resource-constrained project scheduling problem*. Working Papers of Faculty of Economics and Business Administration, Ghent University, Belgium 08/494. Ghent University, Faculty of Economics and Business Administration.

Van Peteghem, V., & Vanhoucke, M. (2010). A genetic algorithm for the preemptive and non-preemptive multi-mode resource-constrained project scheduling problem, *European Journal of Operational Research*, *201*(2), 409-418. https://doi.org/10.1016/j.ejor.2009.03.034

Vanhoucke, M., & Coelho, J. (2019). Resource-constrained project scheduling with activity splitting and setup times. *Computers & Operations Research*, *109*, 230-249. https://doi.org/10.1016/j.cor.2019.05.004

Wang, C., Mao, P., Mao, Y., & Shin, J. G. (2016). Research on scheduling and optimization under uncertain conditions in panel block production line in shipbuilding. *International Journal of Naval Architecture and Ocean Engineering*, *8*(4), 398-408. https://doi.org/10.1016/j.ijnaoe.2016.03.009

Wang, H. W., Lin, J. R., & Zhang, J. P. (2020). Work package-based information modeling for resource-constrained scheduling of construction projects. *Automation in Construction*, *109*, 102958. https://doi.org/10.1016/j.autcon.2019.102958

Wang, Y. M. (2009). Centroid defuzzification and the maximizing set and minimizing set ranking based on alpha level sets. *Computers & Industrial Engineering*, *57*(1), 228-236. https://doi.org/10.1016/j.cie.2008.11.014

Xu, J., & Bai, S. (2023). A reactive scheduling approach for the resource-constrained project scheduling problem with dynamic resource disruption. *Kybernetes*, *In press*. https://doi.org/10.1108/K-09-2022-1339

Yang, Z., & Liu, C. (2018). A hybrid multi-objective gray wolf optimization algorithm for a fuzzy blocking flow shop scheduling problem. *Advances in Mechanical Engineering*, 10(3), 1687814018765535. https://doi.org/10.1177/1687814018765535

Yuguang, Z., Bo, A., & Yong Z. (2016). A PSO algorithm for multi-objective hull assembly line balancing using the stratified optimization strategy. *Computers & Industrial Engineering*, *98*, 53-62. https://doi.org/10.1016/j.cie.2016.05.026

Zadeh, L. A. (1965). Fuzzy sets. *Information and Control*, *8*(3), 338–353. https://doi.org/10.1016/S0019-9958(65)90241-X

Zaman, F., Elsayed, S., Sarker, R., Essam, D., & Coello, C. A. C. (2021). An evolutionary approach for resource constrained project scheduling with uncertain changes. *Computers & Operations Research*, *125*, 105104. https://doi.org/10.1016/j.cor.2020.105104

Zamani, R. (2019). An effective mirror-based genetic algorithm for scheduling multi-mode resource constrained projects. *Computers & Industrial Engineering*, *127*, 914-924. https://doi.org/10.1016/j.cie.2018.11.031

Zhang, H., Xu, H & Peng, W. (2008) A Genetic Algorithm for Solving RCPSP. *2008 International Symposium on Computer Science and Computational Technology*, China. pp. 246-249. https://doi.org/10.1109/ISCSCT.2008.255

Zhang, S., Song, X., Shen, L., & Xu, L. (2023). Complicated time-constrained project scheduling problems in water conservancy construction. *Processes*, *11*(4), 1110. https://doi.org/10.3390/pr11041110

Zhong, Y. G. (2017). Hull mixed-model assembly line balancing using a multi-objective genetic algorithm simulated annealing optimization approach. *Concurrent Engineering*, *25*(1), 30-40. https://doi.org/10.1177/1063293X16666204

Zhou, T., Long, Q., Law, K. M., & Wu, C. (2022). Multi-objective stochastic project scheduling with alternative execution methods: An improved quantum-behaved particle swarm optimization approach. *Expert Systems with Applications*, *203*, 117029. https://doi.org/10.1016/j.eswa.2022.117029

Zhu, L., Lin, J., & Wang, Z. J. (2019). A discrete oppositional multi-verse optimization algorithm for multi-skill resource constrained project scheduling problem. *Applied Soft Computing*, *85*, 105805. https://doi.org/10.1016/j.eswa.2022.117029

Supplementary Materials DOI: 10.33714/masteb.1324266

Scenario A

A1

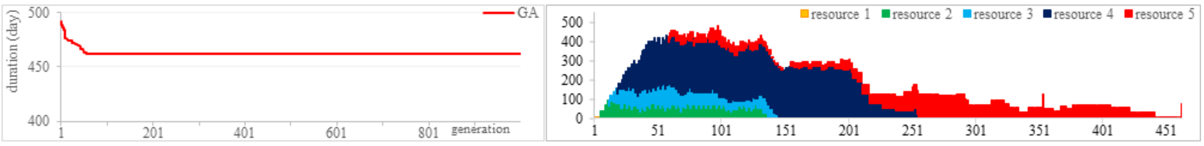


Figure 1: For capacity 1, best local value and resource graph (normal duration).

A2

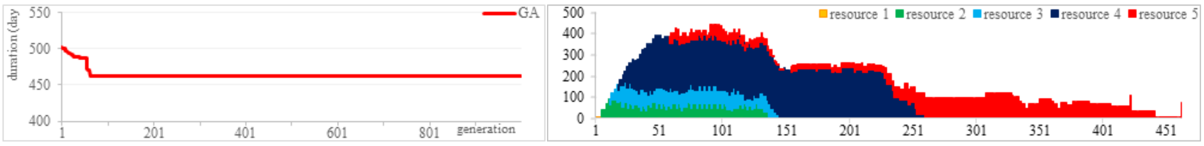


Figure 2: For capacity 2, best local value and resource graph (normal duration).

A3

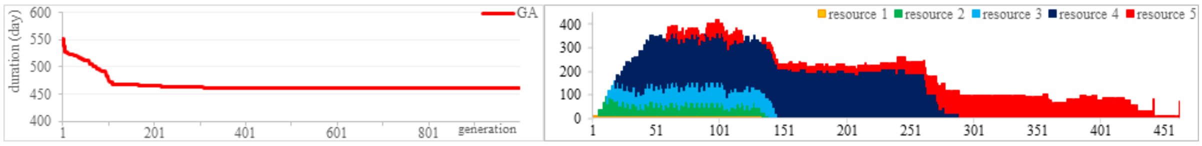


Figure 3: For capacity 3, best local value and resource graph (normal duration).

A4

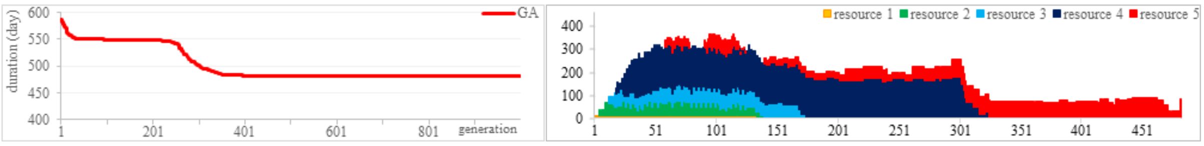


Figure 4: For capacity 4, best local value and resource graph (normal duration).

Scenario B

B1

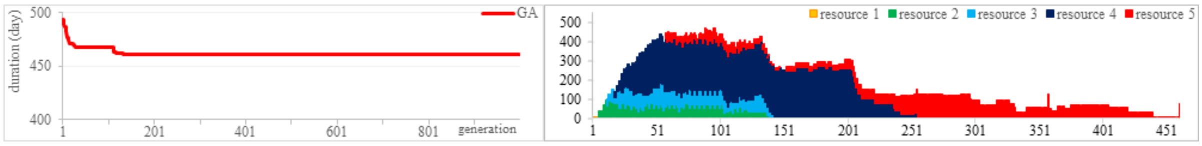


Figure 5: For capacity 1, best local value and resource graph (resource loading).

B2

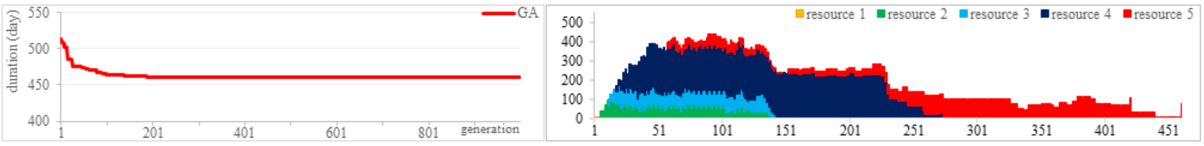


Figure 6: For capacity 2, best local value and resource graph (resource loading).

B3

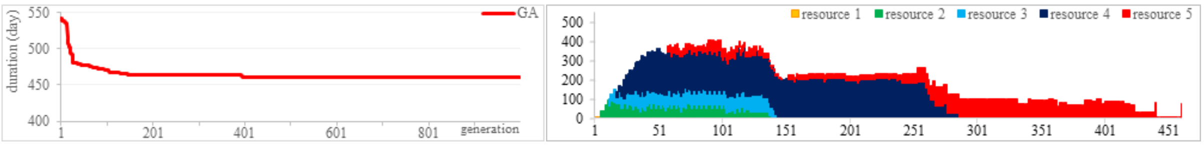


Figure 7: For capacity 3, best local value and resource graph (resource loading).

B4

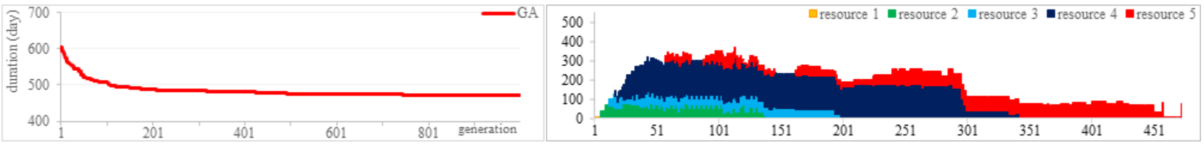


Figure 8: For capacity 4, best local value and resource graph (resource loading).

Supplementary Materials DOI: 10.33714/masteb.1324266

Scenario C

C1

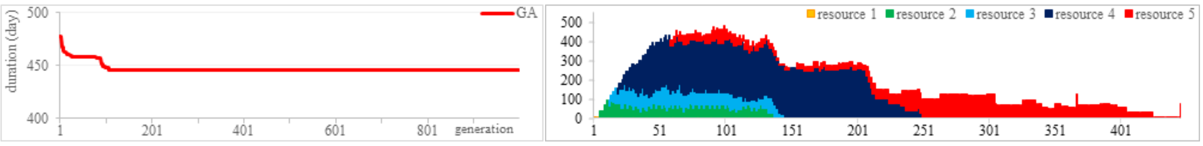


Figure 9: For capacity 1, best local value and resource graph (resource loading of 3 people on critical activities).

C2

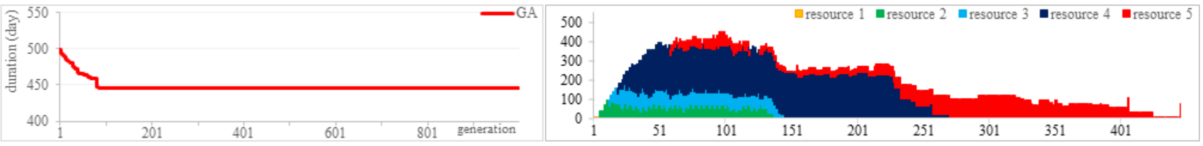


Figure 10: For capacity 2, best local value and resource graph (resource loading of 3 people on critical activities).

C3

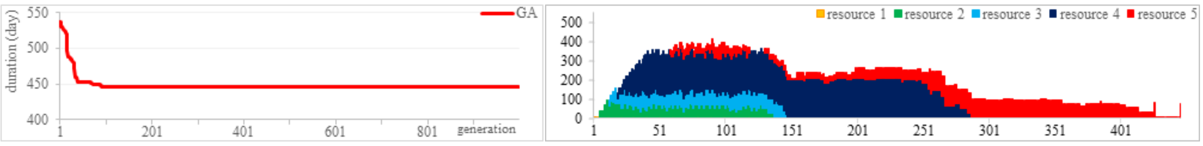


Figure 11: For capacity 3, best local value and resource graph (resource loading of 3 people on critical activities).

C4

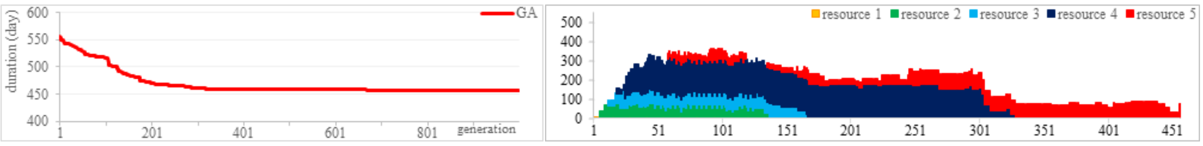


Figure 12: For capacity 4, best local value and resource graph (resource loading of 3 people on critical activities).

Scenario D

D1

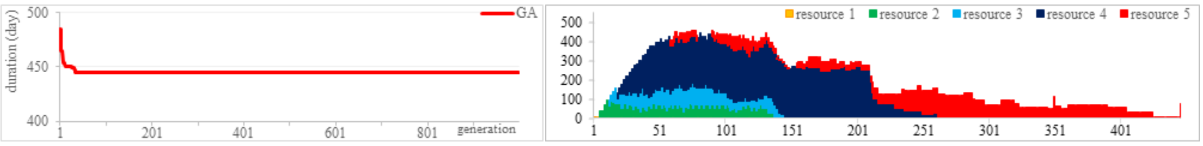


Figure 13: For capacity 1, best local value and resource graph (resource loading of 3 people on critical activities).

D2

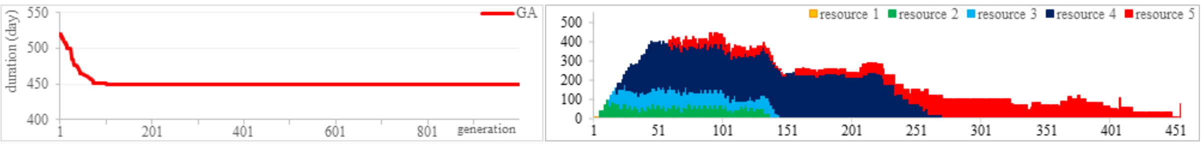


Figure 14: For capacity 2, best local value and resource graph (resource loading of 3 people on critical activities).

D3

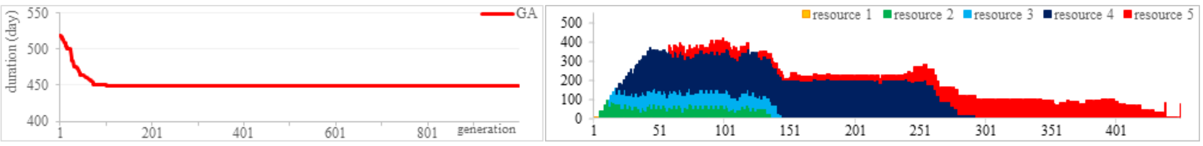


Figure 15: For capacity 3, best local value and resource graph (resource loading of 3 people on critical activities).

D4

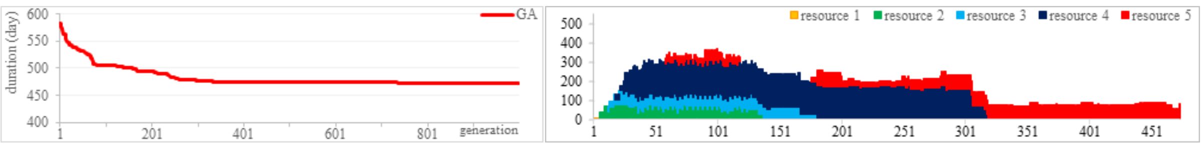


Figure 16: For capacity 4, best local value and resource graph (resource loading of 3 people on critical activities).

Supplementary Materials DOI: 10.33714/masteb.1324266

Scenario E

E1

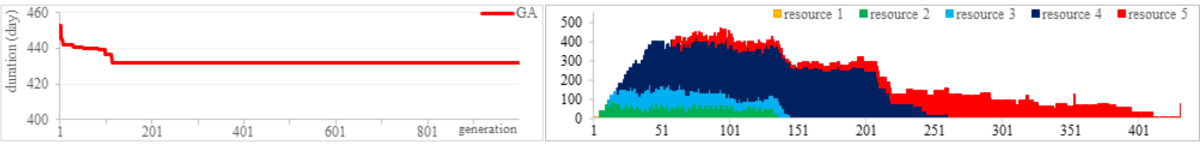


Figure 17: For capacity 1, best local value and resource graph (resource loading of 3 people on critical activities).

E2

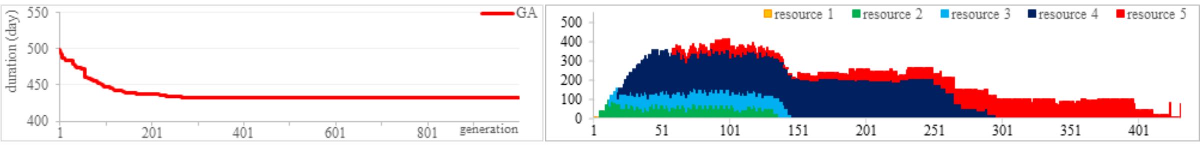


Figure 18: For capacity 2, best local value and resource graph (resource loading of 3 people on critical activities).

E3

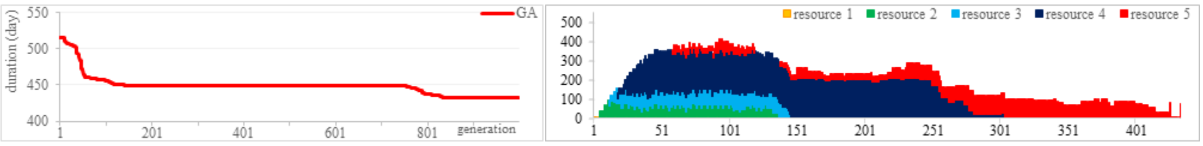


Figure 19: For capacity 3, best local value and resource graph (resource loading of 3 people on critical activities).

E4

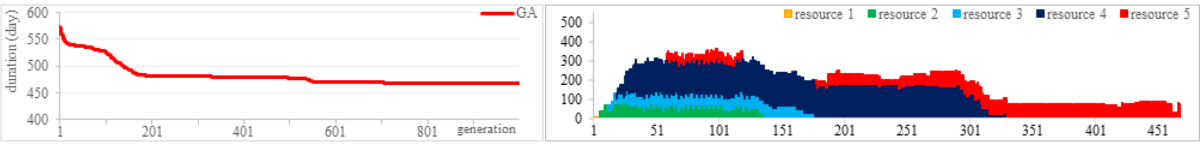


Figure 20: For capacity 4, best local value and resource graph (resource loading of 3 people on critical activities).

Scenario F

F1

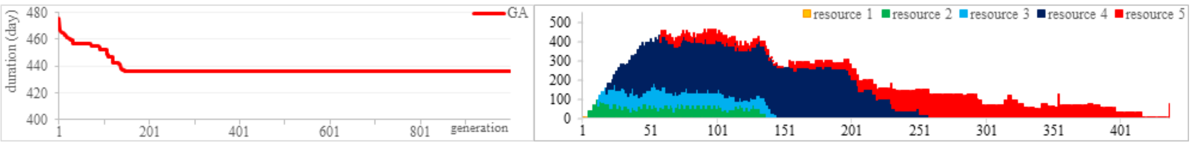


Figure 21: For capacity 1, best local value and resource graph (resource loading of 5 people on critical activities).

F2

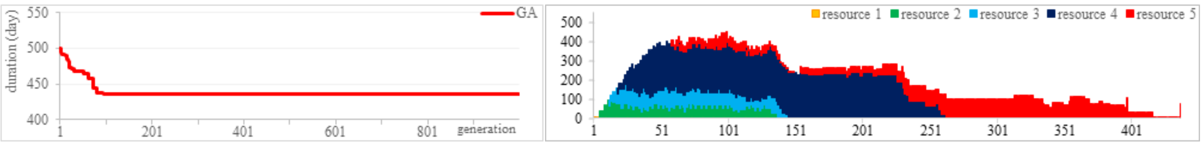


Figure 22: For capacity 2, best local value and resource graph (resource loading of 5 people on critical activities).

F3

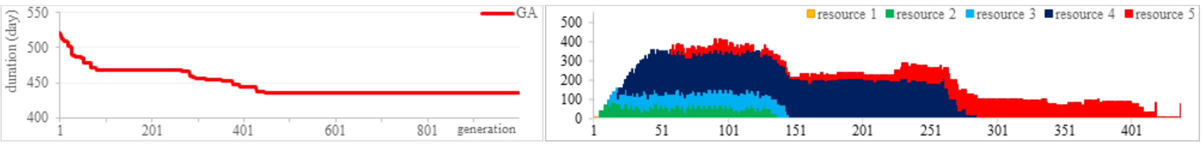


Figure 23: For capacity 3, best local value and resource graph (resource loading of 5 people on critical activities).

F4

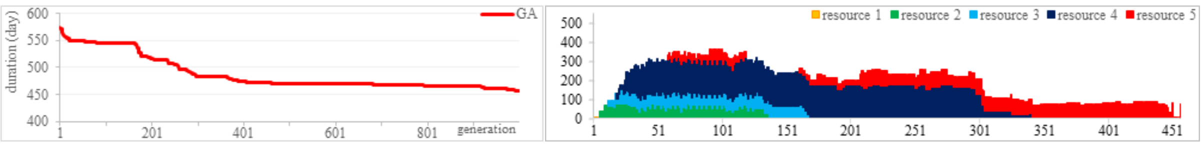


Figure 24: For capacity 4, best local value and resource graph (resource loading of 5 people on critical activities).

Supplementary Materials DOI: 10.33714/masteb.1324266

Scenario G

G1

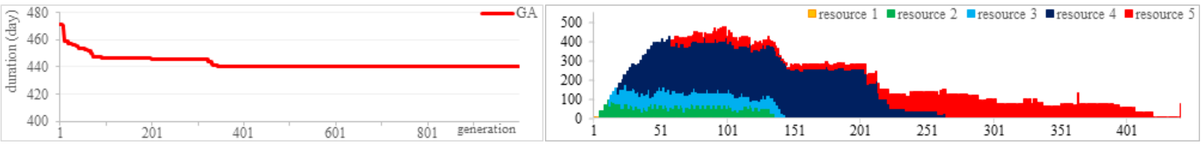


Figure 25: For capacity 1, best local value and resource graph (resource loading of 5 people on critical activities).

G2

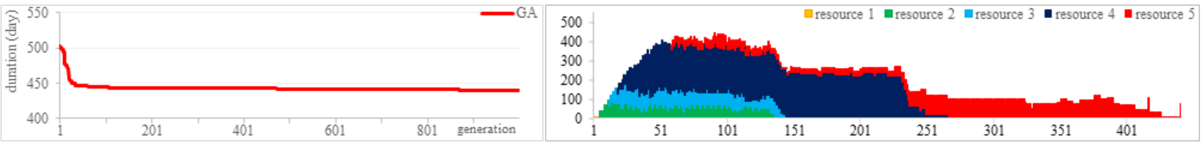


Figure 26: For capacity 2, best local value and resource graph (resource loading of 5 people on critical activities).

G3

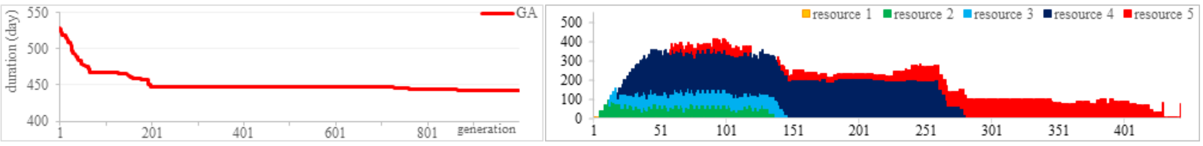


Figure 27: For capacity 3, best local value and resource graph (resource loading of 5 people on critical activities).

G4

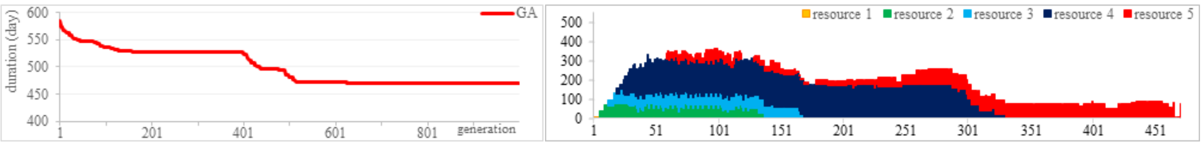


Figure 28: For capacity 4, best local value and resource graph (resource loading of 5 people on critical activities).

Scenario H

H1

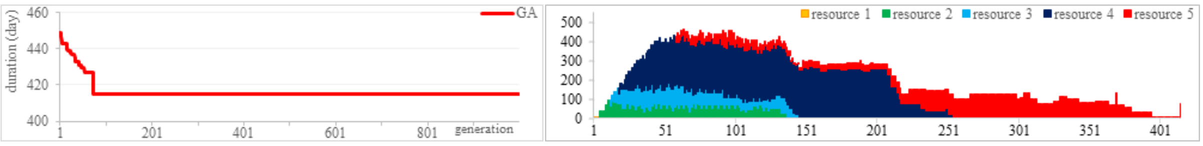


Figure 29: For capacity 1, best local value and resource graph (resource loading of 5 people on critical activities).

H2

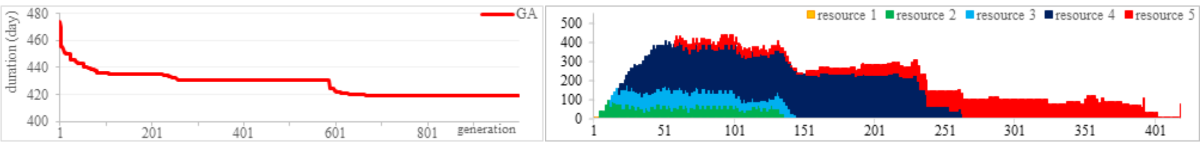


Figure 30: For capacity 2, best local value and resource graph (resource loading of 5 people on critical activities).

H3

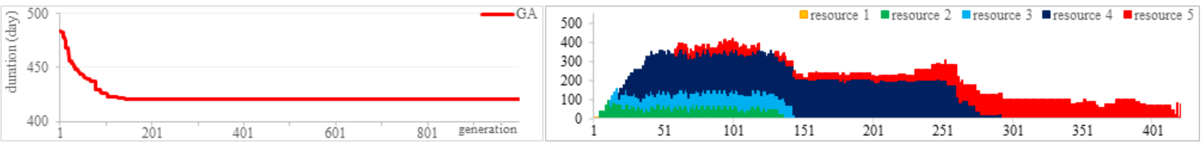


Figure 31: For capacity 3, best local value and resource graph (resource loading of 5 people on critical activities).

H4

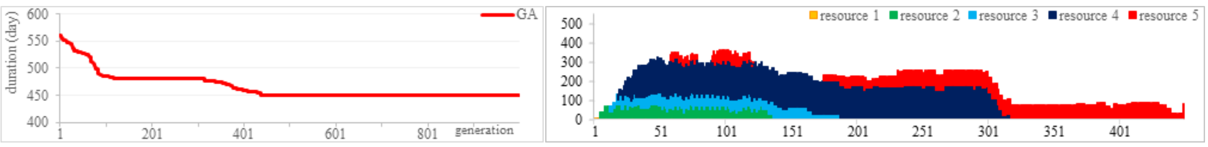


Figure 32: For capacity 4, best local value and resource graph (resource loading of 5 people on critical activities).

Supplementary Materials DOI: 10.33714/masteb.1324266

Appendices

Appendix 1. The block construction activities, predecessors, and manpower values for Ships A and B.

ID	Work Station	Activities	Predecessors	Manpower (Person.Day)	
				Normal	Crashed
1	WS 02	Start		0	0
2	WS 02	A U202 Cutting	1	10	10
3	WS 02	B U102 Cutting	2	10	10
4	WS 02	A U101 Cutting	3;2	10	10
5	WS 02	B U101 Cutting	4;3	10	10
6	WS 02	A U103 Cutting	5;4;2	10	10
7	WS 02	A U104 Cutting	6	10	10
8	WS 02	B U103 Cutting	7;5	10	10
9	WS 02	A U105 Cutting	8;7	10	10
10	WS 02	B U104 Cutting	9;8	10	10
11	WS 02	A U106 Cutting	10;9	10	10
12	WS 02	B U105 Cutting	11;10	10	10
13	WS 02	B U106 Cutting	12	10	10
14	WS 02	A U203 Cutting	13;7;2	10	10
15	WS 02	B U107 Cutting	14;13	10	10
16	WS 02	A U204 Cutting	15;14;7	10	10
17	WS 02	B U203 Cutting	16;3;8;11	10	10
18	WS 02	A U205 Cutting	17;12;16	10	10
19	WS 02	B U204 Cutting	18;7;17	10	10
20	WS 02	A U301 Cutting	19;4;11	10	10
21	WS 02	B U205 Cutting	20;12;19	10	10
22	WS 02	A U302 Cutting	21;20;2	10	10
23	WS 02	B U206 Cutting	22;13;21	10	10
24	WS 02	A U303 Cutting	23;14;22	10	10
25	WS 02	B U301 Cutting	24;15;5	10	10
26	WS 02	A U304 Cutting	25;16;24	10	10
27	WS 02	B U302 Cutting	26;3;25	10	10
28	WS 02	A U305 Cutting	26;18;27	10	10
29	WS 02	B U303 Cutting	28;17	10	10
30	WS 02	A U401 Cutting	29;20;28	10	10
31	WS 02	B U304 Cutting	30;29;19	10	10
32	WS 02	A U402 Cutting	31;22;30	10	10
33	WS 02	B U305 Cutting	32;21;31	10	10
34	WS 02	A U403 Cutting	33;24;32	10	10
35	WS 02	B U306 Cutting	34;33;23	10	10
36	WS 02	A U404 Cutting	35;34;26	10	10
37	WS 02	B U401 Cutting	36;25;35	10	10
38	WS 02	A U405 Cutting	37;28;36	10	10
39	WS 02	B U402 Cutting	38;37	10	10
40	WS 02	A U501 Cutting	39;32;38	10	10
41	WS 02	B U403 Cutting	40;29;39	10	10
42	WS 02	A U502 Cutting	41;32;40	10	10
43	WS 02	B U404 Cutting	42;31;41	10	10
44	WS 02	A U503 Cutting	43;34;42	10	10
45	WS 02	B U405 Cutting	44;43;33	10	10
46	WS 02	A U504 Cutting	45;36;44	10	10

Supplementary Materials DOI: 10.33714/masteb.1324266

47	WS 02	B U406 Cutting	46;35;45	10	10
48	WS 02	A U505 Cutting	47;46;38	10	10
49	WS 02	B U501 Cutting	48;37;39;47	10	10
50	WS 02	A U601 Cutting	49;40	10	10
51	WS 02	B U502 Cutting	50;39;49	10	10
52	WS 02	A U602 Cutting	51;42;44	10	10
53	WS 02	B U503 Cutting	52;51;41	10	10
54	WS 02	A U603 Cutting	53;48	10	10
55	WS 02	B U504 Cutting	54;43;53	10	10
56	WS 02	A U701 Cutting	55;52	10	10
57	WS 02	B U505 Cutting	56;45;55	10	10
58	WS 02	A U801 Cutting	57;56	10	10
59	WS 02	B U506 Cutting	58;47;57	10	10
60	WS 02	B U601 Cutting	59;49	10	10
61	WS 02	B U602 Cutting	60;53;55	10	10
62	WS 02	B U603 Cutting	61;57	10	10
63	WS 02	B U604 Cutting	62;59	10	10
64	WS 02	B U701 Cutting	63;61;62	10	10
65	WS 02	B U801 Cutting	64	10	10
66	WS 04	A U101 Prefabrication	4	25	30
67	WS 04	B U101 Prefabrication	5	25	30
68	WS 04	A U103 Prefabrication	6	20	24
69	WS 04	B U102 Prefabrication	3	30	36
70	WS 04	A U104 Prefabrication	7	20	24
71	WS 04	B U103 Prefabrication	8	25	30
72	WS 04	A U105 Prefabrication	9	20	24
73	WS 04	B U104 Prefabrication	10	20	24
74	WS 04	A U106 Prefabrication	11	20	24
75	WS 04	B U105 Prefabrication	12	20	24
76	WS 04	A U202 Prefabrication	2	30	36
77	WS 04	B U106 Prefabrication	13	15	18
78	WS 04	A U203 Prefabrication	14	20	24
79	WS 04	B U107 Prefabrication	15	6	7
80	WS 04	A U204 Prefabrication	16	20	24
81	WS 04	B U203 Prefabrication	17	25	30
82	WS 04	A U205 Prefabrication	18	4	5
83	WS 04	B U204 Prefabrication	19	25	30
84	WS 04	A U301 Prefabrication	20	20	24
85	WS 04	B U205 Prefabrication	21	20	24
86	WS 04	A U302 Prefabrication	22	20	24
87	WS 04	B U206 Prefabrication	23	20	24
88	WS 04	A U303 Prefabrication	24	20	24
89	WS 04	B U301 Prefabrication	25	20	24
90	WS 04	A U304 Prefabrication	26	10	12
91	WS 04	B U302 Prefabrication	27	20	24
92	WS 04	A U305 Prefabrication	28	20	24
93	WS 04	B U303 Prefabrication	29	20	24
94	WS 04	A U401 Prefabrication	30	20	24
95	WS 04	B U304 Prefabrication	31	20	24
96	WS 04	A U402 Prefabrication	32	6	7
97	WS 04	B U305 Prefabrication	33	20	24

Supplementary Materials DOI: 10.33714/masteb.1324266

98	WS 04	A U403 Prefabrication	34	25	30
99	WS 04	B U306 Prefabrication	35	20	24
100	WS 04	A U404 Prefabrication	36	20	24
101	WS 04	B U401 Prefabrication	37	20	24
102	WS 04	A U405 Prefabrication	38	20	24
103	WS 04	B U402 Prefabrication	39	20	24
104	WS 04	A U501 Prefabrication	40	20	24
105	WS 04	B U403 Prefabrication	41	20	24
106	WS 04	A U502 Prefabrication	42	20	24
107	WS 04	B U404 Prefabrication	43	20	24
108	WS 04	A U503 Prefabrication	44	20	24
109	WS 04	B U405 Prefabrication	45	20	24
110	WS 04	A U504 Prefabrication	46	20	24
111	WS 04	B U406 Prefabrication	47	20	24
112	WS 04	A U505 Prefabrication	48	20	24
113	WS 04	B U501 Prefabrication	49	20	24
114	WS 04	A U601 Prefabrication	50	10	12
115	WS 04	B U502 Prefabrication	51	4	5
116	WS 04	A U602 Prefabrication	52	20	24
117	WS 04	B U503 Prefabrication	53	15	18
118	WS 04	A U603 Prefabrication	54	20	24
119	WS 04	B U504 Prefabrication	55	20	24
120	WS 04	A U701 Prefabrication	56	20	24
121	WS 04	B U505 Prefabrication	57	20	24
122	WS 04	A U801 Prefabrication	58	10	12
123	WS 04	B U506 Prefabrication	59	20	24
124	WS 04	B U601 Prefabrication	60	10	12
125	WS 04	B U602 Prefabrication	61	20	24
126	WS 04	B U603 Prefabrication	62	20	24
127	WS 04	B U604 Prefabrication	63	20	24
128	WS 04	B U701 Prefabrication	64	20	24
129	WS 04	B U801 Prefabrication	65	10	12
130	WS 05	A U101 Panel Production	66	25	30
131	WS 05	B U101 Panel Production	67	25	30
132	WS 05	A U103 Panel Production	68	20	24
133	WS 05	B U102 Panel Production	69	30	36
134	WS 05	A U104 Panel Production	70	20	24
135	WS 05	B U103 Panel Production	71	25	30
136	WS 05	A U105 Panel Production	72	20	24
137	WS 05	B U104 Panel Production	73	20	24
138	WS 05	A U106 Panel Production	74	20	24
139	WS 05	B U105 Panel Production	75	20	24
140	WS 05	A U202 Panel Production	76	30	36
141	WS 05	B U106 Panel Production	77	15	18
142	WS 05	A U203 Panel Production	78	20	24
143	WS 05	B U107 Panel Production	79	6	7
144	WS 05	A U204 Panel Production	80	20	24
145	WS 05	B U203 Panel Production	81	25	30
146	WS 05	A U205 Panel Production	82	4	5
147	WS 05	B U204 Panel Production	83	25	30
148	WS 05	A U301 Panel Production	84	20	24

Supplementary Materials DOI: 10.33714/masteb.1324266

149	WS 05	B U205 Panel Production	85	20	24
150	WS 05	A U302 Panel Production	86	20	24
151	WS 05	B U206 Panel Production	87	20	24
152	WS 05	A U303 Panel Production	88	20	24
153	WS 05	B U301 Panel Production	89	20	24
154	WS 05	A U304 Panel Production	90	10	12
155	WS 05	B U302 Panel Production	91	20	24
156	WS 05	A U305 Panel Production	92	20	24
157	WS 05	B U303 Panel Production	93	20	24
158	WS 05	A U401 Panel Production	94	20	24
159	WS 05	B U304 Panel Production	95	20	24
160	WS 05	A U402 Panel Production	96	6	7
161	WS 05	B U305 Panel Production	97	20	24
162	WS 05	A U403 Panel Production	98	25	30
163	WS 05	B U306 Panel Production	99	20	24
164	WS 05	A U404 Panel Production	100	20	24
165	WS 05	B U401 Panel Production	101	20	24
166	WS 05	A U405 Panel Production	102	20	24
167	WS 05	B U402 Panel Production	103	20	24
168	WS 05	A U501 Panel Production	104	20	24
169	WS 05	B U403 Panel Production	105	20	24
170	WS 05	A U502 Panel Production	106	20	24
171	WS 05	B U404 Panel Production	107	20	24
172	WS 05	A U503 Panel Production	108	20	24
173	WS 05	B U405 Panel Production	109	20	24
174	WS 05	A U504 Panel Production	110	20	24
175	WS 05	B U406 Panel Production	111	20	24
176	WS 05	A U505 Panel Production	112	20	24
177	WS 05	B U501 Panel Production	113	20	24
178	WS 05	A U601 Panel Production	114	10	12
179	WS 05	B U502 Panel Production	115	4	5
180	WS 05	A U602 Panel Production	116	20	24
181	WS 05	B U503 Panel Production	117	15	18
182	WS 05	A U603 Panel Production	118	20	24
183	WS 05	B U504 Panel Production	119	20	24
184	WS 05	A U701 Panel Production	120	20	24
185	WS 05	B U505 Panel Production	121	20	24
186	WS 05	A U801 Panel Production	122	10	12
187	WS 05	B U506 Panel Production	123	20	24
188	WS 05	B U601 Panel Production	124	10	12
189	WS 05	B U602 Panel Production	125	20	24
190	WS 05	B U603 Panel Production	126	20	24
191	WS 05	B U604 Panel Production	127	20	24
192	WS 05	B U701 Panel Production	128	20	24
193	WS 05	B U801 Panel Production	129	10	12
194	WS 12	B U102 Block Assembly	198	30	30
195	WS 05	A U101 Block Production	66;130	25	30
196	WS 05	B U101 Block Production	67;131	25	30
197	WS 09	A U103 Block Production	68;132	20	20
198	WS 09	B U102 Block Production	69;133	30	30
199	WS 09	A U104 Block Production	70;134	20	20

200	WS 09	B U103 Block Production	71;135	25	25
201	WS 09	A U105 Block Production	72;136	20	20
202	WS 09	B U104 Block Production	73;137	20	20
203	WS 09	A U106 Block Production	74;138	20	20
204	WS 09	B U105 Block Production	75;139	20	20
205	WS 09	A U202 Block Production	76;140	30	30
206	WS 09	B U106 Block Production	77;141	15	15
207	WS 09	A U203 Block Production	78;142	20	20
208	WS 09	B U107 Block Production	79;143	6	6
209	WS 09	A U204 Block Production	80;144	20	20
210	WS 09	B U203 Block Production	81;145	25	25
211	WS 09	A U205 Block Production	82;146	4	4
212	WS 09	B U204 Block Production	83;147	25	25
213	WS 09	A U301 Block Production	84;148	20	20
214	WS 09	B U205 Block Production	85;149	20	20
215	WS 09	A U302 Block Production	86;150	20	20
216	WS 09	B U206 Block Production	87;151	20	20
217	WS 09	A U303 Block Production	88;152;215	20	20
218	WS 09	B U301 Block Production	89;153	20	20
219	WS 09	A U304 Block Production	90;154	10	10
220	WS 09	B U302 Block Production	91;155	20	20
221	WS 09	A U305 Block Production	92;156	20	20
222	WS 09	B U303 Block Production	93;157	20	20
223	WS 09	A U401 Block Production	94;158	20	20
224	WS 09	B U304 Block Production	95;159	20	20
225	WS 09	A U402 Block Production	96;160	6	6
226	WS 09	B U305 Block Production	97;161	20	20
227	WS 09	A U403 Block Production	98;162	25	25
228	WS 09	B U306 Block Production	99;163	20	20
229	WS 09	A U404 Block Production	100;164	20	20
230	WS 09	B U401 Block Production	101;165	20	20
231	WS 09	A U405 Block Production	102;166	20	20
232	WS 09	B U402 Block Production	103;167	20	20
233	WS 09	A U501 Block Production	104;168	20	20
234	WS 09	B U403 Block Production	105;169	20	20
235	WS 09	A U502 Block Production	106;170	20	20
236	WS 09	B U404 Block Production	107;171	20	20
237	WS 09	A U503 Block Production	108;172	20	20
238	WS 09	B U405 Block Production	109;173	20	20
239	WS 09	A U504 Block Production	110;174	20	20
240	WS 09	B U406 Block Production	111;175	20	20
241	WS 09	A U505 Block Production	112;176	20	20
242	WS 09	B U501 Block Production	113;177	20	20
243	WS 09	A U601 Block Production	114;178	10	10
244	WS 09	B U502 Block Production	115;179	4	4
245	WS 09	A U602 Block Production	116;180	20	20
246	WS 09	B U503 Block Production	117;181	15	15
247	WS 09	A U603 Block Production	118;182	20	20
248	WS 09	B U504 Block Production	119;183	20	20
249	WS 09	A U701 Block Production	120;184	20	20
250	WS 09	B U505 Block Production	121;185	20	20

251	WS 09	A U801 Block Production	122;186	10	10
252	WS 09	B U506 Block Production	123;187	20	20
253	WS 09	B U601 Block Production	124;188	10	10
254	WS 09	B U602 Block Production	125;189	20	20
255	WS 09	B U603 Block Production	126;190	20	20
256	WS 09	B U604 Block Production	127;191	20	20
257	WS 09	B U701 Block Production	128;192	20	20
258	WS 09	B U801 Block Production	129;193	10	10
259	WS 09	A B23 Module Production	197;207	30	30
260	WS 09	B B23 Module Production	200;210	30	30
261	WS 09	A B24 Module Production	199;209	30	30
262	WS 09	B B24 Module Production	202;212	30	30
263	WS 09	A B25 Module Production	201;203;211;221	30	30
264	WS 09	B B25 Module Production	204;214	30	30
265	WS 09	A B31 Module Production	213;223	30	30
266	WS 09	B B26 Module Production	206;216	30	30
267	WS 09	A B32 Module Production	225;215	30	30
268	WS 09	B B31 Module Production	218;230	30	30
269	WS 09	A B33 Module Production	217;227	30	30
270	WS 09	B B32 Module Production	220;232	30	30
271	WS 09	A B34 Module Production	219;229	30	30
272	WS 09	B B33 Module Production	222;234	30	30
273	WS 09	A B35 Module Production	231;241	30	30
274	WS 09	B B23 Module Assembly	260;194	25	28/30
275	WS 09	B B34 Module Production	224;236	30	30
276	WS 09	A B53 Module Production	245;249	30	30
277	WS 09	B B35 Module Production	226;238	30	30
278	WS 09	B B36 Module Production	228;240	30	30
279	WS 09	B B51 Module Production	248;254	30	30
280	WS 09	B B52 Module Production	250;255	30	30
281	WS 09	B B53 Module Production	252;256	30	30
282	WS 09	B B71 Module Production	257;258	30	30
283	WS 12	A U202 Block Assembly	205	30	30
284	WS 12	A U101 Block Assembly	283;195	25	25
285	WS 09	A B23 Module Assembly	259;283	25	25
286	WS 09	A B24 Module Assembly	261;285	25	25
287	WS 12	A B32 Module Assembly	283;285;267	25	25
288	WS 09	B B24 Module Assembly	262;274	25	25
289	WS 12	B B25 Module Assembly	288;264	25	25
290	WS 12	A B33 Module Assembly	287;269;285	25	25
291	WS 12	B U101 Block Assembly	196;194	25	25
292	WS 12	A B34 Module Assembly	271;290;286	25	25
293	WS 12	B B26 Module Assembly	266;289	25	25
294	WS 12	A B25 Module Assembly	263;286;292	25	25
295	WS 12	B B32 Module Assembly	194;274;270	25	28/30
296	WS 12	B B31 Module Assembly	268;291;295	25	25
297	WS 12	B B33 Module Assembly	272;274;295	25	28/30
298	WS 12	A B35 Module Assembly	239;273;294;292	25	25
299	WS 12	B B34 Module Assembly	288;297;275	25	28/30
300	WS 12	B B35 Module Assembly	277;289;299	25	28/30
301	WS 12	B B36 Module Assembly	300;293;278	25	28/30

Supplementary Materials **DOI: 10.33714/masteb.1324266**

302	WS 12	A B31 Module Assembly	265;292;284	25	25
303	WS 12	A U603 Block Assembly	247;298	5	5
304	WS 12	A U501 Block Assembly	233;287;302	20	20
305	WS 12	A U502 Block Assembly	235;287;304	20	20
306	WS 12	B B51 Module Assembly	279;297;299	25	25
307	WS 12	A U503 Block Assembly	237;305;290	20	20
308	WS 12	B B52 Module Assembly	306;300;280	25	25
309	WS 12	A U504 Block Assembly	239;307;292	20	20
310	WS 12	B B53 Module Assembly	281;308;301	25	25
311	WS 12	A U601 Block Assembly	243;304	10	10
312	WS 12	B B71 Module Assembly	306;308;282	25	25
313	WS 12	A B53 Module Assembly	276;305;307	25	25
314	WS 12	B Shaft Welding	291;194	8	8
315	WS 12	A U801 Block Assembly	251;313	10	10
316	WS 12	A Shaft Welding	284;283	8	8
317	WS 12	B U107 Block Assembly	208;301;293	10	10
318	WS 12	B U503 Block Assembly	297;246;306	15	15
319	WS 12	B U502 Block Assembly	244;295;318	4	4
320	WS 12	B U501 Module Assembly	242;296;295;319	20	20
321	WS 12	A Painting	316;315;309;311;303	10	10
322	WS 12	B U601 Block Assembly	253;320	10	10
323	WS 12	B Painting	314;317	10	10
324	WS 12	A Launching	321	75	75
325	WS 12	B Launching	310;312;322;323	75	75
326	WS 12	Finish	324;325	0	0

Appendix 2. The block construction activities, predecessors, and manpower values for Ships A and B.

ID	Activities	Normal Project		Crashed Project	
		Activities Durations (hour) (a, b, c, d)	*Defuzzification* $\tilde{X}_0(\tilde{A})$	*Activities Durations (hour) (a, b, c, d)*	*Defuzzification* $\tilde{X}_0(\tilde{A})$
1	Start	(0, 0, 0, 0)	0	(0, 0, 0, 0)	0
2	A U202 Cutting	(24, 32, 32, 40)	32	(24, 32, 32, 40)	32
3	B U102 Cutting	(24, 32, 32, 40)	32	(24, 32, 32, 40)	32
4	A U101 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
5	B U101 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
6	A U103 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
7	A U104 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
8	B U103 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
9	A U105 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
10	B U104 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
11	A U106 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
12	B U105 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
13	B U106 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
14	A U203 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
15	B U107 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
16	A U204 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
17	B U203 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
18	A U205 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
19	B U204 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
20	A U301 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
21	B U205 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
22	A U302 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
23	B U206 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
24	A U303 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
25	B U301 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
26	A U304 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
27	B U302 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
28	A U305 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
29	B U303 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
30	A U401 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
31	B U304 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
32	A U402 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
33	B U305 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
34	A U403 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
35	B U306 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
36	A U404 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
37	B U401 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
38	A U405 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
39	B U402 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
40	A U501 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
41	B U403 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
42	A U502 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
43	B U404 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
44	A U503 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
45	B U405 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
46	A U504 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
47	B U406 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
48	A U505 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
49	B U501 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
50	A U601 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
51	B U502 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16

Supplementary Materials **DOI: 10.33714/masteb.1324266**

52	A U602 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
53	B U503 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
54	A U603 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
55	B U504 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
56	A U701 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
57	B U505 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
58	A U801 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
59	B U506 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
60	B U601 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
61	B U602 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
62	B U603 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
63	B U604 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
64	B U701 Cutting	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
65	B U801 Cutting	(18, 24, 24, 30)	24	(18, 24, 24, 30)	24
66	A U101 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
67	B U101 Prefabrication	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
68	A U103 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
69	B U102 Prefabrication	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
70	A U104 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
71	B U103 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
72	A U105 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
73	B U104 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
74	A U106 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
75	B U105 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
76	A U202 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
77	B U106 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
78	A U203 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
79	B U107 Prefabrication	(40, 56, 56, 72)	56	(34, 48, 48, 62)	48
80	A U204 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
81	B U203 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
82	A U205 Prefabrication	(24, 32, 32, 40)	32	(19, 26, 26, 33)	26
83	B U204 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
84	A U301 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
85	B U205 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
86	A U302 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
87	B U206 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
88	A U303 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
89	B U301 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
90	A U304 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
91	B U302 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
92	A U305 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
93	B U303 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
94	A U401 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
95	B U304 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
96	A U402 Prefabrication	(24, 32, 32, 40)	32	(21, 27, 27, 33)	27
97	B U305 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
98	A U403 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
99	B U306 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
100	A U404 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
101	B U401 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
102	A U405 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
103	B U402 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
104	A U501 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
105	B U403 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
106	A U502 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
107	B U404 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47

Supplementary Materials DOI: 10.33714/masteb.1324266

108	A U503 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
109	B U405 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
110	A U504 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
111	B U406 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
112	A U505 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
113	B U501 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
114	A U601 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
115	B U502 Prefabrication	(40, 56, 56, 72)	56	(32, 45, 45, 58)	45
116	A U602 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
117	B U503 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
118	A U603 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
119	B U504 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
120	A U701 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
121	B U505 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
122	A U801 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
123	B U506 Prefabrication	(40, 56, 56, 72)	56	(33, 48, 48, 60)	47
124	B U601 Prefabrication	(12, 16, 16, 20)	16	(10, 13, 13, 16)	13
125	B U602 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
126	B U603 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
127	B U604 Prefabrication	(24, 32, 32, 40)	32	(20, 27, 27, 34)	27
128	B U701 Prefabrication	(36, 48, 48, 60)	48	(30, 40, 40, 50)	40
129	B U801 Prefabrication	(36, 48, 48, 60)	48	(30, 40, 40, 50)	40
130	A U101 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
131	B U101 Panel Production	(60, 80, 80, 100)	80	(50, 67, 67, 84)	67
132	A U103 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
133	B U102 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
134	A U104 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
135	B U103 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
136	A U105 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
137	B U104 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
138	A U106 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
139	B U105 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
140	A U202 Panel Production	(36, 48, 48, 60)	48	(30, 40, 40, 50)	40
141	B U106 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
142	A U203 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
143	B U107 Panel Production	(48, 64,64, 80)	64	(41, 55, 55, 69)	55
144	A U204 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
145	B U203 Panel Production	(60, 80, 80, 100)	80	(50, 67, 67, 84)	67
146	A U205 Panel Production	(18, 24, 24, 30)	24	(14, 19, 19, 24)	19
147	B U204 Panel Production	(60, 80, 80, 100)	80	(50, 67, 67, 84)	67
148	A U301 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
149	B U205 Panel Production	(60, 80, 80, 100)	80	(50, 67, 67, 84)	67
150	A U302 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
151	B U206 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
152	A U303 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
153	B U301 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
154	A U304 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
155	B U302 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
156	A U305 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
157	B U303 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
158	A U401 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
159	B U304 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
160	A U402 Panel Production	(18, 24, 24, 30)	24	(15, 21, 21, 27)	21
161	B U305 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
162	A U403 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
163	B U306 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53

Supplementary Materials **DOI: 10.33714/masteb.1324266**

164	A U404 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
165	B U401 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
166	A U405 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
167	B U402 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
168	A U501 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
169	B U403 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
170	A U502 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
171	B U404 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
172	A U503 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
173	B U405 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
174	A U504 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
175	B U406 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
176	A U505 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
177	B U501 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
178	A U601 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
179	B U502 Panel Production	(48, 64, 64, 80)	64	(38, 51, 51, 64)	51
180	A U602 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
181	B U503 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
182	A U603 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
183	B U504 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
184	A U701 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
185	B U505 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
186	A U801 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
187	B U506 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
188	B U601 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
189	B U602 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
190	B U603 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
191	B U604 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
192	B U701 Panel Production	(48, 64, 64, 80)	64	(40, 53, 53, 66)	53
193	B U801 Panel Production	(18, 24, 24, 30)	24	(15, 20, 20, 25)	20
194	B U102 Block Assembly	(196, 230, 230, 270)	232	(196, 230, 230, 270)	232
195	A U101 Block Production	(255, 320, 320, 385)	320	(213, 267, 267, 321)	267
196	B U101 Block Production	(400, 480, 480, 560)	480	(333, 400, 400, 467)	400
197	A U103 Block Production	(190, 240, 240, 290)	240	(190, 240, 240, 290)	240
198	B U102 Block Production	(440, 520, 520, 600)	520	(440, 520, 520, 600)	520
199	A U104 Block Production	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
200	B U103 Block Production	(190, 240, 240, 290)	240	(190, 240, 240, 290)	240
201	A U105 Block Production	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
202	B U104 Block Production	(190, 240, 240, 290)	240	(190, 240, 240, 290)	240
203	A U106 Block Production	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
204	B U105 Block Production	(210, 280, 280, 350)	280	(210, 280, 280, 350)	280
205	A U202 Block Production	(255, 320, 320, 385)	320	(255, 320, 320, 385)	320
206	B U106 Block Production	(190, 240, 240, 290)	240	(190, 240, 240, 290)	240
207	A U203 Block Production	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
208	B U107 Block Production	(210, 280, 280, 350)	280	(210, 280, 280, 350)	280
209	A U204 Block Production	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
210	B U203 Block Production	(190, 240, 240, 290)	240	(190, 240, 240, 290)	240
211	A U205 Block Production	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
212	B U204 Block Production	(210, 280, 280, 350)	280	(210, 280, 280, 350)	280
213	A U301 Block Production	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
214	B U205 Block Production	(210, 280, 280, 350)	280	(210, 280, 280, 350)	280
215	A U302 Block Production	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
216	B U206 Block Production	(190, 240, 240, 290)	240	(190, 240, 240, 290)	240
217	A U303 Block Production	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
218	B U301 Block Production	(210, 280, 280, 350)	280	(210, 280, 280, 350)	280
219	A U304 Block Production	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168

Supplementary Materials DOI: 10.33714/masteb.1324266

220	B U302 Block Production	(210, 280, 280, 350)	280	(210, 280, 280, 350)	280
221	A U305 Block Production	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
222	B U303 Block Production	(210, 280, 280, 350)	280	(210, 280, 280, 350)	280
223	A U401 Block Production	(190, 240, 240, 290)	240	(190, 240, 240, 290)	240
224	B U304 Block Production	(190, 240, 240, 290)	240	(190, 240, 240, 290)	240
225	A U402 Block Production	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
226	B U305 Block Production	(210, 280, 280, 350)	280	(210, 280, 280, 350)	280
227	A U403 Block Production	(136, 168,168, 200)	168	(136, 168, 168, 200)	168
228	B U306 Block Production	(190, 240, 240, 290)	240	(190, 240, 240, 290)	240
229	A U404 Block Production	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
230	B U401 Block Production	(210, 280, 280, 350)	280	(210, 280, 280, 350)	280
231	A U405 Block Production	(190, 240, 240, 290)	240	(190, 240, 240, 290)	240
232	B U402 Block Production	(210, 280, 280, 350)	280	(210, 280, 280, 350)	280
233	A U501 Block Production	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
234	B U403 Block Production	(190, 240, 240, 290)	240	(190, 240, 240, 290)	240
235	A U502 Block Production	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
236	B U404 Block Production	(190, 240, 240, 290)	240	(190, 240, 240, 290)	240
237	A U503 Block Production	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
238	B U405 Block Production	(210, 280, 280, 350)	280	(210, 280, 280, 350)	280
239	A U504 Block Production	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
240	B U406 Block Production	(210, 280, 280, 350)	280	(210, 280, 280, 350)	280
241	A U505 Block Production	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
242	B U501 Block Production	(880, 1000, 1000, 1120)	1.000	(880, 1000, 1000, 1120)	1.000
243	A U601 Block Production	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
244	B U502 Block Production	(210, 280, 280, 350)	280	(210, 280, 280, 350)	280
245	A U602 Block Production	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
246	B U503 Block Production	(255, 320, 320, 385)	320	(255, 320, 320, 385)	320
247	A U603 Block Production	(40, 56, 56, 72)	56	(40, 56, 56, 72)	56
248	B U504 Block Production	(210, 280, 280, 350)	280	(210, 280, 280, 350)	280
249	A U701 Block Production	(190, 240, 240, 290)	240	(190, 240, 240, 290)	240
250	B U505 Block Production	(255, 320, 320, 385)	320	(255, 320, 320, 385)	320
251	A U801 Block Production	(40, 56, 56, 72)	56	(40, 56, 56, 72)	56
252	B U506 Block Production	(255, 320, 320, 385)	320	(255, 320, 320, 385)	320
253	B U601 Block Production	(120, 160, 160, 200)	160	(120, 160, 160, 200)	160
254	B U602 Block Production	(210, 280, 280, 350)	280	(210, 280, 280, 350)	280
255	B U603 Block Production	(255, 320, 320, 385)	320	(255, 320, 320, 385)	320
256	B U604 Block Production	(280, 360, 360, 440)	360	(280, 360, 360, 440)	360
257	B U701 Block Production	(700, 800, 800, 900)	800	(700, 800, 800, 900)	800
258	B U801 Block Production	(640, 720, 720, 800)	720	(640, 720, 720, 800)	720
259	A B23 Module Production	(90, 120, 120, 150)	120	(90, 120, 120, 150)	120
260	B B23 Module Production	(60, 80, 80, 100)	80	(60, 80, 80, 100)	80
261	A B24 Module Production	(90, 120, 120, 150)	120	(90, 120, 120, 150)	120
262	B B24 Module Production	(60, 80, 80, 100)	80	(60, 80, 80, 100)	80
263	A B25 Module Production	(190, 240 240, 290)	240	(190, 240, 240, 290)	240
264	B B25 Module Production	(60, 80, 80, 100)	80	(60, 80, 80, 100)	80
265	A B31 Module Production	(90, 120, 120, 150)	120	(90, 120, 120, 150)	120
266	B B26 Module Production	(60, 80, 80, 100)	80	(60, 80, 80, 100)	80
267	A B32 Module Production	(90, 120, 120, 150)	120	(90, 120, 120, 150)	120
268	B B31 Module Production	(60, 80, 80, 100)	80	(60, 80, 80, 100)	80
269	A B33 Module Production	(90, 120, 120, 150)	120	(90, 120, 120, 150)	120
270	B B32 Module Production	(60, 80, 80, 100)	80	(60, 80, 80, 100)	80
271	A B34 Module Production	(90, 120, 120, 150)	120	(90, 120, 120, 150)	120
272	B B33 Module Production	(60, 80, 80, 100)	80	(60, 80, 80, 100)	80
273	A B35 Module Production	(90, 120, 120, 150)	120	(90, 120, 120, 150)	120
274	B B23 Module Assembly	(210, 280, 280, 350)	280	(185, 250, 250, 315) (175, 234, 234, 290)	250 233
275	B B34 Module Production	(60, 80, 80, 100)	80	(60, 80, 80, 100)	80

Supplementary Materials **DOI: 10.33714/masteb.1324266**

276	A B53 Module Production	(40, 56, 56, 72)	56	(40, 56, 56, 72)	56
277	B B35 Module Production	(60, 80, 80, 100)	80	(60, 80, 80, 100)	80
278	B B36 Module Production	(60, 80, 80, 100)	80	(60, 80, 80, 100)	80
279	B B51 Module Production	(60, 80, 80, 100)	80	(60, 80, 80, 100)	80
280	B B52 Module Production	(60, 80, 80, 100)	80	(60, 80, 80, 100)	80
281	B B53 Module Production	(60, 80, 80, 100)	80	(60, 80, 80, 100)	80
282	B B71 Module Production	(18, 24, 24, 30)	24	(18, 24, 24, 30)	24
283	A U202 Block Assembly	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
284	A U101 Block Assembly	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
285	A B23 Module Assembly	(12, 16, 16, 20)	16	(12, 16, 16, 20)	16
286	A B24 Module Assembly	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
287	A B32 Module Assembly	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
288	B B24 Module Assembly	(200, 272, 272, 320)	264	(200, 272, 272, 320)	264
289	B B25 Module Assembly	(210, 276, 276, 330)	272	(210, 276, 276, 330)	272
290	A B33 Module Assembly	(84, 112, 112, 140)	112	(84, 112, 112, 140)	112
291	B U101 Block Assembly	(120, 160, 160, 200)	160	(120, 160, 160, 200)	160
292	A B34 Module Assembly	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
293	B B26 Module Assembly	(210, 276, 276, 330)	272	(210, 276, 276, 330)	272
294	A B25 Module Assembly	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
295	B B32 Module Assembly	(640, 720, 720, 800)	720	(571, 643, 643, 715)	643
				(533, 600, 600, 667)	600
296	B B31 Module Assembly	(640, 720, 720, 800)	720	(640, 720, 720, 800)	720
297	B B33 Module Assembly	(440, 520, 520, 600)	520	(393, 464, 464, 535)	464
				(367, 432, 432, 500)	433
298	A B35 Module Assembly	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
299	B B34 Module Assembly	(200, 272, 272, 320)	264	(179, 243, 243, 286)	236
				(167, 227, 227, 266)	220
300	B B35 Module Assembly	(160, 200, 200, 240)	200	(143, 179, 179, 215)	179
				(134, 167, 167, 200)	167
301	B B36 Module Assembly	(210, 280, 280, 350)	280	(185, 250, 250, 315)	250
				(175, 234, 234, 290)	233
302	A B31 Module Assembly	(136, 168, 168, 200)	168	(136, 168, 168, 200)	168
303	A U603 Block Assembly	(7, 8, 8, 9)	8	(7, 8, 8, 9)	8
304	A U501 Block Assembly	(84, 112, 112, 140)	112	(84, 112, 112, 140)	112
305	A U502 Block Assembly	(84, 112, 112, 140)	112	(84, 112, 112, 140)	112
306	B B51 Module Assembly	(120, 160, 160, 200)	160	(120, 160, 160, 200)	160
307	A U503 Block Assembly	(84, 112, 112, 140)	112	(84, 112, 112, 140)	112
308	B B52 Module Assembly	(160, 200, 200, 240)	200	(160, 200, 200, 240)	200
309	A U504 Block Assembly	(84, 112, 112, 140)	112	(84, 112, 112, 140)	112
310	B B53 Module Assembly	(255, 320, 320, 385)	320	(255, 320, 320, 385)	320
311	A U601 Block Assembly	(40, 56, 56, 72)	56	(40, 56, 56, 72)	56
312	B B71 Module Assembly	(190, 240, 240, 290)	240	(190, 240, 240, 290)	240
313	A B53 Module Assembly	(60, 80, 80, 100)	80	(60, 80, 80, 100)	80
314	B Shaft Welding	(60, 80, 80, 100)	80	(60, 80, 80, 100)	80
315	A U801 Block Assembly	(60, 80, 80, 100)	32	(60, 80, 80, 100)	32
316	A Shaft Welding	(320, 400, 400, 480)	80	(320, 400, 400, 480)	80
317	B U107 Block Assembly	(60, 80, 80, 100)	400	(60, 80, 80, 100)	400
318	B U503 Block Assembly	(30, 40, 40, 50)	80	(30, 40, 40, 50)	80
319	B U502 Block Assembly	(160, 200, 200, 240)	40	(160, 200, 200, 240)	40
320	B U501 Module Assembly	(180, 204, 204, 240)	200	(180, 204, 204, 240)	200
321	A Painting	(30, 40, 40, 50)	208	(30, 40, 40, 50)	208
322	B U601 Block Assembly	(60, 80, 80, 100)	40	(60, 80, 80, 100)	40
323	B Painting	(7, 8, 8, 9)	80	(7, 8, 8, 9)	80
324	A Launching	(7, 8, 8, 9)	8	(7, 8, 8, 9)	8
325	B Launching	(0, 0, 0, 0)	8	(0, 0, 0, 0)	8
326	Finish	(60, 80, 80, 100)	0	(60, 80, 80, 100)	0

Mar. Sci. Tech. Bull. (2023) 12(3): 402-410
e–ISSN: 2147–9666
info@masteb.com

dergipark.org.tr/en/pub/masteb
www.masteb.com
DOI: 10.33714/masteb.1337981

Marine Science and Technology Bulletin

PRENSIP
https://prensip.gen.tr/

RESEARCH ARTICLE

The chemical composition, sensory properties, and myofibrillar proteins of surimi produced from tilapia (*Oreochromis niloticus*) meat

Güneş Buyruk[1] • Mehmet Çelik[2] • Aygül Küçükgülmez[3] • Ali Eslem Kadak[4*]

[1] *Çukurova University, Institute of Natural and Applied Sciences, Department of Fisheries, 01330, Adana, Türkiye*
[2] *Çukurova University, Ceyhan Faculty of Veterinary, Department of Food Hygiene and Technology, 01330, Adana, Türkiye*
[3] *Çukurova University, Faculty of Fisheries, Department of Fisheries and Seafood Processing Technology, 01330, Adana, Türkiye*
[4] *Kastamonu University, Fisheries Faculty, Department of Aquaculture, 37150, Kastamonu, Türkiye*

ARTICLE INFO

Article History:
Received: 04.08.2023
Received in revised form: 04.09.2023
Accepted: 04.09.2023
Available online: 28.09.2023

Keywords:
Surimi
Tilapia
Food Composition
Sensory Analysis
Proximate Analysis

ABSTRACT

Surimi, which is defined as the semi-processed minced meat of aquatic products that are discarded or have little fresh consumption, is usually offered for consumption by being made similar to valuable aquatic products such as shrimp, lobster tail, crab legs, and scallops. In this study, the chemical composition, myofibrillar proteins, and sensory properties of surimi manufactured from tilapia (*Oreochromis niloticus*) meat were investigated. Four study groups were created with different spice additives: red pepper, dill, thyme, and control (additive-free). Chemical composition analysis results of surimi were determined as total protein 12.85%, lipid 0.53%, ash 0.36%, moisture 86.59%, and myofibrillar protein 11.93%. Moreover, all groups were offered panelists to perform sensory analysis. At the end of the sensory evaluation, the groups received between 5.5 and 8.8 points on a 10-point scale from panelists regarding appearance, odor, chewiness, juiciness, taste and flavor, and overall acceptance. There were no differences between experimental groups in terms of appearance, odor, chewiness, and juiciness. However, statistical differences were observed between groups for taste and flavor as well as overall acceptance ($p<0.05$).

Please cite this paper as follows:

Buyruk, G., Çelik, M., Küçükgülmez, A., & Kadak, A. E. (2023). The chemical composition, sensory properties, and myofibrillar proteins of surimi produced from tilapia (*Oreochromis niloticus*) meat. *Marine Science and Technology Bulletin*, *12*(3), 402-410. https://doi.org/10.33714/masteb.1337981

* Corresponding author
E-mail address: akadak@kastamonu.edu.tr (A. E. Kadak)

Introduction

Seafood has great importance in terms of nutritional value and especially protein content. It is also very rich in vitamins, amino acids, fatty acids, minerals, and other nutrients. There are different processing techniques for seafood, which have an important role in human nutrition. Among them, minced fish has a significant place (Hosomi et al., 2012; Durazzo et al., 2022).

Minced fish is a raw material for many new foods in aquaculture. One of the main products manufactured from minced fish is the product called "surimi". Surimi, which means minced meat in Japanese, is a kind of semi-manufactured fish protein extract prepared from deboned, minced, and washed fish. Surimi, typically produced and consumed fresh with conventional methods, has reached long-time preservation with the developments in protein denaturation prevention technology, and therefore its consumption has spread over a wider period (Matsumoto, 1978). Through repeated washing processes carried out in the surimi production, all substances other than protein in the fish are cleansed, and thus the fish becomes even healthier. In the manufacturing of surimi, which is a protein product with a neutral taste, unpopular and/or low economic value fish and seafood are utilized by processing directly or in combination with various other products (Frazier & Westhoff, 1978). The development of surimi technology has been achieved with factors such as the successful use of uneconomical and less economical species as raw materials in the Far East, America, and European countries, the long shelf life of frozen surimi and its very high functional protein content, and the manufacture of surimi and surimi-based products with the addition of various additives and with the use of various technological processes (Çaklı & Duyar, 2001; Duangmal & Taluengphol, 2010; Monto et al., 2022; Buamard et al., 2023). The steps of surimi production are shown in Figure 1.

Tilapia (*O. niloticus*), which is one of the fish species of low economic value in our country, occupies a very large place in terms of its aquaculture potential. It constitutes a natural potential, especially in the climatic conditions of the Mediterranean and Aegean regions, and its farming is performed with ease. In addition, tilapia is a very valuable fish species in terms of the nutritional quality of its meat. It may be beneficial for the economy to make this species, which is considered very useful in terms of both its high production capacity and nutritional quality, more palatable with various spices and flavors to increase its consumption by using modern processing technologies. Although there are many studies in the literature on surimi manufacture from different aquatic products (Alvarez et al., 1995; Gomez-Guillén & Montero, 1996; Gomez-Guillén et al., 1997; Yongsawatdigul et al., 1997; Lee & Park, 1998; Kong et al., 1999; Ramirez-Suarez et al., 2000; Nowsad et al., 2000; Kyaw et al., 2001; Huda et al., 2001a, 2001b; Choi & Park, 2002; Barrera et al., 2002; Luo et al., 2008; Panpipat et al., 2010; Oujifard et al., 2012; Singh et al., 2019; Chen et al., 2020; Yi et al., 2020; Fang et al., 2021; Pei et al., 2023), studies of surimi obtained from tilapia is very limited (Rohani et al., 1995; Klesk et al., 2000; Yongsawatdigul et al., 2000; Lou et al., 2005; Hleap & Velasco, 2010; Kobayashi & Park, 2017; Buamard et al., 2023). Therefore, in the present study, the sensory evaluation of the product was aimed by adding different spices to surimi prepared from tilapia. In addition, through chemical analysis, it is aimed to evaluate the nutritional value of surimi produced from tilapia, which is considered a valuable food source in terms of human nutrition.

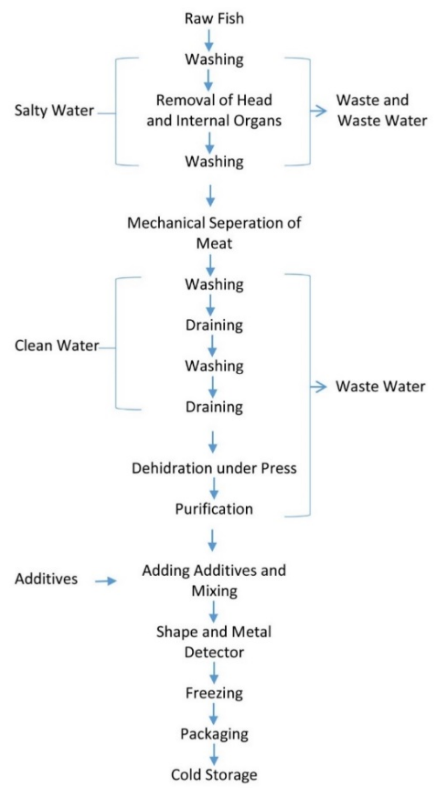


Figure 1. Flow diagram of surimi production (Lee, 1984)

Material and Method

Material

Tilapia (*O. niloticus*) was used as the material in the research. The mean weight of the fish was measured as 145 g and the mean length was measured to be 20 cm.

Method

Surimi Preparation

In the present study, skinless fillets of the fish were first obtained for the production of surimi from tilapia meat. The fillets were minced in a meat grinder of which the hole diameter is 1-5 mm. The finely minced fish meat was washed to eliminate undesired compounds. The washing process was repeated 3 times with clean water cooled in the refrigerator below 10°C, 0.3% salt was added to the final washing water, and the washing process was completed. The washed samples were passed through a fine mesh strainer and this process was repeated three times. Thusly, water-soluble proteins, proteolytic enzymes, pigments, blood, lipids, and all compounds that give the special taste and flavor were completely eliminated. At the end of the washing process, the minced fish was filtered for 3-4 hours under refrigerated conditions in cloth bags prepared earlier until the water content is 86% and the surimi was obtained.

Proximate Analysis

The fish fillets were obtained after removing the head, skin, bones, and viscera. The fillets were thoroughly cleaned by washing and homogenized. The meat's moisture and ash content were determined with the methods according to the AOAC (1990). The nitrogen content was analyzed as per Kjeldahl's procedure (AOAC, 1990) and was converted to determine the crude protein content of the meat. The lipid content was determined according to Bligh & Dyer (1959). All procedures were performed in triplicate.

Myofibrillar Protein Analysis

The extraction of myofibrillar proteins was carried out according to the method of Dyer et al. (1950). For extraction, firstly 5% NaCl and 0.02 M $NaHCO_3$ were added to 1 L of distilled water. The homogenized 50 g sample was extracted for 1 minute with the pre-cooled extraction solution in a Waring blender fitted with a defoamer to prevent foaming. Afterward, the obtained homogenate was centrifuged at 4°C, 4000 rpm for 30 minutes in a temperature-controlled centrifuge. One ml of the upper phase of the solution obtained as a result of the extraction was taken and placed in test tubes and the solution was completed to 5 ml with distilled water. This prepared solution was mixed thoroughly by adding a biuret solution and left to rest for the formation of violet color.

Bovine Serum Albumin was used as the standard for myofibrillar proteins (Snow, 1950). For the preparation of the Bovine Serum Albumin standard, 0.075 g BSA was completed to 25 ml. Blind and the samples were read in UV-Vis spectrophotometer at 540 nm wavelength and the absorbance values were recorded. The recorded values were calculated by placing them in the Equation (1):

$$B = \frac{1000 \times a \times b}{c} \tag{1}$$

In Equation (1);

a: BSA standard amount;

b: BSA added to the test tube;

c: The volume of the container in which the BSA standard was prepared.

This coefficient obtained from the standard was multiplied by the read spectrophotometer value to obtain the R value given in the equation below.

The absorbance values of the myofibrillar proteins obtained from the spectrophotometer were determined as percent protein by the Equation (2).

$$EP = \frac{(\frac{R}{V3} \times V4 + M \times W2/100) \times 100}{W2 \times 10} \tag{2}$$

In Equation (2);

EP: Amount of extracted (dissolved) protein (g/100 g meat);

R: Total mg of protein read in test tubes obtained from the protein standard plot;

V3: Amount of extract added to test tubes (ml);

V4: Amount of extracted solution put into the blender (ml);

M: Moisture content determined in the fish meat (ml);

W2: Weight of the fish used for the extraction (g);

Sensory Evaluation

Manufactured surimi samples were divided into four equal portions. One group being plain (control); certain proportions of red pepper, dill, and thyme were added separately to each of the remaining 3 groups. The prepared mixtures were put into molds and cooked in a microwave oven at 450 W for 20 minutes and served to the panelists. For the sensory evaluation, the product's appearance, odor, chewiness, juiciness, taste and flavor, and overall acceptance criteria were used. Each criterion was evaluated on a 10-point scale (Gülyavuz & Tömek, 1991).

Statistical Analysis

Statistical analysis was conducted by using the SPSS software for Windows (SPSS Inc., Chicago, IL, USA). Data were subjected to one-way analysis of variance (ANOVA). The differences between groups were revealed by Duncan's multiple range test at a significance level of 0.05.

RESULTS AND DISCUSSION

Proximate Composition

The proximate composition and myofibrillar protein content of surimi manufactured from tilapia (*O. niloticus*) meat are shown in Table 1.

According to the chemical analyses, the moisture content of the surimi manufactured was determined as 85.59%. The protein content after surimi manufacture was found to be 12.85%. Soluble proteins were eliminated after salt treatment, which is amongst the surimi production stages, and the remaining myofibrillar protein was determined as 11.39%. Moreover, the lipid content decreased considerably by the washing stage applied during the manufacturing process and was measured as 0.53%. As a result of the analysis conducted, the crude ash content was determined as 0.36%. According to a similar study, the proximate analysis results of surumin were determined as protein 10.77%, lipid 0.75%, moisture 78.23%, and collagen 1.15% (Zhou et al., 2017). Hosseini-Shekarabi et al. (2018) found the protein value of surumin produced as 17.77%, lipid value 0.94%, ash 0.58%, moisture 79.58%, and yield 36.56% in their study with blackmouth croaker fish. In another study, protein, lipid, ash, and moisture analyzes of surimi prepared from Talang quinfish fish obtained from the local market were performed, the results were determined as 16.97, 0.43, 2.77, and 67.09%, respectively (Moosavi-Nasab et al., 2019). In a similar study, Oh et al. (2019) reported the analysis results of basic nutritional components of surimi obtained from olive flounder fish as protein 18.93%, lipid 0.11%, ash 0.10, and moisture 73.18%. In another study, according to the physicochemical analysis results of surumin obtained from tilapia fish, protein was 11.1%, lipid 1.8%, ash 2.15%, and moisture 72.5% (Priyadarshini et al., 2021). The results obtained in the current study were compared with the results obtained by other researchers who worked with similar products. It is thought that the different results determined according to this comparison vary depending on the species, sex, production method and diet of the fish.

Sensory Evaluation

Surimi manufactured from Tilapia (*O. niloticus*), one group being plain (control), was prepared by adding red pepper, dill, and thyme, and presented to the panelists according to the quality criteria of appearance, odor, chewiness, juiciness, taste and flavor, and overall acceptance. The mean values of sensory analysis performed based on the quality criteria and the Duncan multiple comparison test results of these data are shown in Table 2.

In terms of appearance, ranking from best to worst, the panelists evaluated group B (dill) with 8.6, group C (thyme) with 8.2, group A (red pepper) with 7.6, and group D (control) with 6.8 points. Based on the sensory analysis according to the odor criterion, two groups of values, i.e., 7.6 and 8.6, were recorded. Accordingly, in the order of preference, groups B and C were evaluated with 8.6 points, and groups A and D with 7.6 points. Chewiness was evaluated by the panelists with 7.8 points for group C, 7.6 points for group B, 7.2 points for group D, and 6.6 points for Group A. The juiciness values of the prepared surimi were evaluated by the panelists with 6.8 points for group C, 6.6 points for group B, 6.2 points for group D, and 5.8 points for group A. In the taste and flavor analysis, scores between 6.8 and 8.8 were recorded and in the order of preference, group B received 8.8 points, group C received 8.6 points, group A received 7.6 points, and group D received 6.8 points. According to the overall acceptance criterion, scores between 6.4 and 8.4 were recorded in the experimental groups, and the analysis data from best to worst were determined as 8.4 for group C, 8.0 for group B, 7.0 for group A, and 6.4 for group D. In a similar study conducted by adding camellia tea oil at different rates, the control group got the lowest sensory evaluation score, and the color, texture, taste-flavor and overall acceptability scores increased as the amount of added oil increased (Zhou et al., 2017). Similarly, in another study comparing minced fish and surimi, the sensory scores of surimi samples were found to be color 9.00, odor 8.86, texture 9.00, taste 8.57, and overall desirability 8.14 (Hosseini-Shekarabi et al., 2018).

Table 1. Proximate composition and myofibrillar protein of surimi manufactured from tilapia meat (%)

	Protein	Lipid	Ash	Moisture	Myofibrillar protein
Surimi	12.85±0.21	0.53±0.02	0.36±0.00	86.59±0.47	11.93±0.7

Note: Means (±sd) are based on triplicate analyses.

Table 2. The mean sensory evaluation values of surimi enriched with different additives

	A (Red pepper)	B (Dill)	C (Thyme)	D (Control)
Appearance	7.6±1.52^{a}	8.6±0.54^{a}	8.2±0.84^{a}	6.8±2.49^{a}
Odor	7.6±1.14^{a}	8.6±0.55^{a}	8.6±1.52^{a}	7.6±1.67^{a}
Chewiness	6.6±0.55^{a}	7.6±1.34^{a}	7.8±1.64^{a}	7.2±0.84^{a}
Juiciness	5.8±1.10^{a}	6.6±1.95^{a}	6.8±2.17^{a}	6.2±1.48^{a}
Taste and flavor	7.6±0.55^{ab}	8.8±0.84^{b}	8.6±0.55^{b}	6.8±1.30^{a}
Overall acceptance	7.0±0.00^{ab}	8.0±0.71^{bc}	8.4±0.89^{c}	6.4±1.52^{a}

Note: In the statistical analysis, the findings expressed with different letters in the same row were found to be different at $p<0.05$ significance level (A: Red pepper, B: Dill, C: Thyme, D: Control).

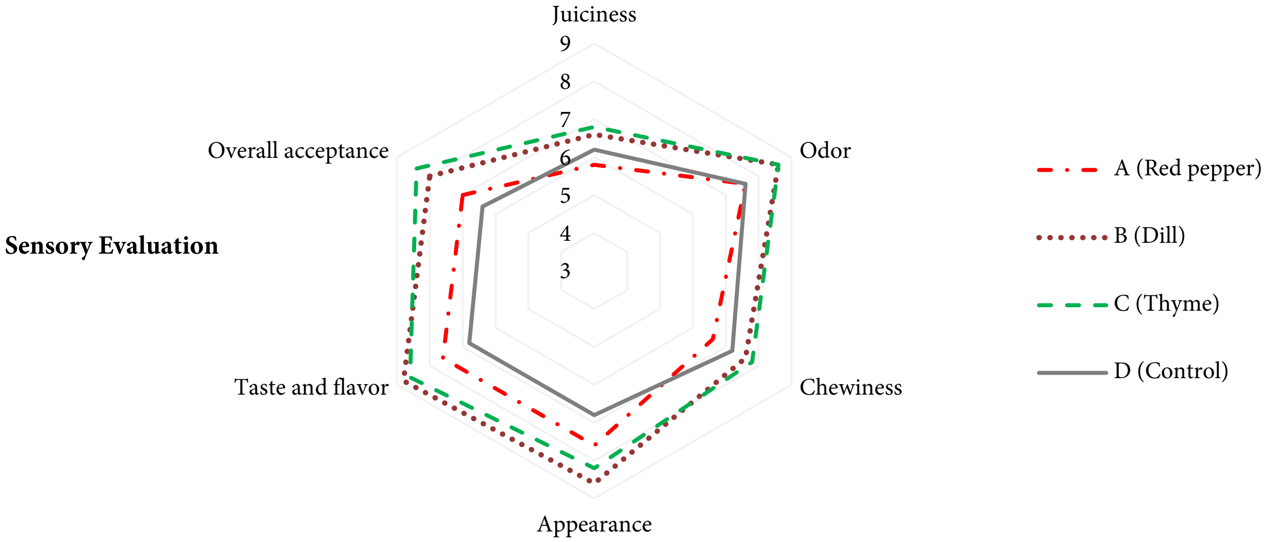


Figure 2. Sensory evaluation values of surimi enriched with different additives

In order for the fish introduced to the market for consumption to possess a high market share, it should have a long shelf life and a marketing potential with diversifiable sensory characteristics such as taste, odor, and aroma. For this purpose, in addition to methods such as smoking, freezing, canning, drying, and salting applied to fresh fish, surimi is a product that can also increase the consumption rate of seafood products. Moreover, considering the consumption possibilities by adding spices and similar seasonings according to the regional taste demands, surimi was attempted to be determined as a result of the sensory analysis conducted in this study whether it is a suitable product. The surimi was diversified by manufacturing with additives such as dill, thyme, and red pepper in accordance with the taste preference of the local people of our country. As a result of the sensory analysis, the most preferred products were determined to be the ones enriched with thyme and dill (Figure 2). Furthermore, the appearance, odor, juiciness, and chewiness of the product were also included in the sensory analysis criteria. In terms of these criteria, the products received scores between 5.8 and 8.8 out of 10 in the sensory evaluation. In addition to the sensory evaluation, chemical analyses were made in the manufactured surimi, and according to the results obtained as a result of these analyses, it was determined that surimi is a low-fat and high-protein source. This shows that it is a highly beneficial food in terms of human nutrition (Jaziri et al., 2021).

It is known that fish and seafood products, which are not preferred to be consumed fresh or less preferred in some parts of the world, especially in Southwest Asia and Far East countries, are transformed into new products by employing various processing techniques and thereby their market share is increased. Increasing consumption by offering species with these characteristics to people in different forms is possible through creating new products using the state-of-the-art technologies. It is inaccurate to state that tilapia, which is considered to possess high aquaculture potential in the south and west regions of our country, is highly preferred for fresh consumption. Despite its high potential for aquaculture, the farming of this fish has not been developed in our country due to the low habit of eating freshwater fish. The results obtained in this study show that tilapia, which is typically disliked because it is usually consumed fresh, can be preferred by the consumer if it is offered to the market in the form of surimi. This can lead to extremely positive results for a less preferred fish species such as tilapia. Manufacturing surimi from tilapia under suitable conditions and presenting it to the consumer by providing different tastes and flavors in line with the taste and eating habits means creating a new market for this fish species. When people find the taste and flavor they desire, from which fish the product is manufactured will take second place in their ranking of priorities. Thus, the breeders will be able to offer this fish species to the public in different areas and have the chance to give a new impetus to tilapia farming. This can both create a new market in our country, which is extremely rich in terms of inland waters, and increase our societal fish consumption.

Conclusion

The dissemination of surimi technology, which has limited use in Türkiye, may provide a number of advantages. These are;

- Processing a portion of the product, offered to the market as fresh, with surimi technology may encourage the consumption to be spread over a year on a regular basis.
- The possibility of utilization of wastes resulting from the surimi processing may emerge by processing them into fish meal and similar products,
- It may provide the opportunity to increase the consumption of fish, which have low economic value, are not consumed with pleasure, and have limited fresh consumption in the market, such as tilapia,
- An opportunity to offer an alternative product can be provided to people who tend toward preferring seafood against the problem of excessive weight gain caused by overeating,
- Since it provides a new taste and flavor, it may increase the variety of processed fish products and therefore can function as a consumption enhancer,
- With the dissemination of surimi technology, it may create the opportunity to start new businesses and therefore generate employment,
- When the resulting products are used as additives, it may enable lowering of the food prices and increase their nutritional values,
- In addition to its direct contribution to the economy, it may also indirectly be impactful on the formation of a stable market structure in the production and consumption of seafood products.

Acknowledgements

This article was part of MSc Thesis of Güneş Buyruk.

Compliance With Ethical Standards

Authors' Contributions

GB: Investigation, Laboratory experiments, Methodology, Writing.
MC: Supervision, Data curation, Reading, Review & Editing.
AK: Laboratory experiments, Manuscript design, Draft checking.
AEK: Visualisation, Writing, Draft checking, Reading, Editing.
All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author, [AEK], upon reasonable request.

References

Alvarez, C., Couso, I., & Tejada, M. (1995). Sardine surimi gel as affected by salt concentration, blending, heat treatment and moisture. *Journal of Food Science*, *60*(3), 622-626. https://doi.org/10.1111/j.1365-2621.1995.tb09842.x

AOAC. (1990). Official methods of analysis. *Association of the Official Analytical Chemists* (15th. Ed). Washington.

Barrera, A. M., Ramirez, J. A., Gonzalez-Cabriales, J. J., & Vazquez, M. (2002). Effect of pectins on the gelling properties of surimi from silver carp. *Food Hydrocolloids*, *16*(5), 441-447. https://doi.org/10.1016/s0268-005x(01)00121-7

Bligh, E. G., & Dyer, W. J. (1959). A rapid method of total lipid extraction and purification. *Canadian Journal of Biochemistry and Physiology*, *37*(8), 911-917. https://doi.org/10.1139/o59-099

Buamard, N., Singh, A., Zhang, B., Hong, H., Singh, P., & Benjakul, S. (2023). Ethanolic extract of duea ching fruit: extraction, characterization and its effect on the properties and storage stability of sardine surimi gel. *Foods*, *12*(8), 1635. https://doi.org/10.3390/foods12081635

Çaklı, Ş., & Duyar, H. A. (2001). Surimi teknolojisi. *E.Ü. Su Ürünleri Dergisi, 18*(1-2), 255-269.

Chen, J., Deng, T., Wang, C., Mi, H., Yi, S., Li, X., & Li, J. (2020). Effect of hydrocolloids on gel properties and protein secondary structure of silver carp surimi. *Journal of the Science of Food and Agriculture*, *100*(5), 2252-2260. https://doi.org/10.1002/jsfa.10254

Choi, Y. J., & Park, J. W. (2002). Acid-aided protein recovery from enzyme-rich pacific whiting. *Journal of Food Science,* *67*(8), 2962–2967. https://doi.org/10.1111/j.1365-2621.2002.tb08846.x

Duangmal, K., & Taluengphol, A. (2010). Effect of protein additives, sodium ascorbate, and microbial transglutaminase on the texture and colour of red tilapia surimi gel. *International Journal of Food Science & Technology*, *45*(1), 48-55. https://doi.org/10.1111/j.1365-2621.2009.02102.x

Durazzo, A., Di Lena, G., Gabrielli, P., Santini, A., Lombardi-Boccia, G., & Lucarini, M. (2022). Nutrients and bioactive compounds in seafood: quantitative literature research analysis. *Fishes*, *7*(3), 132. https://doi.org/10.3390/fishes7030132

Dyer, W. J., Fench, H. V., & Snow, J. M. (1950). Proteins in fish muscle. I. Extraction of protein fraction in fresh fish. *Journal of the Fisheries Research Board of Canada*, *7*(10), 585. https://doi.org/10.1139/f47-052

Fang, Q., Shi, L., Ren, Z., Hao, G., Chen, J., & Weng, W. (2021). Effects of emulsified lard and TGase on gel properties of threadfin bream (*Nemipterus virgatus*) surimi. *LWT, 146*, 111513. https://doi.org/10.1016/j.lwt.2021.111513

Frazier, W. C., & Westhoff D. C. (1978). *Food microbiology*. 3rd Edition. Hill Publishing Co.

Gomez-Guillén, C., & Montero, P. (1996). Addition of hydrocolloids and nonmuscle proteins to sardine (*Sardine pilchardus*) mince gels effect of salt concentration. *Food Chemistry*, *56*(4), 421-427. https://doi.org/10.1016/0308-8146(95)00211-1

Gomez-Guillén, C., Solas, T., & Montero, P. (1997). Influence of added salt and non-muscle proteins on the rheology and ultrastructure of gels made from minced flesh of sardine (*Sardine pilchardus*). *Food Chemistry*, *58*(3), 193-202. https://doi.org/10.1016/s0308-8146(96)00092-1

Gülyavuz, H., & Tömek, S. (1991). Balık etinden sosis yapımı teknolojisi. *Su Ürünleri Sempozyumu Bildiriler Kitabı, Türkiye*. pp. 286-289.

Hleap, J. I., & Velasco, V. A. (2010). Análisis de las propiedades de textura durante el almacenamiento de salchichas elaboradas a partir de tilapia roja (*Oreochromis sp.*). *Biotecnología en el Sector Agropecuario y Agroindustrial*, *8*(2), 46-56. https://doi.org/10.18684/bsaa.v19.n2.2021.1425

Hosomi, R., Yoshida, M., & Fukunaga, K. (2012). Seafood consumption and components for health. *Global Journal of Health Science*, *4*(3), 72-86. https://doi.org/10.5539/gjhs.v4n3p72

Hosseini-Shekarabi, S. P., Hosseini, S. E., Soltani, M., Kamali, A., & Valinassab, T. (2018). A comparative study on physicochemical and sensory characteristics of minced fish and surimi from black mouth croaker (*Atrobucca nibe*). *Journal of Agricultural Science and Technology*, *16*, 1289-1300.

Huda, N., Abdullah, A., & Babji, A. S. (2001a). Functional properties of surimi powder from three Malaysian marine fish. *International Journal of Food Science & Technology,* *36*(4), 401-406. https://doi.org/10.1046/j.1365-2621.2001.00473.x

Huda, N., Abdullah, A., & Babji, A. S. (2001b). Physicochemical properties of Malaysian fish balls. *Fishery Technology*, *38*(1), 14-17.

Jaziri, A. A., Shapawi, R., Mokhtar, R. A. M., Noordin, W. N. M., & Huda, N. (2021). Chemical composition of lizardfish surimi by-product: Focus on macro and micro-minerals contents. *Current Research in Nutrition and Food Science Journal,* *9*(1), 52-61. https://doi.org/10.12944/crnfsj.9.1.06

Klesk, K., Yongsawatdigul, J., Park, J. W., Viratchakul, S., & Virulhakul, P. (2000). Gel forming ability of tropical tilapia surimi as compared with Alaska pollock and Pacific whiting surimi. *J. Aquatic Food Product Technology*, *9*(3), 91-103. https://doi.org/10.1300/j030v09n03_07

Kobayashi, Y., & Park, J. W. (2017). Physicochemical characterizations of tilapia fish protein isolate under two distinctively different comminution conditions. *Journal of Food Processing and Preservation*, *41*(6), e13233. https://doi.org/10.1111/jfpp.13233

Kong, C. S., Ogewa, H., & Iso, N. (1999). Temparature dependency of compression properties of fish-meat gel as affected by added starch. *Journal of Food Science*, *64*(6), 1048-11052. https://doi.org/10.1111/j.1365-2621.1999.tb12279.x

Kyaw, Z. Y., Yu, S. Y., Cheow, C. S., Dzulkifly, M. H., & Howell, N. K. (2001). Effect of fish to starch ration on viscoelastic properties and microstructure of fish cracker (Keropok) dough. *International Journal of Food Science & Technology*, *36*(7), 741-747. https://doi.org/10.1111/j.1365-2621.2001.00481.x

Lee, C. M. (1984). Surimi process technology, *Food Technology*, *38*(11), 69-80.

Lee, H. G. & Park, J. W. (1998). Calcium compounds to improve gel functionality of Pacific whiting and Alaska pollock surimi. *Journal of Food Science, 53*, 969-974. https://doi.org/10.1111/j.1365-2621.1998.tb15835.x

Lou, S., Chen, H., Hsu, Y., & Chang, H. (2005). Changes in purine content of tilapia surimi products during processing. *Fisheries Science, 71*, 889-895. https://doi.org/10.1111/j.1444-2906.2005.01042.x

Luo, Y., Shen, H., Pan, D., & Bu, G. (2008). Gel properties of surimi from silver carp (*Hypophthalmichthys molitrix*) as affected by heat treatment and soy protein isolate. *Food Hydrocolloids*, *22*(8), 1513-1519. https://doi.org/10.1016/j.foodhyd.2007.10.003

Matsumoto, J. J. (1978). Minced fish technology and its potential for developing countries. *Fish Utilization Technology and Marketing*, *18*, 267-271.

Monto, A. R., Li, M., Wang, X., Wijaya, G. Y. A., Shi, T., Xiong, Z., Yuan, L., Wengang, J., Jianrong, L., & Gao, R. (2022). Recent developments in maintaining gel properties of surimi products under reduced salt conditions and use of additives. *Critical Reviews in Food Science and Nutrition*, *62*(30), 8518-8533. https://doi.org/10.1080/10408398.2021.1931024

Moosavi-Nasab, M., Asgari, F., & Oliyaei, N. (2019). Quality evaluation of surimi and fish nuggets from Queen fish (*Scomberoides commersonnianus*). *Food Science & Nutrition*, *7*(10), 3206-3215. https://doi.org/10.1002/fsn3.1172

Nowsad, A. A., Chanda, S. C., Kanoh, S., & Niwa, E. (2000). Gel forming ability and other properties of eleven underutilized tropical marine fish species. *J. Aquatic Food Product Technology*, *9*(3), 71-89. https://doi.org/10.1300/j030v09n03_06

Oh, J. Y., Kim, E. A., Lee, H., Kim, H. S., Lee, J. S., & Jeon, Y. J. (2019). Antihypertensive effect of surimi prepared from olive flounder (*Paralichthys olivaceus*) by angiotensin-I converting enzyme (ACE) inhibitory activity and characterization of ACE inhibitory peptides. *Process Biochemistry*, *80*, 164-170. https://doi.org/10.1016/j.procbio.2019.01.016

Oujifard, A., Benjakul, S., Ahmad, M., & Seyfabadi, J. (2012). Effect of Bambara groundnut protein isolate on autolysis and gel properties of surimi from threadfin bream (*Nemipterus bleekeri*). *LWT*, *47*(2), 261-266. https://doi.org/10.1016/j.lwt.2012.01.016

Panpipat, W., Chaijan, M., & Benjakul, S. (2010). Gel properties of croaker–mackerel surimi blend. *Food Chemistry*, *122*(4), 1122-1128. https://doi.org/10.1016/j.foodchem.2010.03.096

Pei, Z., Wang, H., Xia, G., Hu, Y., Xue, C., Lu, S., Chuan, L., & Shen, X. (2023). Emulsion gel stabilized by tilapia myofibrillar protein: Application in lipid-enhanced surimi preparation. *Food Chemistry*, *403*, 134424. https://doi.org/10.1016/j.foodchem.2022.134424

Priyadarshini, M. B., Xavier, K. M., Dhanabalan, V., Nayak, B. B., & Balange, A. K. (2021). Development of ready-to-cook shrimp analogue from surimi: Effect of natural plant extracts on the chemical quality during refrigerated storage. *LWT*, *135*, 110239. https://doi.org/10.1016/j.lwt.2020.110239

Ramirez-Suarez, J. C., Pacheco-Aguilar, R., & Mazorra-Manzano, M. A. (2000). Washing effects on gelling properties and color of Monterey sardine (*Sardinops sagax caerulea*) minced flesh. *J. Aquatic Food Product Technology*, *9*(2), 55-67. https://doi.org/10.1300/j030v10n02_08

Rohani, A. C., Indon, A., & Yunus, J. M. (1995). Processing of surimi from freshwater fish-tilapia. *MARDI Research Journal*, *23*, 183-190.

Singh, A., Benjakul, S., & Prodpran, T. (2019). Effect of chitooligosaccharide from squid pen on gel properties of sardine surimi gel and its stability during refrigerated storage. *International Journal of Food Science & Technology, 54*(10), 2831-2838. https://doi.org/10.1111/ijfs.14199

Snow, J. M. (1950). Proteins in fish muscle. II. Colorimetric estimation of fish muscle protein. *Canadian Journal of Fisheries and Aquatic Sciences, 7*(10), 1950. https://doi.org/10.1139/f47-053

Yi, S., Li, Q., Qiao, C., Zhang, C., Wang, W., Xu, Y., & Li, J. (2020). Myofibrillar protein conformation enhance gel properties of mixed surimi gels with *Nemipterus virgatus* and *Hypophthalmichthys molitrix*. *Food Hydrocolloids, 106*, 105924. https://doi.org/10.1016/j.foodhyd.2020.105924

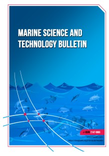
Yongsawatdigul, J., Park, J. W., Virulhakul, P., & Viratchakul, S. (2000). Proteplytic degradation of tropical tilapia surimi. *Journal of Food Science, 65*(1), 129-133. https://doi.org/10.1111/j.1365-2621.2000.tb15967.x

Yongsawatdigul, J., Park, J.W., & Koble, E. (1997). Degradation kinetics of miyozin heavy chain of pacific whiting surimi. *Journal of Food Science, 62*(4), 724-728. https://doi.org/10.1111/j.1365-2621.1997.tb15444.x

Zhou, X., Jiang, S., Zhao, D., Zhang, J., Gu, S., Pan, Z., & Ding, Y. (2017). Changes in physicochemical properties and protein structure of surimi enhanced with camellia tea oil. *LWT, 84*, 562-571. https://doi.org/10.1016/j.lwt.2017.03.026

Mar. Sci. Tech. Bull. (2023) 12(3): 411-422
e–ISSN: 2147–9666
info@masteb.com

dergipark.org.tr/en/pub/masteb
www.masteb.com
DOI: 10.33714/masteb.1327417



Marine Science and Technology Bulletin

PRENSIP
https://prensip.gen.tr/

RESEARCH ARTICLE

An overview of the status of sturgeons and cetaceans accidentally captured in southern Black Sea coastal zone of Türkiye

Süleyman Özdemir[1]* • Ercan Erdem[2] • Zekiye Birinci Özdemir[3]

[1] *Sinop University, Fisheries Faculty, Department of Fishing Technology, 57000, Sinop, Türkiye*
[2] *Central Union of Fisheries Cooperatives of Türkiye, 06100 Ankara, Türkiye*
[3] *Sinop University, Fisheries Faculty, Marine Biology Department, 57000, Sinop, Türkiye*

ARTICLE INFO

Article History:
Received: 04.08.2023
Received in revised form: 07.09.2023
Accepted: 08.09.2023
Available online: 28.09.2023

Keywords:
Accidental mortality
Acipenseridae
Black Sea
Delphinus delphis ponticus
Incidental catch
Phocoena phocoena relicta

ABSTRACT

This study was conducted out in the southern Black Sea coastal zone, in 2011-2016 fishing seasons. In the study, bycatch of sturgeons and cetaceans were examined both in small scale (turbot gillnets) and large scale (trawlers) fisheries. During the fishing operations within the study, 66 sturgeons (41 Danube sturgeon - *Acipenser gueldenstaedtii* and 25 starry sturgeon - *Acipenser stellatus*) and 49 cetaceans (40 harbor porpoises - *Phocoena phocoena relicta* and 9 short beaked dolphin - *Delphinus delphis ponticus*) were captured. Length-weight relationships of Danube sturgeon and starry sturgeon were determined as $W=0.0123L^{2.8808}$ (R=0.9964, negative allometric growth) and $W=0.0345L^{2.5351}$ (R=0.9961, negative allometric growth), respectively. Mean total length were calculated as 60.02±1.04 cm for Danube sturgeons, 46.42±1.17 cm for starry sturgeon and mean fork length were established as 126.75±3.36 cm for harbor porpoises, 163.74±1.42 cm for short beaked dolphins in the study.

Please cite this paper as follows:

Özdemir, S., Erdem, E., & Birinci Özdemir, Z. (2023). An overview of the status of sturgeons and cetaceans accidentally captured in southern Black Sea coastal zone of Türkiye. *Marine Science and Technology Bulletin*, *12*(3), 411-422. https://doi.org/10.33714/masteb.1327417

Introduction

Direct interactions between fishing gear and marine livings such as fish, cetacean, turtles and seals occur in many fisheries worldwide and may result in accidental catch and mortality of several aquatic organisms (Read et al., 2006). Stocks of some fish species have been significantly reduced due to over-fishing pressures and marine pollution in the Black Sea shores of Türkiye (Bat et al., 2007). Bycatch is considered to pose a significant threat for several fish species stocks (e.g., sturgeons, turbot, brown meagre, shi drum and tub gurnard) in the Black Sea (Özdemir et al., 2019). Sturgeon species in the Black Sea

* Corresponding author
E-mail address: suleymanozdemir57@gmail.com (S. Özdemir)

basin entered to the IUCN Red List of Threatened Species and categorized as critically endangered (Qiwei, 2010; Gessner et al., 2010).

The sturgeons are one of the ancient fishes on the world (Ustaoğlu & Okumus, 2004). There have been lived 5 species of sturgeons in the Black Sea coast of Türkiye. These are *Huso huso, Acipencer gueldenstaedtii, Acipencer stellatus, Acipencer nudiventris* and *Acipencer sturio* (Billard & Lecointre, 2000). Most species are at least partially anadromous, spawning in fresh water and feeding in nutrient-rich, brackish waters of estuaries or undergoing significant migrations along coastlines. Existence of the future generation of sturgeon is under serious threats. Environmental breakdown such as construction of dams on the stream and limiting water flows, extreme fishing pressure and water pollution which become unsuitable to migration and breeding of sturgeons are resulted to decline of stocks (Ustaoğlu, 2006).

Since, marine mammals are on the higher level of the food chain, the presence of these species are crucial for the presence of fish and other marine organisms. In the case of overfishing or absence of the marine mammals, the presence of the other organism will also be affected. Around the world's marine and inland waters, 90 cetacean species are existed in total (Jefferson et al., 2015). There are 23 different cetacean species in Mediterranean including Black Sea (Dede & Tonay, 2010; Özsandıkçı, 2021). Existence of 10 species of cetaceans (*Delphinus delphis, Tursiops truncatus, Phocoena phocoena, Stenella coeruleoalba, Grampus griseus, Pseudorca crassidens, Globicephala melas, Ziphius cavirostris, Balaenoptera physalus, Physeter macrocephalus*) in all over the Türkiye waters were reported (Husson & Holthuis, 1974) and 3 of these species (*Delphinus delphis ponticus, T. truncatus, Phocoena phocoena relicta*) has been living in the Black Sea (Öztürk, 1999; Tonay et al., 2012; Özsandıkçı, 2021). Nowadays, some cetacean species in the seas and oceans are among the endangered species (Bilgin & Köse, 2018). Marine mammals are under threat for mainly anthropogenic effects such as water and noise pollution, drifting wastes, bycatch, overfishing and killing deliberately (Dede & Tonay, 2010). Cetacean bycatch in bottom gillnets, trammel nets, midwater trawls pound nets and purse seine has been reported via a combination between questionnaire studies with fishermen and on-board observation (ACCOBAMS, 2021a).

In Türkiye, fishing, landing, transporting and selling of these species were prohibited by "Notification Regulating Commercial Fishing" for marine mammals since 1983 and for sturgeons since 1996. However, there are considerable amount of incidental catch of these species by turbot gillnets, purse seine and trawls in the Black Sea coasts (Tonay & Öztürk, 2003; Dede & Tonay, 2010; Özdemir & Erdem, 2011; Özdemir et al., 2017a; Gönener & Özsandikçi, 2017; Duyar & Bilgin, 2018; Bilgin & Köse, 2018; ACCOBAMS, 2021a).

The present study demonstrates some biological characteristics of sturgeons and two cetacean species that accidentally have been captured by the coastal fishing and industrial fishing gears in the Black Sea coasts. Moreover, suggestions were presented on protection strategy and prevention methods of sturgeon and cetacean bycatch.

Material and Method

The study was carried out in the Sinop and Samsun shores of Black Sea. Sea trails and sampling were conducted in the Black Sea in 2011-2016 fishing seasons (between September and May). The fishing vessels were chosen randomly from commercial fishing vessels and planned the sea trials. Biological characteristics of sturgeon and cetacean that were accidental captured by commercial trawlers and turbot gillnets were examined. Codend mesh size of demersal trawls and midwater trawls and mesh size of turbot gillnets used on the sea trials have 40 mm, 24 mm and 320 mm (knot to knot) respectively. Turbot gillnets have multifilament material. One set of turbot gillnet has a length about 68 meters.

Turbot gillnets used by fishermen in the region generally consist of 35 net sets. The average time the nets stay in the sea varies between 7-15 days. Turbot gillnets are used at depths between 30-90 meters. The towing time of midwater trawl nets varies between 120-180 minutes depending on the target fish and shoal status. The towing speed is between 2-3 knots. Nets are generally used at depths between 20-80 meters. In bottom trawl nets, the tow duration is between 60-90 minutes. The tow speed of the net is 2-2.5 knots.

The regions are important small scale fishery areas in the Black Sea (Figure 1). In these regions, as sturgeons enter to Yeşilırmak and Kızılırmak estuaries for reproduction. Similarly, cetacean forms big shoals for feeding with small pelagic fishes in these shores.

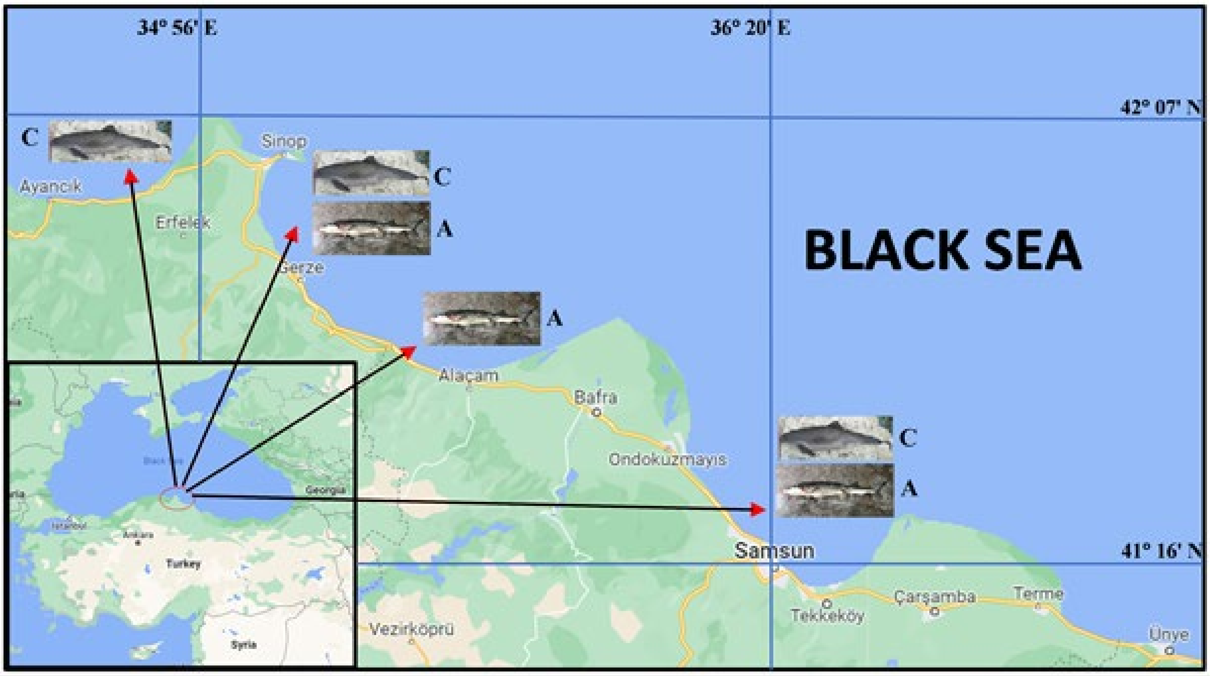


Figure 1. Study area (Samsun-Sinop coasts of Black Sea) C: Cetacean, A: *Acipenser*

The species of sturgeons was defined by considering the morphological and biological characteristics of fishes (Fischer et al., 1987; Sokolov & Berdicheskii, 1989; Holcik, 1989; Bat et al.; 2008; Froese & Pauly, 2023). Mainly, the head shape, the position of the mouth, the shape and structure of the barbels of the fish the provide distinct features for practical identification.

The structure of head part (blunt rounded, wide and flat), dorsal fin shape (blunt-tipped, curved, tall and short), nose structure (long, slender, beak, blunt) color of some part of the body (whitish, yellowish, dark grey, light grey and grey) and flippers color (grey, dark grey, light grey) are very important for cetacean species define. Jefferson et al. (2015) was used for the species identification of cetaceans.

In the study, total length and weight of sturgeons and fork length of cetacean species were recorded. After measurements done, the specimens were discarded. All sturgeons were alive while discarding but dolphins were already dead when they landed to board from set nets and trawl codends (Figure 2).

Length-weight relationship (LWR) for sturgeons were calculated from equation $W=aL^b$. W is the wet weight, L is the total length, "a" is the intercept, and "b" is the slope in the equal. Length-weight relationships are also actually used to ensure information on the condition of fish and may assistance define whether somatic growth is isometric (b=3) or allometric (b<3: negative allometric and b>3: positive allometric) (Ricker, 1973; Santos et al., 2002). The b value for sturgeons was analyzed with Student's t-test whether it was significantly varied from the estimated values for isometric growth (Morey et al., 2003).

The Student's *t test* was used for comparison of the slopes.

$$t = \frac{Sd_{logL}}{Sd_{logW}} \frac{|b-3|}{\sqrt{1-r^2}} \sqrt{n-2} \qquad (1)$$

where Sd_{logTL} is the standard deviation of the *log TL* values, Sd_{logW} is the standard deviation of the *log W* values, n is the number of samples used in the calculation. The value of b is different from b = 3 if computed t value is greater than the tabled t values for n-2 degrees of freedom (Pauly, 1984).

Table 1. Biological data of incidentally captured sturgeons

Sturgeon species	N	Total length (cm)			Weight (g)		
		Min	*Max*	*Mean*	*Min*	*Max*	*Mean*
A. gueldenstaedtii	41	48.9	75.2	60.02±1.04	904	3161	1691.1±86.6
A. stellatus	25	37.2	60.2	46.42±1.17	321	1105	596.7±39.3

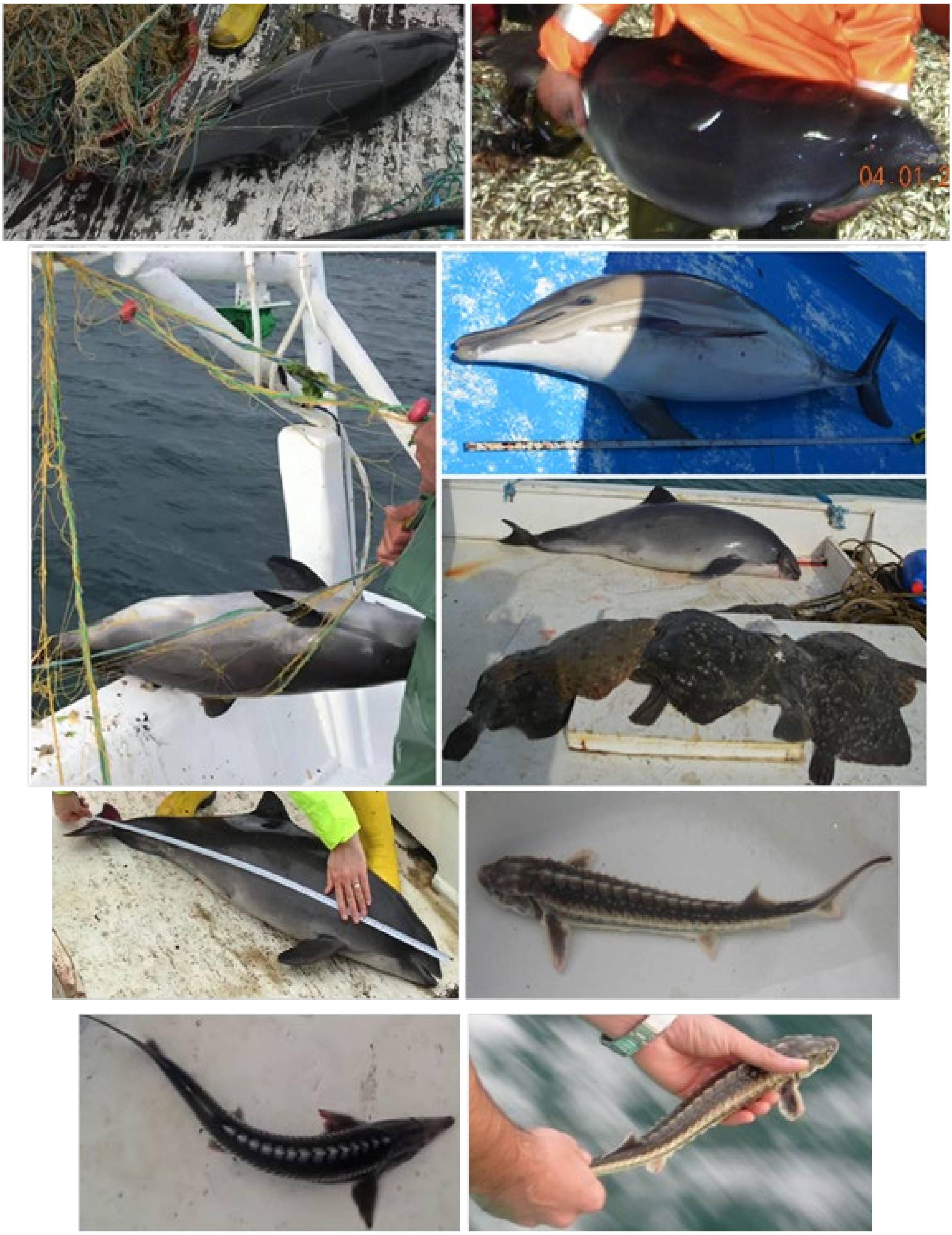


Figure 2. Accidental mortality (cetaceans) and accidental catch (sturgeons) captured by fishing gears

Results and Discussion

In the study, a total of 66 sturgeons and 49 cetaceans were captured accidentally in 60 trawl net hauls and 40 turbot gillnet fishing operations. Sturgeons were incidentally captured by the turbot gillnets, midwater trawls and demersal trawls, 12 individuals (*A. stellatus*: 4 and A. *gueldenstaedtii*: 8), 10 individuals (*A. stellatus*: 4 and *A. gueldenstaedtii*: 6) and 44 individuals (*A. stellatus*: 17 and *A. gueldenstaedtii*: 27), respectively.

All of the incidentally captured sturgeons were juvenile size. Mean length and weight of caught sturgeons were determined as 60.02±1.04 cm and 1691.1±86.6 g for *A. gueldenstaedtii* and 46.42±1.17 cm and 596.7±39.3 g for *A. stellatus* (Table 1).

While, total length of the *A. stellatus* varied between 37.2 and 60.2 cm, it is ranged from 48.9 cm to 75.2 cm for *A. gueldenstaedtii*. Length frequency distributions showed major peaks at 60 cm for *A. gueldenstaedtii* and at 50 cm for *A. stellatus*, respectively (Figure 3).

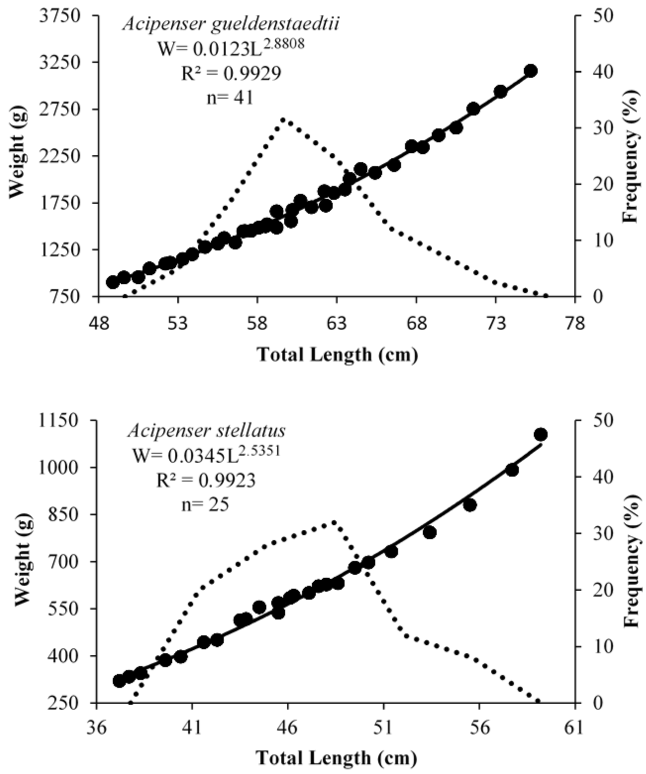


Figure 3. Length-weight relationship and length frequency for sturgeons

Descriptive statistics presented in Table 2 shows that there was a significant relationship between length and weight for all species ($P < 0.05$). The value of the parameter *b* varied between 2.5 and 2.9 for *A. stellatus* and *A. gueldenstaedtii*. Allometry coefficient (*b*) calculated as 2.8808 for *A. gueldenstaedtii* and 2.5351 for *A. stellatus*. The growth for both sturgeon species estimated as negative allometric ($b < 3$).

Table 2. LWR parameters for species of sturgeons

Parameters	*A. gueldenstaedtii*	*A. stellatus*
N	41	25
a	0.0123	0.0345
b	2.8808	2.5351
Standard error of b	0.0390	0.0465
95% confident of b	2.8019-2.9597	2.4386-2.6314
95% confident of a	0.0089-0.0170	0.0238-0.0498
R	0.9964	0.9961
P value	< 0.05	< 0.05
Growth	- Allometric	- Allometric

The variations in *b* values may be attributed to one or more factors: the seasons and effects of different areas, differences in salinity, temperature and pollution of aquatic environment, sex, nutrient quality and bait availability, differences in the quantity of fish analyzed, as well as in the observed size ranges of the sampled species (Gonçalves et al., 1997; Froese et al., 2012).

In the present study, *b* values for *A. stellatus* showed similar results (negative allometric) with most of the other studies conducted in the region. However, only two of eight studies which reported isometric growth have significantly different b values, in the Black Sea (Zengin et al., 2010) and Caspian Sea (Mousavi & Ghafor, 2014). Nevertheless, all of other studies have reported isometric growth for *A. gueldenstaedtii*, it is calculated as negative allometric growth in this study (Table 3).

Incidentally captured cetaceans by the fishing gears in the fishing operations were not alive when they are boarded. Minimum, maximum and average fork length of accidentally caught cetacean was established 77.3 cm, 152.7 cm, 126.75±3.36 cm for *P. phocoena relicta* and 156.4 cm, 169.1 cm, 163.74±1.42 cm for *D. delphis ponticus.*

Total number of *P. phocoena relicta* that were accidentally caught by trawl nets and turbot gillnets 9 individuals and 31 individuals respectively. While 8 individuals of *D. delphis ponticus* were incidentally caught by turbot gillnets, only 1 specimen was fished by trawl nets. Length frequency distribution of cetaceans were given in Figure 4.

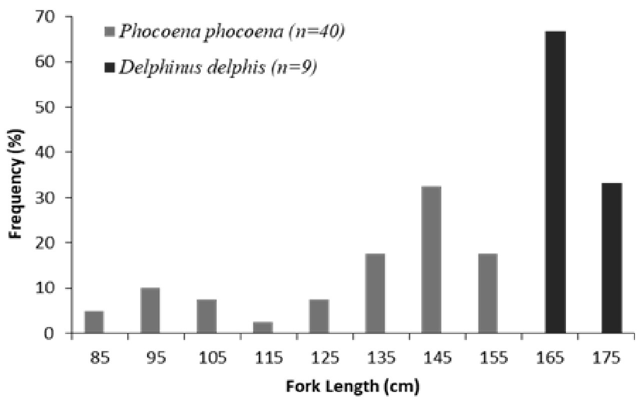


Figure 4. Distribution of length composition for cetaceans

Cetacean species mostly are caught incidentally by set nets and especially turbot gillnets (400 mm mesh size) in the Black Sea and which the most dangerous fishing gears are in accidentally captured the cetacean (Radu et al., 2003). In the study two of three *T. truncatus* cetacean species that are existed in Black Sea (*P. phocoena relicta* and *D. delphis ponticus*) were observed as incidental catch but bottlenose dolphins (*T. truncatus*) were not encountered.

Marine mammals' bycatch in the turbot gillnet fisheries have been noticed by several research conducted in the Black Sea shores of Türkiye (Tonay & Öztürk 2003; Tonay, 2016; Özdemir et al., 2017a; Bilgin et al., 2018a; Kratzer et al., 2021). Özdemir et al. (2017b) determined the mean length of *P. phocoena* captured by turbot gillnets as 162.5±3.00 cm. Duyar & Bilgin (2018) reported the mean length of *D. delphis* that are incidental captured by turbot gillnets in the western Black Sea coasts as 161±12.14 cm. Furthermore, mean total length of *P. phocoena* and *D. delphis* were established 116.0 cm and 167.6 cm respectively in the eastern Black Sea coasts (Bilgin et al., 2018b).

Today, there is a critical conservation concern for sturgeons once distributed widely areas and highly abundant in the aquatic environments. Sturgeon species today exist as fragmented stocks alive limited geographic regions and including relatively few individuals. (Gross et al., 2002). Accidental of sturgeons still have been captured by gillnets, trawl nets and purse seiners in southern coast of Black Sea. Sturgeon species have been listed as endangered living in the Black Sea. Sturgeons were under special protection after 1996 in the Türkiye fishery law and prohibited fishery. The legal fisheries authorities have to take more strong and strict precautions in order to prevent illegal fishing and marketing to the sturgeons. It is necessary to be secured that the incidentally captured sturgeons to be released to natural environments again by the fishermen (Ustaoğlu, 2006).

Captured marine organisms can usually survive easily, if they are immediately released to the sea again. Exclusion devices (selection grids) have also been used recently in attempts to mitigate mega fauna bycatch in trawl nets (Figure 5).

An exclusion device within the extension of a trawl net enables target species to pass through the grid or mesh barrier and on into the codend but prevents the passage of larger animals which are ejected out through an escape opening or swim back out of the mouth of the net (Misund & Beltestad, 2000; Lyle & Willcox, 2008). Overall, modifications to gear and/or fishing practices have produced equivocal results for cetaceans, other fish species and marine organisms (Hamer & Goldsworthy, 2006; Tilzey et al., 2006; Aydin & Tosunoğlu, 2010). On the other hand, Özdemir et al. (2014) suggested grid systems used on trawl nets for prevent of jellyfish bycatch. Moreover, one of alternative method might be using grid and square mesh panel combination for escape of bycatch and discard (especially juvenile fishes) from trawl nets.

Table 3. Previous studies on length-weight relationship of sturgeons in different regions

Species	Author	Region	Total Length Min-Max	a	b	R	Growth
A. stellatus	Tyurin (1927)	Caspian Sea	98-138	0.0192	2.792	0.9889	- Allometry
	Chugunov & Chugunova (1964)	Azov Sea	13–188	0.0340	2.584	0.9818	-Allometry
	Ceapa et al. (2002)	Danube River	82–133	0.0192	2.284	0.7790	-Allometry
	Kynard et al. (2002)	Danube River	90-135	0.0027	2.610	09695	-Allometry
	Zengin et al. (2010)	Black Sea	37-100	0.0031	3.008	0.8667	Isometry
	Bakhshalızadeh et al. (2012)	Caspian Sea	83-173	0.0006	2.396	0.7549	-Allometry
	Zengin et al. (2013)	Black Sea	17–143	0.0014	2.090	0.9192	-Allometry
	Mousavi & Ghafor (2014)	Caspian Sea	95–250	0.0104	2.780	0.9492	Isometry
	Present study (2023)	**Black Sea**	**37–60**	**0.0345**	**2.535**	**0.9961**	**- Allometry**
A. gueldenstaedtii	Chugunov & Chugunova (1964)	Azov Sea	18–183	0.0085	2.994	0.9929	Isometry
	Ambroz (1964)	Black Sea	91–210	0.0039	3.056	0.9989	Isometry
	Zengin et al. (2010)	Black Sea	40-200	0.0037	3.061	0.9773	Isometry
	Zengin et al. (2013)	Black Sea	33-359	0.0054	2.946	0.9534	Isometry
	Mousavi & Ghafor (2014)	Caspian Sea	35–225	0.0097	2.880	0.9497	Isometry
	Present study (2023)	**Black Sea**	**49–75**	**0.0123**	**2.880**	**0.9964**	**- Allometry**

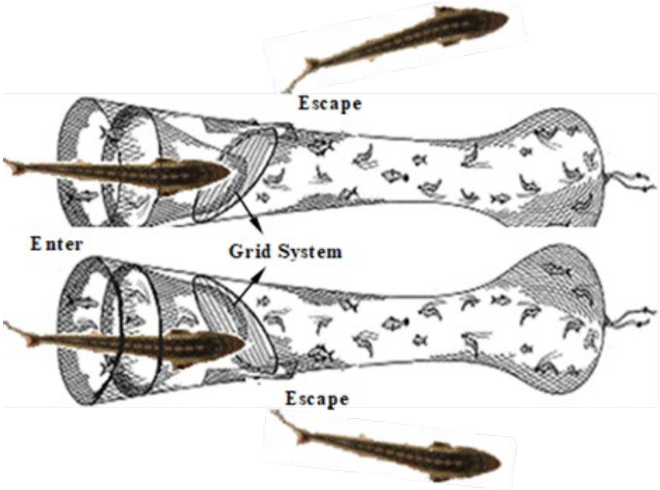


Figure 5. An example for prevent of incidental sturgeon catch in trawl nets (Grid system)

Devices with some sound frequency may be effective on cetaceans for example pingers, can partially prevent the approach of the cetaceans to the set nets. The use of these devices can prevent accidental catch and mortality of cetaceans (Gazo et al., 2008; Özsandıkçı, 2016; Özdemir et al., 2017b; ACCOBAMS, 2021a; Bilgin et. al., 2022a). Gönener & Özdemir (2011) were demonstrated that usage of the acoustic devices for commercial gillnet fisheries, nets were less damaged by cetaceans to bring a profit. In recent PAL (Pinger) trials conducted in the Western Black Sea, it is stated that the devices reduce the damage to gill nets by 30% by cetaceans. Therefore, it is pointed out that both the labor and time losses of fishermen in repairing their nets and the financial losses for making new nets are reduced. According to the results of the study, it is recommended that coastal fishermen use PAL devices in the whiting and red mullet gillnets (Bilgin et al., 2022b). However, the acoustic signals of pinger kinds also did not affect bycatch (especially harbour porpoise) of turbot gillnets in the Eastern Black Sea coasts (Bilgin & Köse, 2018). Cetacean deterrent/repellent PAL pinger devices used on gillnets were shown in Figure 6.

Figure 6. Acoustic device (PAL - Pinger) for prevent of cetacean bycatch in the gillnets

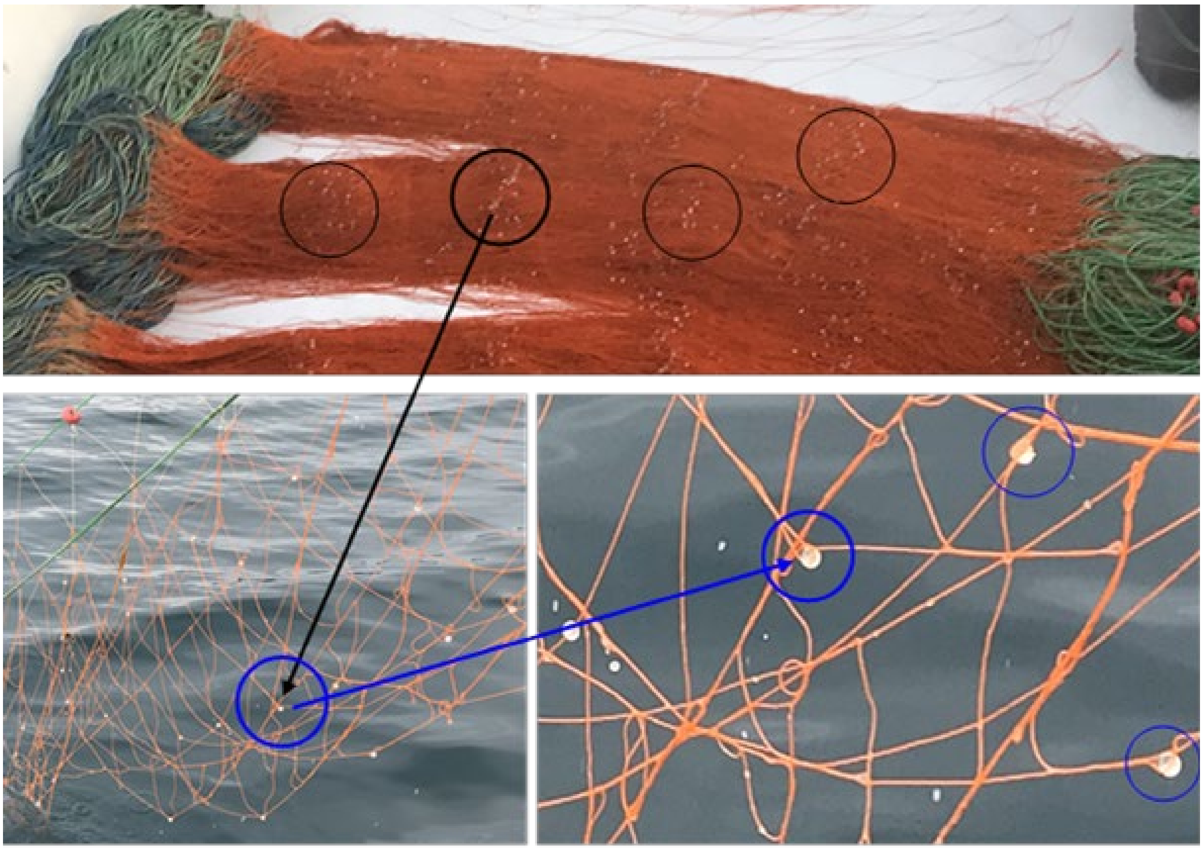


Figure 7. A new technic: acoustic acrylic spheres for reduction of the cetacean bycatch in the gillnets

In recent years, in addition to PAL pinger devices used to reduce cetacean bycatch, acoustic acrylic spheres (Figure 7) have been tested in fishing gear in the Baltic and North Seas (Kratzer et al., 2020, 2022) It is stated that the results of the most recent study on marine mammal reduction with acoustic acrylic spheres were used for the turbot gillnets as new method in the Black Sea are promising (Kratzer et al., 2021).

Conclusion

Consequently, it is encouraging to observe the endangered sturgeon species in the Black Sea coast of Türkiye. Also, it is necessary for permanence of natural reproduction of fish life of the field creation, conservation, cultivation of the conscious efforts to support by the fishers.

In recent years, it is frequently mentioned by fishers that dolphin populations are getting increase in excessive amounts in the Black Sea causes feeding pressure on small pelagic fish stocks and damages to fishing gears. Therefore, scientific studies regarding the current state of cetacean stocks and the relationship with fishing activities were started widely in the Black Sea (Gönener and Özdemir, 2011; ACCOBAMS, 2021b; Bilgin et al., 2022b). Finally, training should be provided to fishers to raise consciousness and awareness on accidental catch, bycatch and discard.

Acknowledgements

We would like to thank the commercial fishermen of the Sinop and Samsun regions for their contributions to the collection of fish samples and their support in the field studies.

Compliance With Ethical Standards

Authors' Contributions

SÖ: Study design, Field sampling, Data collection, Laboratory experiments, Drafting, Writing, Data curation, Data analysis, Data visualization, Review and editing, Final checking.

EE: Field sampling, Data collection, Laboratory experiments, Writing, Review and editing, Data curation, Data visualization, Final checking

ZBÖ: Drafting, Data analysis, Writing, Review and editing, Final checking.

All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Data Availability Statement

All data generated or analyzed during this study are included in this published article.

References

ACCOBAMS, (2021a). Conserving whales, dolphins and porpoises in the Mediterranean Sea, Black Sea and adjacent areas: An ACCOBAMS status report 2021. By: Notarbartolo di Sciara G., & Tonay A. M. (Eds). ACCOBAMS, Monaco. 160 p.

ACCOBAMS, (2021b). Estimates of abundance and distribution of cetaceans in the Black Sea from 2019 surveys. By Paiu R. M., Panigada S., Cañadas A., Gol`din P., Popov D., David L., Roul M., Amaha Ozturk A., Glazov D. (Eds.), ACCOBAMS - ACCOBAMS Survey Initiative/CeNoBS Projects, Monaco, 54 p.

Ambroz, A. I. (1964). Sturgeons of the northwestern Black Sea. *Trudy VNIRO*, *51*, 287-347.

Aydin, C., & Tosunoğlu, Z. (2012). Evaluation of sorting grids for deepwater rose shrimp (*Parapenaeus longirostris*) in the Eastern Mediterranean demersal trawl fishery. *Journal of Applied Ichthyology*, *28*(1), 102-106. https://doi.org/10.1111/j.1439-0426.2011.01897.x

Bakhshalizadeh, S., Abdolmalaki, S., & Bani, A. (2012). Aspects of the life history of *Acipenser stellatus* (Acipenseriformes, Acipenseridae), the starry sturgeon, in Iranian waters of the Caspian Sea. *Aqua: International Journal of Ichthyology, 18*(2), 103-112.

Bat, L., Erdem, Y., Tırıl Ustaoğlu, S., & Yardım, Ö. (2008). *Balık sistematiği*. Nobel Yayın Dağıtım.

Bat, L., Şahin, F., Satılmış, H. H., Üstün, F., Birinci-Özdemir Z., Kideys, A. E., & Shulman, G. E. (2007). *Karadeniz'in değişen ekosistemi ve hamsi balikçiliğina etkisi* [The changed ecosystem of the black sea and its impact on anchovy fisheries]. *Journal of FisheriesSciences.com*, *1*(4), 191-227.

Bilgin, S., & Köse, O. (2018). Testing two types of acoustic deterrent devices (pingers) to reduce harbour porpoise, *Phocoena phocoena* (Cetacea: Phocoenidae), by catch in turbot (*Psetta maxima*) set gillnet fishery in the Black Sea, Turkey. *Cahiers de Biologie Marine*, *59*(5), 473-479. https://doi.org/10.21411/CBM.A.D5B58D5B

Bilgin, S., Köse, O., & Yeşilçiçek, T. (2018a). Incidental catches of endangered (*Phocoena phocoena*) and vulnerable (*Delphinus delphis*) cetaceans and catch composition of turbot bottom gillnet fisheries in the southeastern Black Sea, Turkey. *Cahiers de Biologie Marine*, *59*(6), 571-577. https://doi.org/10.21411/CBM.A.E3AED15B

Bilgin, S., Onay, H., Köse, O., & Yeşilçiçek, T. (2018b). *Karadeniz'de karaya vuran ve kazara yakalanan yunuslar (Cetacea) hakkında: ölüm nedenleri, beslenme özellikleri ve gebelik durumu* [About stranding and accidentally caught cetaceans in the Black Sea: Death reasons, feeding characteristics and pregnancy status]. *Turkish Journal of Agricultural and Natural Sciences*, *5*(4), 447–454. https://doi.org/10.30910/turkjans.471239

Bilgin, S., Özdemir S., Aydın, Ü., & Cevahir, K. (2022a). Effect of PAL Pingers to reduce of bycatch of marine mammals (Cetaceans) in the turbot gillnets, Scientific Report 2 (By-catch). In Strengthening the EU-Turkey Civil Society Cooperation for the Conservation of Cetaceans in the Black Sea (pp. 203-226), EU Project Final Report, 278 p. Retrieved on March 23, 2023 from http://www.conceta.org/katalog/index.html

Bilgin, S., Özdemir S., Aydın, Ü., & Cevahir, K. (2022b). Depredation effects of the PAL pingers for the marine mammals on whiting / red mullet gillnets, Scientific Report 1. In Strengthening the EU-Turkey Civil Society Cooperation for the Conservation of Cetaceans in the Black Sea (pp. 187-202), EU Project Final Report, 278 p. Retrieved on March 23, 2023 from http://www.conceta.org/katalog/index.html

Billard, R., & Lecointre, G. (2000). Biology and conservation of sturgeon and paddlefish. *Reviews in Fish Biology and Fisheries*, *10*, 355-392. https://doi.org/10.1023/A:1012231526151

Ceapa, C., Williot, P., & Bacalbasa-Dobrovici, N. (2002). Present state and perspectives of stellate sturgeon brood fish in the Romanian part of the Danube. *International Review of Hydrobiology*, *87*(5-6), 507-513. https://doi.org/10.1002/1522-2632(200211)87:5/6%3C507::AID-IROH507%3E3.0.CO;2-W

Chugunov, N. L., & Chugunova, N. I. (1964). Comparative commercial and biological characteristics of sturgeons of the Azov Sea. *Trudy VNIRO*, *52*, 87-182.

Dede, A., & Tonay, A. M. (2010). Cetacean sightings in the Western Black Sea in autumn 2007. *Journal of Environmental Protection and Ecology*, *11*(4), 1491-1494.

Duyar, H. A., & Bilgin S. (2018). Common dolphin, *Delphinus delphis* (Cetacean: Dolphinidae) stranding off Sinop Peninsula in the Black Sea. *Y.Y.U. Journal of Agricultural Sciences*, *28*(2), 209-214. https://doi.org/10.29133/yyutbd.411834

Fischer, W., Bauchot, M. L., & Schneider, M. (1987). Fiches FAO d'identification des espèces pour les besoins de la pêche. (Revision 1). Méditerranée et mer Noire. Zone de pêche 37. Volume II. Vertebres. Food and Agriculture Organization, FAO-Rome, 1530 p.

Froese, R., Tsikliras, A. C., & Stergiou, K. I. (2011). Editorial note on weight-length relations of fishes. *Acta Ichthyologica et Piscatoria*, *41*(4), 261-263. https://doi.org/10.3750/AIP2011.41.4.01

Froese, R., & Pauly, D. (2023). FishBase. World Wide Web electronic publication. www.fishbase.org, version (06/2023). https://www.fishbase.se/summary/4712 and https://www.fishbase.se/summary/2065

Gazo, M., Gonzalvo, J., & Aguilar, A. (2008). Pingers as deterrents of bottlenose dolphins interacting with trammel nets. *Fisheries Research*, *92*, 70-75. https://doi.org/10.1016/j.fishres.2007.12.016

Gessner, J., Freyhof, J., & Kottelat. M. (2010). *Acipenser gueldenstaedtii*. The IUCN Red List of Threatened Species 2010: e.T232A13042340. Retrieved on March 8, 2023 from https://doi.org/10.2305/IUCN.UK.2010-1.RLTS.T232A13042340.en

Gonçalves, J. M. S., Bentes, L., Lino, P. G., Ribeiro, J., Canário, A. V. M., & Erzini, K. (1997). Weight-length relationships for selected fish species of the small-scale demersal fisheries of the South and South-west coast of Portugal. *Fisheries Research*, *30*(3), 253-256. https://doi.org/10.1016/S0165-7836(96)00569-3

Gönener, S., & Özdemir, S. (2011). Investigation of the interaction between bottom gillnet fishery (Sinop, Black Sea) and bottlenose dolphins (*Tursiops truncatus*) in terms of economy. *Turkish Journal of Fisheries and Aquatic Sciences* *15*(4), 222-211. https://doi.org/10.4194/1303-2712-v12_1_14

Gönener, S., & Özsandıkçı, U. (2017). Technical measures in order to decrease interactions between dolphins and fishermen: pingers. *Journal of Aquaculture Engineering and Fisheries Research*, *3*(3), 151-159. https://doi.org/10.3153/JAEFR17018

Gross, M. R., Repka, J., Robertson, C. T., Secor, D. H., & Van Winkle, W (2002). Sturgeon conservation: insights from elasticity analysis. *American Fisheries Society Symposium*, *28*, 13-30.

Hamer, D. J., & Goldsworthy, S. D. (2006). Seal–fishery operational interactions: Identifying the environmental and operational aspects of a trawl fishery that contribute to by-catch and mortality of Australian fur seals *Arctocephalus pusillus doriferus*. *Biological Conservation*, *130*(4), 517-529. https://doi.org/10.1016/j.biocon.2006.01.014

Holcik, J. (1989). The freshwater fishes of Europe. Volume 1, Part II. General Introduction to Fishes Acipenseriformes. AULA-Verlag Wiesbaden.

Husson, A. M., & Holthuis, L. B. (1974). *Physeter macrocephalus* Linneaus, 1758, The valid name for the sperm whale. *Zoologiche Mededelingen*, *48*(19), 2005-217.

Jefferson, T. A., Webber, M. A., & Pitman, R. L. (2015). *Marine mammals of the world a comprehensive guide to their identification*. Second Edition. Academic Press/Elsevier.

Kratzer, I. M. F., Brooks, M. E., Bilgin, S., Özdemir, S., Larsen, L. K., Larsen, F., & Stepputtis, D. (2021). Using acoustically visible gillnets to reduce bycatch of a small cetacean: First pilot trials in a commercial fishery. *Fisheries Research*, *243*, 106088. https://doi.org/10.1016/j.fishres.2021.106088

Kratzer, I. M. F., Schafer, I., Stoltenberg, A., Chladek, J. C., Kindt-Larsen, L., Larsen, F., & Stepputtis, D., (2020). Determination of optimal acoustic passive reflectors to reduce bycatch of odontocetes in Gillnets. *Frontiers in Marine Science*, *7*(539), 1-18. https://doi.org/10.3389/fmars.2020.00539

Kratzer, I. M. F., Stepputtis, D., Santos, J., Lutkefedder, F., Stoltenberg, A., Hartkens, L., Schaber, M., Larsen, L. K., & Larsen, F. (2022). Angle-dependent acoustic reflectivity of gillnets and their modifications to reduce bycatch of odontocetes using sonar imaging. *Fisheries Research*, *250*, 106278. https://doi.org/10.1016/j.fishres.2022.106278

Kynard, B., Suciu, R., & Horgan, M. (2002). Migration and habitats of diadromous Danube River sturgeons in Romania:1998–2000. *Journal of Applied Ichthyology*, *18*, 529-535. https://doi.org/10.1046/j.1439-0426.2002.00404.x

Lyle, J. M., & Willcox, S. T. (2008). Dolphin and seal interactions with mid-water trawling in the Commonwealth Small Pelagic Fishery, including an assessment of bycatch mitigation strategies. Australian Government, Fisheries Management Authority Final Report, Project R05/0996, 39 p.

Misund, O. A., & Beltestad, A. K. (2000). Survival of mackerel and saithe that escape through sorting grids in purse seines. *Fisheries Research*, *48*(1), 31-41. https://doi.org/10.1016/S0165-7836(00)00118-1

Morey, G., Morantai, J., Massut, E., Grau, A., Linde, M., Riera, F., & Morales, N. B. (2003). Weight-length relationships of littoral to lower slope fishes from the western Mediterranean. *Fisheries Research*, *62*, 89-96. https://doi.org/10.1016/S0165-7836(02)00250-3

Mousavi, S., & Ghafor, A. (2014). On the conditions impressing Sturgeon fish. *International Journal of Advanced and Applied Sciences, 1*(4), 1-5.

Özdemir, S. & Erdem, E. (2011). Incidental catch in the pelagic trawl fishery of the Black Sea (Turkey-Samsun): Sturgeons and dolphins. *Proceedings of the 3rd Bi-annual BS Scientific Conference and UP-GRADE BS-SCENE Project Joint Conference* Ukraine, pp. 124.

Özdemir, S., Erdem, E., & Birinci Özdemir, Z. (2014). Preliminary study of a bycatch of pelagic trawl fishery in the southern Black Sea coast of Turkey: Moon Jellyfish *Aurelia aurita*. *Indian Journal of Geo-Marine Science*, *43*(10), 1832-1838.

Özdemir, S., Erdem, Y., Özsandıkçı, U., & Büyükdeveci, F. (2017a). Seasonal catch compositions of turbot gillnets in Southern Black Sea Coasts (in Turkish). *Yunus Research Bulletin, 4*, 325-334.

Özdemir, S., Erdem, Y., Özsandıkçı, U., & Büyükdeveci, F. (2017b). Incidental catch problem of common porpoise (*Phocoena phocoena*) in the Black Sea coastal fisheries. *Proceedings of the VIII. International Symposium on Ecology and Environmental Problems*, Türkiye, pp. 171.

Özdemir, S., Özsandıkçı, U., & Büyükdeveci, F. (2019). A new maximum length with length–weight relationship of tub gurnard (*Chelidonichthys lucerna* Linnaeus, 1758) from Central Black Sea coasts of Turkey. *Marine Science and Technology Bulletin*, *8*(2), 85-91. https://doi.org/10.33714/masteb.641702

Özsandıkçı, U. (2016). *Karadeniz'de yunus ve balikçilik etkileşimleri* [Interaction between dolphin and fisheries in the Black Sea]. In Sezgin, M., Şahin, F., & Özsandıkçı, U. (Eds.), *Karadeniz ve Balıkçılık Çalıştayı Kitabı* [Black Sea and Fisheries Workshop Book] (pp. 109-116) Sinop University Publications.

Özsandıkçı, U. (2021). *Karadeniz'in Sinop kıyılarındaki Cetacea türlerinin bolluk ve dağılımlarının tahmini* [Estimation of cetacean abundance and distribution in Sinop coasts of Black Sea] [PhD. Thesis, Sinop University].

Öztürk, B. (1999). Black Sea biological diversity: Turkey. GEF Black Sea Environmental Programme, United National Publications, 144 p.

Pauly, D. (1984). Fish population dynamics in tropical waters: a manual for use with programmable calculators. *International Center for Living Aquatic Resources Management (ICLARM) Studies and Reviews*, *8*, 325 p.

Qiwei, W. (2010). *Acipenser stellatus*. The IUCN Red List of Threatened Species 2010: e.T229A13040387. Retrieved on March 08, 2023 from https://doi.org/10.2305/IUCN.UK.2010-1.RLTS.T229A13040387.en

Radu, G., Nicolaev, S., Anton E., Maximov, V., & Radu, E. (2003). Preliminary data about the impact of fishing gears on the dolphins from the Black Sea Romanian waters. In Öztürk, B. (Ed.), *Workshop on Demersal Resources in the Black Sea and Azov Sea* (pp. 115-129). Turkish Marin Research Foundation (TUDAV) Office press.

Read, A. J., Drinker, P., & Northridge, S. (2006). Bycatch of marine mammals in U.S. and global fisheries. *Conservation Biology*, 20(1), 163-169. https://doi.org/10.1111/j.1523-1739.2006.00338.x

Ricker, W. E. (1973). Linear regressions in fishery research. *Journal of the Fisheries Research Board of Canada, 30*(3), 409-434. https://doi.org/10.1139/f73-072

Santos, M. N., Gaspar, M. B., Vasconcelos, P., & Monteiro, C. C. (2002). Weight-length relationships for 50 selected fish species of the Algarve (southern Portugal). *Fisheries Research*, *59*, 289-295. https://doi.org/10.1016/S0165-7836(01)00401-5

Sokolov, L. I., & Berdicheskii, L. S. (1989). Acipenseridae. In J. Holcík (Ed.) *The freshwater fishes of Europe. Volume 1, Part II General introduction to fishes Acipenseriformes* (pp. 150-153). AULA-Verlag Wiesbaden.

Tilzey, R., Goldsworthy, S. D., Cawthorn, M., Calvert, N., Hamer, D., Russel, S., Shaughnessy, P., Wise, B., & Stewardson, C. (2006). Assessment of seal-fishery interactions in the winter blue grenadier fishery off West Tasmania and the development of fishing practices and Seal Exclusion Devices to mitigate seal bycatch by factory trawlers. Australian Government, (FRDC), Project Final Report, (BRC) 2001/008, 69 p.

Tonay, A. M. (2016). Estimates of cetacean by-catch in the turbot fishery on the Turkish Western Black Sea Coast in 2007 and 2008. *Journal of the Marine Biological Association of the United Kingdom*, *96*(4), 993-998. https://doi.org/10.1017/S0025315416000060

Tonay, A. M., & Öztürk, B. (2003). Cetacean bycatches in turbot fishery on the western coast of the Turkish Black Sea. *Proceedings of the International Symposium of Fisheries and Zoology*, Türkiye, pp. 131-138.

Tonay, A. M., Dede, A. Öztürk A. A., & Öztürk, B. (2012). Cetacean strandings in the Turkish Western Black Sea coast during 2007-2009. *Journal of Black Sea/Mediterranean Environment*, *18*(2), 246-250.

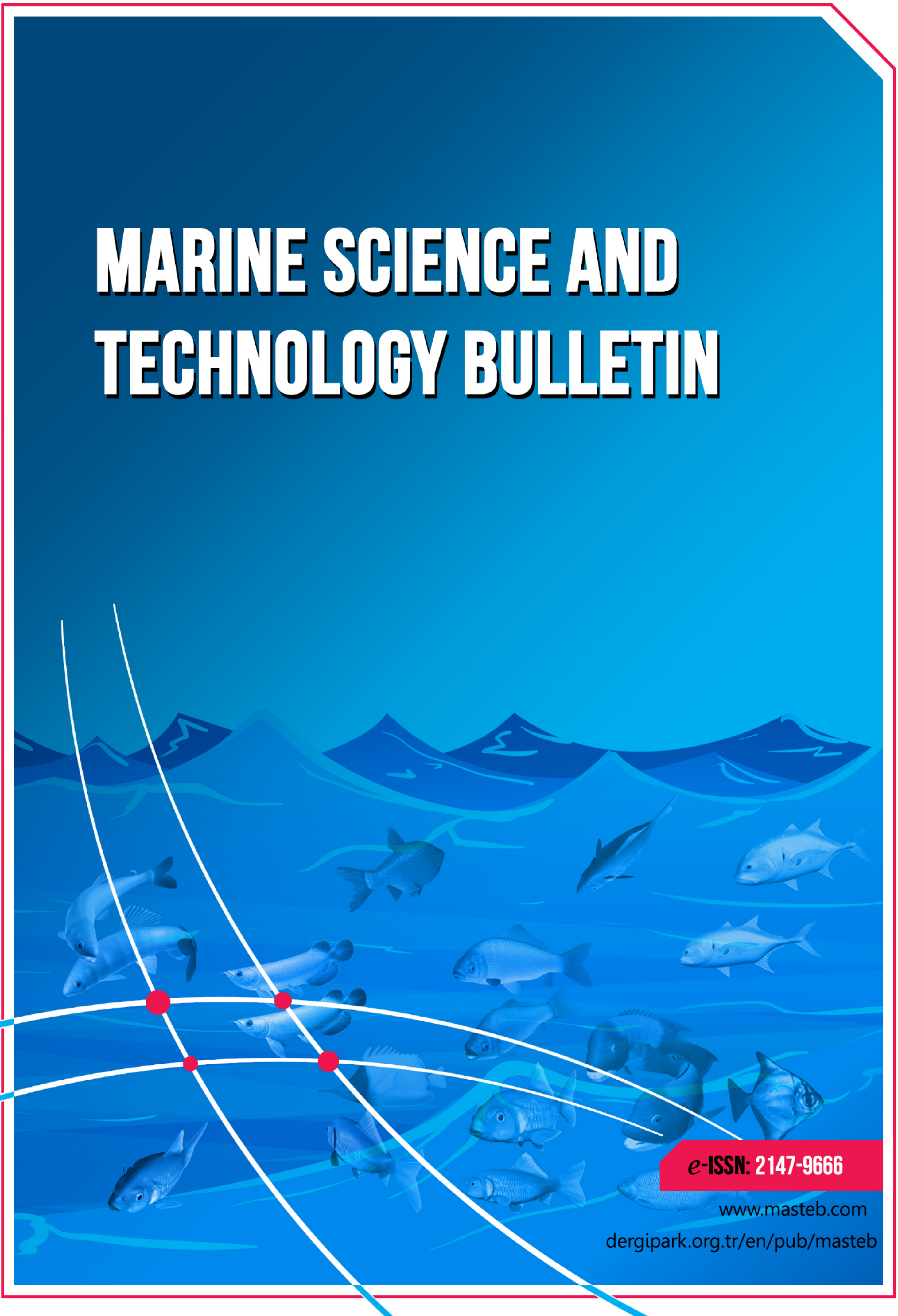
Tyurin, P. V. (1927). About the relation between the length of the fish and its weight. *Rep. Icht. Lab. Siberia*, *2*(3), 3-21.

Ustaoğlu, S. (2006). *Nesli tükenme tehlikesindeki mersin balıklarını (Acipenseridae) koruma stratejilerinin değerlendirilmesi* [Evaluate of conservation strategies for endangered sturgeons (Acipenseridae)]. *Ege University Journal of Fisheries and Aquatic Sciences*, 23(1/3), 509-514.

Ustaoğlu, S., & Okumuş, İ. (2004). The sturgeons: Fragile species need conservation. *Turkish Journal of Fisheries and Aquatic Sciences*, *4*, 49-57.

Zengin, M., Gümüş, A., Dagtekin, M., & Firidin, Ş. (2013). Biological data derived from sturgeon (Aci*penser stellatus*, *Acipenser gueldenstaedtii* and *Huso huso*) by-catch along the coasts of the Southern Black Sea (Turkey). *Turkish Journal of Fisheries and Aquatic Sciences*, *13*, 745-752.

Zengin, M., Ustaoğlu Tırıl, S., Dağtekin, M., Gül, M., Can, T., & Eryıldırım, H. (2010). Preliminary study on the status of sturgeon populations (*Acipenser sp*) in the South Eastern Black Sea Coast (Yesilirmak and Kizilirmak Rivers' Basin) in the early 21st century. FAO, Organization of United Nations-Rome, EIFAC Occasional Paper, SEC/AIFAC/OP, 44: 44-55.


MARINE SCIENCE AND
TECHNOLOGY BULLETIN
e-ISSN: 2147-9666
www.masteb.com
dergipark.org.tr/en/pub/masteb