ACADEMIC
PERSPECTIVE

APJESS

Journal of Engineering and Smart Systems

Volume : 11
Issue : 1
Year : 2023

Volume 11 / Issue 1

Academic Platform Journal of Engineering and Smart Systems

Correspondence Address
Academic Platform Journal of Engineering and Smart Systems
Akademik Perspektif Derneği, Tığcılar Mahallesi Kadir Sokak No:12
Kat:1 Adapazarı SAKARYA

+90 551 628 9477 (WhatsApp only)
https://dergipark.org.tr/tr/pub/apjess

Issue Link: https://dergipark.org.tr/tr/pub/apjess/issue/75064

Aim and Scope

Academic Platform Journal of Engineering and Smart Systems (APJESS) is a peer reviewed open-access journal which focuses on the research and applications related to smart systems and artificial intelligence. APJESS accepts both **original research papers** and **review articles** written in **English**. It is essential that the information created in scientific study needs to be new, suggest new method or give a new dimension to an existing information. Articles submitted for publication are evaluated by at least two referees in case the editor finds potential scientific merit, and final acceptance and rejection decision are taken by editorial board. The authors are not informed about the name of referees who evaluate the papers. In similar way, the referees are not allowed to see the names of authors. The papers which do not satisfy the scientific level of the journal can be refused with unexplained reason.

There are two key principles that APJESS was founded on: Firstly, to publish the most exciting, novel, technically sound, and clearly presented researches with respect to the subjects of smart systems and artificial intelligence. Secondly, to provide a rapid turn-around time possible for reviewing and publishing, and to disseminate the articles freely for research, teaching and reference purposes.

Any information about a submitted manuscript cannot be disclosed by the editor and any other editorial staff to anyone other than the corresponding author, reviewers, potential reviewers, other editorial advisers, and the publisher. No confidential information or ideas obtained through peer review can be used for personal advantage.

Journal History

The journal was published between 2013-2021 with the title of "Academic Platform - Journal of Engineering and Science". It will be published under its new title "Academic Platform Journal of Engineering and Smart Systems" after 2022.

Former Title: Academic Platform - Journal of Engineering and Science

Years: 2013-2021

Scope

APJESS aims to publish research and review papers dealing with, but not limited to, the following research fields:

- Knowledge Representation and Reasoning,
- Data Mining & Data Science,
- Supervised, Semi-Supervised and Unsupervised Learning,
- Machine Learning (ML) and Neural Computing,
- Evolutionary Computation,
- Natural Language Processing, Internet of Things, Big Data
- Fuzzy Systems,
- Intelligent Information Processing,
- AI Powered Robotic Systems,
- Multi-agent Systems and Programming for Smart Systems

Author Guidelines

Article Types

Manuscripts submitted to APJESS should neither be published previously nor be under consideration for publication in another journal.

The main article types are as follows:

ResearchArticles: Original research manuscripts. The journal considers all original research manuscripts provided that the work reports scientifically sound experiments and provides a substantial amount of new information.

Review Articles: These provide concise and precise updates on the latest progress made in a given area of research.

Checklist for Submissions

Please,

• read the Aims & Scope to see if your manuscript is suitable for the journal,
• use the Microsoft Word template to prepare your manuscript;
• Download Copyright Transfer Form and signed by all authors.
• make sure that issues about Ethical Principles and Publication Policy, Copyright and Licensing, Archiving Policy, Repository Policy have been appropriately considered;
• Ensure that all authors have approved the content of the submitted manuscript.

The main text should be formed in the following order:

Manuscript: The article should start with an introduction written in scientific language, putting thoughts together from diverse disciplines combining evidence-based knowledge and logical arguments, conveying views about the aim and purpose of the article. It must address all readers in general. The technical terms, symbols, abbreviations must be defined at the first time when they are used in the article. The manuscript should be formed in the following order:

Introduction,

Material and Method,

Findings,

Discussion and Conclusion.

References: At the end of the paper provide full details of all references cited in-text. The reference list should be arranged in the order of appearance of the in-text citations, not in an alphabetical order, beginning with [1], and continuing in an ascending numerical order, from the lowest number to the highest. In the reference list, only one resource per reference number is acceptable.
References must be numbered in order of appearance in the text (including citations in tables and legends) and listed individually at the end of the manuscript. We recommend preparing the references with a bibliography software package, such as EndNote, Reference Manager or Zotero to avoid typing mistakes and duplicated references. Include the digital object identifier (DOI) for all references where available. Please use IEEE style.

IEEE Sample Reference List

[1] R. E. Ziemer and W. H. Tranter, Principles of Communications: Systems, Modulation, and Noise, 7th ed. Hoboken, NJ: Wiley, 2015.
[2] J. D. Bellamy et al., Computer Telephony Integration, New York: Wiley, 2010.

[3] C. Jacks, High Rupturing Capacity (HRC) Fuses, New York: Penguin Random House, 2013, pp. 175–225.
[4] N. B. Vargafik, J. A. Wiebelt, and J. F. Malloy, "Radiative transfer," in Convective Heat. Melbourne: Engineering Education Australia, 2011, ch. 9, pp. 379–398.
[5] H. C. Hottel and R. Siegel, "Film condensation," in Handbook of Heat Transfer, 2nd ed. W. C. McAdams, Ed. New York: McGraw-Hill, 2011, ch. 9, pp. 78–99.
[6] H. H. Gaynor, Leading and Managing Engineering and Technology, Book 2: Developing Managers and Leaders. IEEE-USA, 2011. Accessed on: Oct. 15, 2016. [Online]. Available: http://www.ieeeusa.org/communications/ebooks/files/sep14/n2n802/Leading-and-Managing-Engineering-and-Technology-Book-2.pdf
[7] G. H. Gaynor, "Dealing with the manager leader dichotomy," in Leading and Managing Engineering and Technology, Book 2, Developing Leaders and Mangers. IEEE-USA, 2011, pp. 27–28. Accessed on: Jan. 23, 2017. [Online]. Available: http://www.ieeeusa.org/communications/ebooks/files/sep14/n2n802/Leading-and-Managing-Engineering-and-Technology-Book-2.pdf
[8] M. Cvijetic, "Optical transport system engineering," in Wiley Encyclopedia of Telecommunications, vol. 4, J. G. Proakis, Ed. New York: John Wiley & Sons, 2003, pp. 1840–1849. Accessed on: Feb. 5, 2017. [Online]. Available: http://ebscohost.com
[9] T. Kaczorek, "Minimum energy control of fractional positive electrical circuits", Archives of Electrical Engineering, vol. 65, no. 2, pp.191–201, 2016.
[10] P. Harsha and M. Dahleh, "Optimal management and sizing of energy storage under dynamic pricing for the efficient integration of renewable energy", IEEE Trans. Power Sys., vol. 30, no. 3, pp. 1164–1181, May 2015.
[11] A. Vaskuri, H. Baumgartner, P. Kärhä, G. Andor, and E. Ikonen, "Modeling the spectral shape of InGaAlP-based red light-emitting diodes," Journal of Applied Physics, vol. 118, no. 20, pp. 203103-1–203103-7, Jul. 2015. Accessed on: Feb. 9, 2017. [Online]. Available: doi: 10.1063/1.4936322
[12] K. J. Krishnan, "Implementation of renewable energy to reduce carbon consumption and fuel cell as a back-up power for national broadband network (NBN) in Australia," Ph.D dissertation, College of Eng. and Sc., Victoria Univ., Melbourne, 2013.
[13] C. R. Ozansoy, "Design and implementation of a Universal Communications Processor for substation integration, automation and protection," Ph.D. dissertation, College of Eng. and Sc., Victoria Univ., Melbourne, 2006. [Online]. Accessed on: June 22, 2017. [Online]. Available: http://vuir.vu.edu.au/527/
[14] M. T. Long, "On the statistical correlation between the heave, pitch and roll motion of road transport vehicles," Research Master thesis, College of Eng. and Sc., Victoria Univ., Melb., Vic., 2016.
[15] Safe Working on or Near Low-voltage Electrical Installations and Equipment, AS/NZS 4836:2011, 2011.

Ethical Principles and Publication Policy

Peer Review Policy

Academic Platform Journal of Engineering and Smart Systems (APJESS) applies double blind peer-review process in which both the reviewer and the author are anonymous. Reviewer selection for each submitted article is up to area editors, and reviewers are selected based on the reviewer's expertise, competence, and previous experience in reviewing papers for APJES.

Every submitted article is evaluated by area editor, at least, for an initial review. If the paper reaches minimum quality criteria, fulfills the aims, scope and policies of APJES, it is sent to at least two reviewers for evaluation.

The reviewers evaluate the paper according to the Review guidelines set by editorial board members and return it to the area editor, who conveys the reviewers' anonymous comments back to the author. Anonymity is strictly maintained.

The double-blind peer-review process is managed using “ULAKBİM Dergi Sistemleri”, namely Dergipark platform.

Open Access Policy

APJESS provides immediate open access for all users to its content on the principle that making research freely available to the public, supporting a greater global exchange of knowledge.

Archiving Policy

APJESS is accessed by Dergipark platform which utilizes the LOCKSS system to create a distributed archiving system among participating libraries and permits those libraries to create permanent archives of the journal for purposes of preservation and restoration.

Originality and Plagiarism Policy

Authors by submitting their manuscript to APJESS declare that their work is original and authored by them; has not been previously published nor submitted for evaluation; original ideas, data, findings and materials taken from other sources (including their own) are properly documented and cited; their work does not violate any rights of others, including privacy rights and intellectual property rights; provided data is their own data, true and not manipulated. Plagiarism in whole or in part without proper citation is not tolerated by APJESS. Manuscripts submitted to the journal will be checked for originality using anti-plagiarism software.

Journal Ethics and Malpractice Statement

For all parties involved in the publishing process (the author(s), the journal editor(s), the peer reviewers, the society, and the publisher) it is necessary to agree upon standards of expected ethical behavior. The ethics statements for APJESS are based on the Committee on Publication Ethics (COPE) Code of Conduct guidelines available at www.publicationethics.org.

1. Editor Responsibilities

Publication Decisions & Accountability

The editor of APJESS is responsible for deciding which articles submitted to the journal should be published, and, moreover, is accountable for everything published in the journal. In making these decisions, the editor may be guided by the journal’s editorial board and/or area editors, and considers the policies of the journal. The editor should maintain the integrity of the academic record, preclude business needs from compromising intellectual and ethical standards, and always be willing to publish corrections, clarifications, retractions, and apologies when needed.

Fair play

The editor should evaluate manuscripts for their intellectual content without regard to race, gender, sexual orientation, religious belief, ethnic origin, citizenship, or political philosophy of the author(s).

Confidentiality

The editor and any editorial staff must not disclose any information about a submitted manuscript to anyone other than the corresponding author, reviewers, potential reviewers, other editorial advisers, and the publisher, as appropriate.

Disclosure, conflicts of interest, and other issues

The editor will be guided by COPE's Guidelines for Retracting Articles when considering retracting, issuing expressions of concern about, and issuing corrections pertaining to articles that have been published in APJES.

Unpublished materials disclosed in a submitted manuscript must not be used in an editor's own research without the explicit written consent of the author(s). Privileged information or ideas obtained through peer review must be kept confidential and not used for personal advantage.

The editor should seek so ensure a fair and appropriate peer-review process. The editor should recuse himself/herself from handling manuscripts (i.e. should ask a co-editor, associate editor, or other member of the editorial board instead to review and consider) in which they have conflicts of interest resulting from competitive, collaborative, or other relationships or connections with any of the authors, companies, or (possibly) institutions connected to the papers. The editor should require all contributors to disclose relevant competing interests and publish corrections if competing interests are revealed after publication. If needed, other appropriate action should be taken, such as the publication of a retraction or expression of concern.

2. Reviewer Responsibilities

Contribution to editorial decisions

Peer review assists the editor in making editorial decisions and, through the editorial communication with the author, may also assist the author in improving the manuscript.

Promptness

Any invited referee who feels unqualified to review the research reported in a manuscript or knows that its timely review will be impossible should immediately notify the editor so that alternative reviewers can be contacted.

Confidentiality

Any manuscripts received for review must be treated as confidential documents. They must not be shown to or discussed with others except if authorized by the editor.

Standards of objectivity

Reviews should be conducted objectively. Personal criticism of the author(s) is inacceptable. Referees should express their views clearly with appropriate supporting arguments.

Acknowledgement of sources

Reviewers should identify relevant published work that has not been cited by the author(s). Any statement that an observation, derivation, or argument had been previously reported should be accompanied by the relevant citation. Reviewers should also call to the editor's attention any substantial similarity or overlap between the manuscript under consideration and any other published data of which they have personal knowledge.

Disclosure and conflict of interest

Privileged information or ideas obtained through peer review must be kept confidential and not used for personal advantage. Reviewers should not consider evaluating manuscripts in which they have conflicts of interest resulting from competitive, collaborative, or other relationships or connections with any of the authors, companies, or institutions connected to the submission.

3. Author Responsibilities

Reporting standards

Authors reporting results of original research should present an accurate account of the work performed as well as an objective discussion of its significance. Underlying data should be represented accurately in the manuscript. A paper should contain sufficient detail and references to permit others to replicate the work. Fraudulent or knowingly inaccurate statements constitute unethical behavior and are unacceptable.

Originality and plagiarism

The authors should ensure that they have written entirely original works, and if the authors have used the work and/or words of others that this has been appropriately cited or quoted.

Multiple, redundant, or concurrent publication

An author should not in general publish manuscripts describing essentially the same research in more than one journal or primary publication. Parallel submission of the same manuscript to more than one journal constitutes unethical publishing behavior and is unacceptable.

Acknowledgement of sources

Proper acknowledgment of the work of others must always be given. Authors should also cite publications that have been influential in determining the nature of the reported work.

Authorship of a manuscript

Authorship should be limited to those who have made a significant contribution to the conception, design, execution, or interpretation of the reported study. All those who have made significant contributions should be listed as co-authors. Where there are others who have participated in certain substantive aspects of the research project, they should be named in an Acknowledgement section. The corresponding author should ensure that all appropriate co-authors are included in the author list of the manuscript, and that all co-authors have seen and approved the final version of the paper and have agreed to its submission for publication. All co-authors must be clearly indicated at the time of manuscript submission. Request to add co-authors, after a manuscript has been accepted will require approval of the editor.

Hazards and human or animal subjects

If the work involves chemicals, procedures, or equipment that has any unusual hazards inherent in their use, the authors must clearly identify these in the manuscript. Additionally, manuscripts should adhere to the principles of the World Medical Association (WMA) Declaration of Helsinki regarding research study involving human or animal subjects.

Disclosure and conflicts of interest

All authors should disclose in their manuscript any financial or other substantive conflict of interest that might be construed to influence the results or their interpretation in the manuscript. All sources of financial support for the project should be disclosed.

Fundamental errors in published works

In case an author discovers a significant error or inaccuracy in his/her own published work, it is the author’s obligation to promptly notify the journal’s editor to either retract the paper or to publish an appropriate correction statement or erratum.

4. Publisher Responsibilities

Editorial autonomy

Academic Perspective Foundation is committed to working with editors to define clearly the respective roles of publisher and of editors in order to ensure the autonomy of editorial decisions, without influence from advertisers or other commercial partners.

Intellectual property and copyright

We protect the intellectual property and copyright of Academic Perspective Foundation, its imprints, authors and publishing partners by promoting and maintaining each article's published version of record. Academic Perspective Foundation ensures the integrity and transparency of each published article with respect to: conflicts of interest, publication and research funding, publication and research ethics, cases of publication and research misconduct, confidentiality, authorship, article corrections, clarifications and retractions, and timely publication of content.

Scientific Misconduct

In cases of alleged or proven scientific misconduct, fraudulent publication, or plagiarism the publisher, in close collaboration with the editors, will take all appropriate measures to clarify the situation and to amend the article in question. This includes the prompt publication of a correction statement or erratum or, in the most severe cases, the retraction of the affected work.

Contents

Research Paper
Academic Platform Journal of Engineering and Smart Systems (APJESS) 11(1), 1-10, 2023
ISSN: 2822-2385
Received: 16-Apr-2022 Accepted: 04-Oct-2022
https://doi.org/10.21541/apjess.1104601

An Integrated Fuzzy MCDM Method for the Evaluation of R&D Projects

*[1]Mehtap DURSUN, [2]Melike KILIÇ

[1] Decision Analysis Research and Application Center, Galatasaray University, İstanbul, Türkiye, mdursun@gsu.edu.tr
[2] Decision Analysis Research and Application Center, Galatasaray University, İstanbul, Türkiye, melikegsu88@yahoo.com

Abstract

Research and development (R&D) activities are essential to guarantee continuity of firms, meet customer requirements and keep ahead in competition. R&D project selection constitutes a significant part of project management in order to achieve the desired results and outputs. In this study, an integrated fuzzy multi-criteria group decision making approach is developed for R&D project selection. The problem includes a hierarchical structure of the criteria, uncertainty in evaluating the relative importance of criteria/sub-criteria and rating of candidate projects. The method employs the ordered weighted average (OWA) operator as the aggregation operator, which helps to fully reflect the real behavior of the decision makers in group decision making problems. Fuzzy integral method, which does not require the assumption of the mutual independence of criteria, is used to rank the alternatives. The case study is conducted in a small-sized company in Turkey, which designs and produces special purpose machines. A R&D project selection model is developed to maximize the desired outputs. The results of the analysis show that technological, environmental, marketing, organizational, national and financial issues should be considered simultaneously in the evaluation process. The proposed method is shown to be efficient, generalizable and practical and it has several significant merits compared to the other methods.

Keywords: Decision support systems; Fuzzy integral; Hierarchical decision making; OWA; R&D project selection.

1. INTRODUCTION

In recent years, global competitive environment leads many organizations to venture in research and development (R&D) activities since outstanding R&D activities are essential in order to guarantee continuity of firms, meet customer requirements and keeping ahead in competition. Consequently, the selection of R&D projects has become one of the most important investment decisions in the success of companies. R&D is always purposed to new discoveries, proceeding from hypotheses, original notions and their judgement. R&D is predominantly ambiguous regarding its ultimate results, the required period and required resources to accomplish it. Considering these issues, the management of R&D projects is one of compelling tasks in any establishment. Therefore, each decision maker who designated limited resources to a group of potential projects face to evaluate the potential rate of an R&D project in an organization.

The assessment, prioritizing, and selection of projects is a prospering action in project-oriented firms where limited resources (such as human, budget and equipment etc.) are struggled to be evaluated for a group of alternatives. With a rapid increase in competition and restrictions of financial capabilities, the R&D project selection method that maximize the benefit of the organization has emerged as crucial factor. Project selection decisions are elaborate, due to uncertainness of data, technology dynamics, market, and long delivery time for R&D. Moreover, interdependency between organization resources and complicated projects make project decisions much more problematic. Inadequate R&D project selection may result as a negative affect significantly on corporations for many years [1].

The evaluation of R&D project alternatives, which needs to consider multiple conflicting criteria with the involvement of a group of experts, is an important multi-criteria group decision making problem. In classical multi-criteria decision making (MCDM) methods, the ratings and the weights of the criteria are assumed to be known precisely. In general, crisp data are not sufficient to model real-life situations, which involve imprecision and vagueness. Moreover, if the number of performance attributes increases in the evaluation process, constructing a multi-level hierarchical structure of the criteria is preferred to conduct more effective analysis. Hierarchical decision of the R&D project selection provides an efficient analysis enabling the mind to cope with diversity.

In group decision making problems, the comprehension, analysis and support of the process become increasingly difficult since each decision maker have his or her own idea on the problem. In retrospect, the decision process is most valuable in that it enables the group to identify and better appreciate the differences and similarities of their judgments [2]. For this type of problem, in order to fully reflect the real behavior of the group, a final decision should be made on significant level of consensus. Therefore, aggregation of expert opinions is key to properly conduct the evaluation process.

In this study, ordered weighted average (OWA) integrated fuzzy integral method is used for R&D project selection in a small-sized company in Turkey, which designs and produces special purpose machines for its customers from different industries including white goods, automotive, aerospace sectors. It is project-oriented company and has a R&D center authorized by the Ministry of Industry and Technology of Turkey. The ministry provides tax and R&D expense incentives for the firm for R&D centers, so they expect from the firm to make R&D activities and contribute to national R&D aims. Within this framework, the related company is forced to increase its R&D level to meet expectation and maintain sustainability of R&D center. Therefore, the firm needs to determine a model for R&D project selection with multi-criteria to meet both the R&D center requirements and to maximize the outcomes.

The advantages of this study can be summarized as follows. First, the method is a group decision making processes, which enable the group to identify and better appreciate the differences and similarities of their judgments. Second, the employed approach can handle evaluation criteria that are structured in multi-level hierarchies. Third, the methodology is apt to incorporate imprecise data into the analysis using fuzzy set theory. Fourth, it employs the OWA operator as the aggregation operator. OWA operator differs from the classical weighted average in that coefficients are not associated directly with a particular attribute but rather with an ordered position. It encompasses several operators since it can implement different aggregation rules by changing the order weights. Finally, the proposed approach does not employ fuzzy number ranking methods that can produce inconsistent results or even rankings contrary to intuition while comparing alternatives. Moreover, the proposed methodology does not require the assumption of the mutual independence of criteria. Considering the above-mentioned merits, proposed decision making framework is apt to conduct robust evaluation of the R&D project alternatives.
The rest of the study is organized as follows. Literature review part is provided in Section 2. Section 3 explains materials and methods. The application of the methodology to R&D project evaluation problem is illustrated in Section 4. Section 5 gives managerial implications and discussions. Finally, conclusions are provided in the last section.

2. LITERATURE REVIEW

In the literature, different techniques and methods have emerged for project assessment process varying from qualitative review to quantitative techniques and a plenty of studies have been published. Henriksen and Traynor [3] classify R&D project selection methods as rating, programming, decision analysis, economic models, artificial intelligence, interactive methods, portfolio optimization, and unconstructed studies.

Bhattacharyya et al. [4] used a fuzzy multi-objective programming method to decide the best alternative among candidate R&D projects to maximize outcomes and minimize cost and risk considering the limitations on resources, budget and interdependencies. Feng et al. [5] developed an integrated method which consists of weighted geometric averaging, analytic hierarchy process (AHP), and scoring methods for collaborative R&D projects in China regarding ten criteria. Khalili-Damghania and Sadi-Nezhad [6] improved decision support system for multi-objective project selection problem. Khalili-Damghania and Sadi-Nezhad [7] also offered a hybrid fuzzy multiple criteria group decision making method under six main criteria for the project selection problem. Hassanzadeh et al. [8] applied a multi-objective binary integer programming for R&D project portfolio selection and robust optimization is executed to handle imprecision. Bhattacharyya [1] introduced R&D project portfolio selection as a grey theory based multiple attribute decision making issue.

Arratia et al. [9] presented mixed-integer linear programming for project portfolio selection. Cluzel et al. [10] adapted eco-innovation technique for R&D project portfolio selection in industries which eco-design prerequisites are favorably particular. Hosseini et al. [11] applied different project delivery method (PDM) to decide the most appropriate alternative regarding different selection criteria. Karasakal and Aker [12] executed multiple criteria sorting methods based on DEA to evaluate R&D projects. Jafarzadeh et al. [13] applied combination of fuzzy quality function deployment (QFD) and data envelopment analysis (DEA) for project portfolio selection regarding three significant constituents. Rad and Rowzan [14] purposed two-stage MO-PSO with TOPSIS for select project portfolio selection. Song et al. [15] proposed stochastic multi-criteria acceptability analysis (SMAA) to evaluate the multi-criteria project portfolio selection and scheduling problem. Liu et al. [16] developed the data-driven evidential reasoning rule-based model for project selection to gain verification from decision makers' evaluations as registered in previous datasets.

More recently, Binici and Aksakal [17] employed utility additive method for the evaluation of R&D projects. Mohagheghi et al. [18] develop and apply a novel Pythagorean fuzzy sets approach for construction project selection. Liu et al. [19] investigated a novel risk-based decision model to address the uncertainty and risk in the R&D project selection for a medical device company.

Although previously reported studies developed approaches for project selection process, further studies are necessary that considers a hierarchy of evaluation criteria and their related sub-criteria and also that does not require the assumption of the mutual independence of criteria. Moreover, aggregation of decision makers' opinions is crucial to properly conduct the evaluation process in the presence of multiple decision-makers, each one of them having his or her own viewpoint regarding the way the problem should be handled and the decision to be made. In this study, OWA integrated fuzzy integral method is proposed for R&D project selection problem. The proposed approach manages evaluation criteria that are structured in multi-level hierarchies and it employs the OWA operator as the aggregation operator, which helps to fully reflect the real behavior of the decision makers in group decision making problems.

3. MATERIALS AND METHODS

3.1. Ordered weighted average

One of key points in multi-criteria issues is aggregation of scorings, which obtained from decision makers, to gain an overall assessment for alternatives. Aggregation is simply described as the procedure of unifying a number of scorings into one representative score by means of an aggregation operator to acquire a universal value. In MCDM problems, each decision maker possesses her/his idea and might have diverse knowledge about alternatives. Considering these situations, aggregation methodologies are essential to cope with the process to actualize the overall characteristic of group decision making [20].

Various aggregation techniques have been examined to handle multiplicity characteristics in group decision making. In this paper, the OWA operator is utilized to aggregate decision-makers' assessments. The OWA operator was initially suggested by Yager [21]. It enables an aggregation between the "and", which needs all the criteria to be fulfilled; and the "or", which needs at least one of the criteria is fulfilled. Coefficients in this operator are directly related to an ordered arrangement rather than specific attribute. It can apply several aggregation rules by altering the order weights. The concept of OWA can be described as below [22].

Let $F = \{a_1, a_2, \ldots, a_n\}$ be a group of values aggregated. OWA operator F is stated as:

$$F\{a_1, a_2, \ldots, a_n\} = \boldsymbol{w}\boldsymbol{b}^{\boldsymbol{T}} = \sum_{j=1}^{n} w_j b_j \tag{1}$$

$\boldsymbol{w} = (w_1, w_2, \ldots, w_n)$ is a weighting vector where $w_i \in [0,1]$ and $\sum_{i=1}^{n} w_i = 1$, $\mathbf{b}$ is the related value vector which is ordered from the biggest one to the smallest one.

The characteristic of the OWA operator is that a_i is not related with a specific weight w_i, but a weight w_i is related with an ordered arrangement of a_n [22]. Determining weights of OWA operator is a vital issue to implement it for decision making process. Weights of OWA operator are computed by means of fuzzy linguistic quantifiers as [23]

$$w_i = Q\left({i}/{n}\right) - Q\left({(i-1)}/{n}\right), \ \ i = 1, \ldots, n \tag{2}$$

A non-decreasing relative quantifier Q is stated by [23]

$$Q(y) = \begin{cases} 0, & y < a \\ \frac{y-a}{b-a}, & a \le y \le b \\ 1, & y > b \end{cases} \tag{3}$$

Some non-decreasing relative quantifiers are classified by terms "as many as possible", "most" and "at least half" with parameters (a,b) provided as (0.5, 1), 0.3, 0.8) and (0, 0.5), respectively. Since quantifiers have the ability of summarizing the properties of a class of objects without enumerating them, linguistic quantification is a very important topic in the field of knowledge representation and reasoning. Quantifiers in natural languages are usually vague in some sense. It is clear that two-valued logic is not suited to cope with vague quantifiers. There has been, therefore, increasing interest about logical treatment of quantifiers in human languages in fuzzy logic community [24].

3.2. Fuzzy measures and fuzzy integral

In many real-world problems, most criteria can have interdependent or interacting structure. This state makes their assessment complicated by additive measures precisely. Therefore, fuzzy integral models with λ-measure have been proposed for a better assessment of human subjectivity [25].

Fuzzy measures and integrals were firstly introduced by Choquet [26], in his paper "Theory of Capacities". In the related study, he proposed the usage of non-additive measures. The theory of fuzzy measures and theory of fuzzy set are well unified in a way that the fuzzy integral is an adequate instrument to aggregate the values of membership functions of fuzzy sets. Later, Sugeno [27] developed further Choquet's ideas. Sugeno offered two kinds of aggregation operators: one is named as fuzzy discrete Choquet integral and the other one is named as fuzzy discrete Sugeno integral. Outcome of aggregation executing Choquet integral depends on the value of each criterion while Sugeno integral is utilized to aggregate for the outcome depends on criteria rating on ordered scale aggregation. Therefore, the Sugeno integral is more suitable for qualitative criteria aggregation whereas the Choquet integral is more adequate for quantitative criteria aggregation [27].

The fuzzy integral regards the objective assessment provided by each information source (h-function) and each subset of these sources (by favor of fuzzy measure) in decision making procedure. This integrates information source and the value of these sources according to the decision. This fusion enables to tackle the uncertainty related with the procedure of emerging and processing information [28].

Basic definitions for fuzzy integral are presented as below.

Definition 1. Let X be a group of information sources. g fuzzy measure is described on the power set of X with range [0,1], that satisfies below properties [28]:

(1) $g(\emptyset) = 0$ and $g(X) = 1$
(2) $g(A) \le g(B)\ if\ A \subseteq B$
(3) If $\{A_i\}$ is an increasing sequence of subsets of X, then $\lim_{i\to\infty} g(A_i) = g(\bigcup_{i=1}^{\infty} A_i)$

A fuzzy measure g is called as Sugeno measure (g_λ-fuzzy measure), if it also satisfies below property:

(4) For all $A, B \subseteq X$ with $A \cap B = \emptyset$, $g_\lambda(A \cup B) = g_\lambda(A) + g_\lambda(B) + \lambda g_\lambda(A) g_\lambda(B)$ where $\lambda > -1$

Definition 2. Think about the group of information sources and let $g^i = g(\{x_i\})$. The $x_i \rightarrow g^i$ mapping is called as a fuzzy density function. g^i, the fuzzy density value is represented as the importance of each information source x_i [10].

The value of λ for any Sugeno fuzzy measure can be determined by solving following equation [28]:

$$1 + \lambda = \prod_{i=1}^{n} (1 + \lambda g^i) \quad (4)$$

The fuzzy integral is described as:

$$\int_A h(x) o g(.) = \sup_{E \subseteq X} \left[min \left(\min_{x \in E} h(x), g(A \cap E) \right) \right] = \sup_{\alpha \in [0,1]} [min(\alpha, g(A \cap F_\alpha)] \quad (5)$$

where $F_\alpha = \{x \mathrm{I} h(x) \geq \alpha\}$.

Assume that $h(x_1) \geq h(x_2) \geq \cdots \geq h(x_n)$ for a finite state. Then the fuzzy integral can be indicated as below

$$e = max_{i=1}^{n} [\min((h(x_i), g(A_i))], \quad (6)$$

where $A_i = \{x_1, \ldots . x_i\}$

The value of $g(A_i)$ can be iteratively defined as

$$g(A_1) = g(\{x_1\}) \quad (7)$$
$$g(A_i) = g^i + g(A_{i-1}) + \lambda g^i g(A_{i-1}), \qquad \text{for } 1 < i \leq n$$

3.3. Employed decision methodology

The process of the employed method, which is illustrated in Figure 1, can be summarized as below.

Step 1. Build a team of decision-makers. Establish the alternates, decision criteria, and associated sub-criteria in a hierarchy.

Step 2. Structure decision matrices that specifies the scorings of alternate *i* according to sub-criterion *k* of criterion *j*, importance value of sub-criterion *k* of criterion *j*, and importance value of criterion *j* for the l^{th} decision-maker, respectively**.**

Step 3. Calculate the OWA weights of each decision maker. In this study quantifier "most" is employed as decision strategy.

Step 4. Find the aggregated fuzzy evaluations of alternatives according to sub-criteria ($\tilde{x}_{ijk}$), the aggregated fuzzy importance weights of sub-criteria ($\tilde{w}_{jk}$), and the aggregated fuzzy importance weights of sub-criteria ($\tilde{w}_j$).

Step 5. Unit-free and comparable sub-criteria values are attained by normalization of the aggregated decision matrix. The normalized values for the data are computed by means of equation (8) taking into account benefit-related sub-criteria (CB_j) as well as cost-related sub-criteria (CC_j).

$$\tilde{r}_{ijk} = \begin{cases} \left(\dfrac{x_{ijk}^1 - x_{jk}^-}{x_{jk}^* - x_{jk}^-}, \dfrac{x_{ijk}^2 - x_{jk}^-}{x_{jk}^* - x_{jk}^-}, \dfrac{x_{ijk}^3 - x_{jk}^-}{x_{jk}^* - x_{jk}^-} \right), k \in CB_j \\ \left(\dfrac{x_{jk}^* - x_{ijk}^3}{x_{jk}^* - x_{jk}^-}, \dfrac{x_{jk}^* - x_{ijk}^2}{x_{jk}^* - x_{jk}^-}, \dfrac{x_{jk}^* - x_{ijk}^1}{x_{jk}^* - x_{jk}^-} \right), k \in CC_j \end{cases} \quad (8)$$

In equation (8), $\tilde{r}_{ijk}$ represents the normalized value of $\tilde{x}_{ijk}$, *m* is the number of alternates, *n* is the number of criteria, $x_{jk}^* = max_i x_{ijk}^3$ and $x_{jk}^- = min_i x_{ijk}^1$. The greater value is much preferred state for benefit-related sub-criteria, whereas the greater value is less preferred state for cost-related sub-criteria.

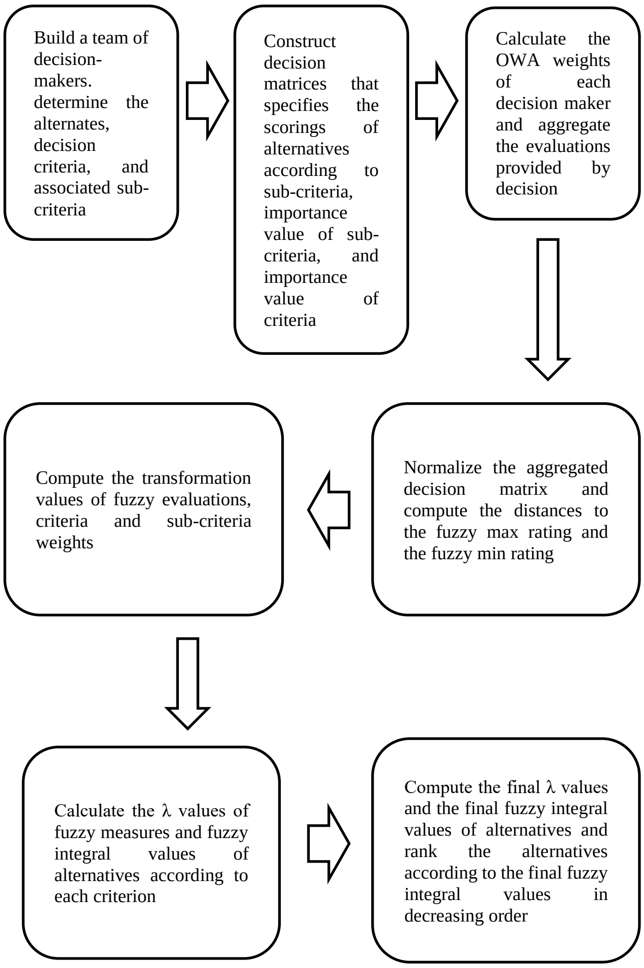

Figure 1. Illustration of the proposed method

Step 6. The fuzzy max rating, $\tilde{P}^*$ (1,1,1), and the fuzzy min rating, $\tilde{P}^-$ (0,0,0), are defined. Then, the distances of the criteria weight and related sub-criteria weight, and the fuzzy ratings to the fuzzy max rating and the fuzzy min rating are calculated using Eq. (9).

$$d_v(\tilde{A}, \tilde{B}) = 0.5\{max(|a_1 - b_1|, |a_3 - b_3|) + |a_2 - b_2|\} \quad (9)$$

Step 7. The transformation values of fuzzy weights of entire sub-criteria and criteria are computed as

$$RW_{jk} = {wd_{jk}^-}\Big/\left(wd_{jk}^- + wd_{jk}^*\right) \quad (10)$$

$$RW_j = {wd_j^-}\Big/\left(wd_j^- + wd_j^*\right) \quad (11)$$

where wd_j^*, wd_{jk}^*, wd_j^- and wd_{jk}^- represent the distances of the criteria weight and related sub-criteria weight to the fuzzy max rating and the fuzzy min rating, respectively.

Step 8. The transformation values of all normalize fuzzy evaluations are computed.

$$RI_{ijk} = {d_{ijk}^-}\Big/\left(d_{ijk}^- + d_{ijk}^*\right) \quad (12)$$

where d_{ijk}^* and d_{ijk}^- represent the distances of the fuzzy ratings to the fuzzy max rating and the fuzzy min rating, respectively.

Step 9. λ values of fuzzy measures and fuzzy integral values of whole options according to each criterion are calculated with the help of using Equation (4)-(7). The h function is the transformation values of normalized fuzzy evaluations RI_{ijk} and $g(A_1) = g^1 = RW_1$.

Step 10. The final λ values and the final fuzzy integral values of options are computed. The options are ranked with respect to the final fuzzy integral values in decreasing order.

4. CASE STUDY

In this study, OWA integrated fuzzy integral method is used for R&D project selection in a small-sized company in Turkey, which designs and produces special purpose machines for its customers from different industries including white goods, automotive, aerospace sectors. The problem includes a hierarchical structure of the criteria, uncertainty in evaluating the relative importance of criteria/sub-criteria and rating of candidate projects.

Table 1. The candidate projects

No	Project Name
P_1	Fuse Assembly Machine
P_2	Hot-forging Press Machine Automation
P_3	Glass Shelf Assembly Machine
P_4	Gear Console Assembly Machine
P_5	Sponge Conditioning and Separation Line
P_6	Lever Assembly Machine
P_7	Clips Feeder Line
P_8	Sleeve Production Line

The company has eight candidate R&D projects as explained in Table 1.

The evaluation criteria and sub-criteria are derived from literature and experts' opinions as in Table 2. To provide a better understanding of project selection criteria, they are categorized as 27 sub-criteria which are aggregated into six major criteria.

Table 2. R&D project selection criteria

Selection Criteria
Technological Issues (C_1) ([29], [30])
Innovation of technology (C_{11})
Advancement of technology (C_{12})
Key of technology (C_{13})
Patentability (C_{14})
Uniqueness of technology/product (C_{15})
Technological extendibility (C_{16})
Environmental Issues (C_2) ([30], [31], [32])
Safety considerations (C_{21})
Benefits for human life (C_{22})
Political factors (C_{23})
Job creation opportunity (C_{24})
The satisfaction of the employee (C_{25})
Marketing Issues (C_3) ([30], [31])
Opportunity/probability of market success (C_{31})
Potential size of market (C_{32})
Degree of competition (C_{33})
Opportunity for new technology/market (C_{34})
Organizational Issues (C_4) ([31])
Competence and experience on similar projects (C_{41})
Knowledge/skills availability (C_{42})
Facilities availability (C_{43})
Research staff availability (C_{44})
National Advantages Issues (C_5) ([30])
Collaboration of University and Industry (C_{51})
Contribution to national economy (C_{52})
Conducting Market Research (C_{53})
Contributions to the state of knowledge (C_{54})
Financial Issues (C_6) ([29], [33])
Investment cost (C_{61})
Outsourced benefits and services cost (C_{62})
Contribution of profitability (C_{63})
Risk for development cost (C_{64})

The evaluation is conducted by a committee of four decision makers that includes general manager, R&D center director, design team leader and project manager. The decision makers scored alternatives with respect to criteria and sub-criteria by using the linguistic scale given in Figure 2.

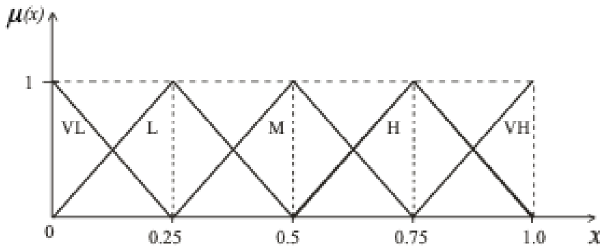

Figure 2. Fuzzy linguistic term set [23]

The obtained evaluations are aggregated by using OWA operator and the weights of OWA operator are calculated by employing the non-decreasing relative quantifier Q stated in Equations 2 and 3 as **w** = (0.0, 0.4, 0.5, 0.1). The results are given in Tables 3 and 4.

The aggregated values are normalized by using Equation 8. The fuzzy max rating, $\tilde{P}^*$ (1,1,1), and the fuzzy min rating, $\tilde{P}^-$ (0,0,0), are defined. Then, the distances, are calculated regarding the Equation 9. The transformation values of fuzzy weights of criteria and sub-criteria are calculated by using Equation 10 and 11. The results are listed in Table 5.

Table 3. The aggregated ratings of projects according to sub-criteria

Sub-Criterion	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8
C_{11}	(0.725,0.975,1.000)	(0.225,0.475,0.725)	(0.725,0.975,1.000)	(0.000,0.225,0.475)	(0.500,0.750,1.000)	(0.600,0.850,1.000)	(0.600,0.850,1.000)	(0.500,0.750,1.000)
C_{12}	(0.700,0.950,0.975)	(0.100,0.350,0.600)	(0.700,0.950,0.975)	(0.100,0.350,0.600)	(0.575,0.825,0.975)	(0.475,0.725,0.975)	(0.250,0.500,0.750)	(0.475,0.725,0.975)
C_{13}	(0.700,0.950,0.975)	(0.325,0.575,0.825)	(0.575,0.825,0.975)	(0.250,0.500,0.750)	(0.575,0.825,0.975)	(0.700,0.950,0.975)	(0.575,0.825,0.975)	(0.475,0.725,0.975)
C_{14}	(0.675,0.925,0.950)	(0.000,0.025,0.275)	(0.450,0.700,0.950)	(0.000,0.250,0.500)	(0.550,0.800,0.950)	(0.450,0.700,0.950)	(0.675,0.925,0.950)	(0.450,0.700,0.950)
C_{15}	(0.675,0.925,0.950)	(0.000,0.225,0.475)	(0.450,0.700,0.950)	(0.000,0.225,0.475)	(0.675,0.925,0.950)	(0.550,0.800,0.950)	(0.100,0.350,0.600)	(0.450,0.700,0.950)
C_{16}	(0.725,0.975,1.000)	(0.450,0.700,0.950)	(0.500,0.750,1.000)	(0.225,0.475,0.725)	(0.500,0.750,1.000)	(0.500,0.750,1.000)	(0.600,0.850,1.000)	(0.500,0.750,1.000)
C_{21}	(0.750,1.000,1.000)	(0.750,1.000,1.000)	(0.750,1.000,1.000)	(0.750,1.000,1.000)	(0.750,1.000,1.000)	(0.750,1.000,1.000)	(0.750,1.000,1.000)	(0.750,1.000,1.000)
C_{22}	(0.750,1.000,1.000)	(0.500,0.750,1.000)	(0.750,1.000,1.000)	(0.350,0.600,0.850)	(0.000,0.250,0.500)	(0.725,0.975,1.000)	(0.100,0.350,0.600)	(0.325,0.575,0.825)
C_{23}	(0.100,0.350,0.600)	(0.100,0.350,0.600)	(0.100,0.350,0.600)	(0.100,0.350,0.600)	(0.100,0.350,0.600)	(0.100,0.350,0.600)	(0.100,0.350,0.600)	(0.100,0.350,0.600)
C_{24}	(0.200,0.450,0.700)	(0.000,0.250,0.500)	(0.200,0.450,0.700)	(0.000,0.250,0.500)	(0.200,0.450,0.700)	(0.200,0.450,0.700)	(0.200,0.450,0.700)	(0.200,0.450,0.700)
C_{25}	(0.725,0.975,1.000)	(0.100,0.350,0.600)	(0.500,0.750,1.000)	(0.000,0.250,0.500)	(0.600,0.850,1.000)	(0.750,1.000,1.000)	(0.350,0.600,0.850)	(0.600,0.850,1.000)
C_{31}	(0.725,0.975,1.000)	(0.100,0.350,0.600)	(0.500,0.750,1.000)	(0.350,0.600,0.850)	(0.500,0.750,1.000)	(0.475,0.725,0.975)	(0.500,0.750,1.000)	(0.500,0.750,1.000)
C_{32}	(0.750,1.000,1.000)	(0.225,0.450,0.700)	(0.750,1.000,1.000)	(0.000,0.250,0.500)	(0.725,0.975,1.000)	(0.350,0.600,0.850)	(0.575,0.825,0.975)	(0.500,0.750,1.000)
C_{33}	(0.750,1.000,1.000)	(0.325,0.550,0.800)	(0.725,0.975,1.000)	(0.325,0.575,0.825)	(0.750,1.000,1.000)	(0.725,0.975,1.000)	(0.725,0.975,1.000)	(0.725,0.975,1.000)
C_{34}	(0.750,1.000,1.000)	(0.225,0.475,0.725)	(0.750,1.000,1.000)	(0.100,0.325,0.575)	(0.725,0.975,1.000)	(0.725,0.975,1.000)	(0.750,1.000,1.000)	(0.500,0.750,1.000)
C_{41}	(0.750,1.000,1.000)	(0.225,0.475,0.725)	(0.725,0.975,1.000)	(0.000,0.250,0.500)	(0.750,1.000,1.000)	(0.750,1.000,1.000)	(0.350,0.600,0.850)	(0.500,0.750,1.000)
C_{42}	(0.500,0.750,1.000)	(0.500,0.750,1.000)	(0.500,0.750,1.000)	(0.500,0.750,1.000)	(0.500,0.750,1.000)	(0.500,0.750,1.000)	(0.500,0.750,1.000)	(0.500,0.750,1.000)
C_{43}	(0.500,0.750,1.000)	(0.500,0.750,1.000)	(0.500,0.750,1.000)	(0.500,0.750,1.000)	(0.500,0.750,1.000)	(0.500,0.750,1.000)	(0.500,0.750,1.000)	(0.500,0.750,1.000)
C_{44}	(0.600,0.850,1.000)	(0.325,0.575,0.825)	(0.500,0.750,1.000)	(0.325,0.575,0.825)	(0.600,0.850,1.000)	(0.600,0.850,1.000)	(0.475,0.725,0.975)	(0.500,0.750,1.000)
C_{51}	(0.500,0.750,1.000)	(0.000,0.000,0.250)	(0.500,0.750,1.000)	(0.000,0.000,0.250)	(0.575,0.825,0.975)	(0.725,0.975,1.000)	(0.000,0.250,0.500)	(0.500,0.750,1.000)
C_{52}	(0.750,1.000,1.000)	(0.275,0.525,0.775)	(0.750,1.000,1.000)	(0.250,0.500,0.750)	(0.750,1.000,1.000)	(0.600,0.850,1.000)	(0.750,1.000,1.000)	(0.725,0.975,1.000)
C_{53}	(0.750,1.000,1.000)	(0.475,0.725,0.975)	(0.750,1.000,1.000)	(0.250,0.500,0.750)	(0.750,1.000,1.000)	(0.500,0.750,1.000)	(0.750,1.000,1.000)	(0.500,0.750,1.000)
C_{54}	(0.750,1.000,1.000)	(0.225,0.475,0.725)	(0.725,0.975,1.000)	(0.100,0.350,0.600)	(0.750,1.000,1.000)	(0.750,1.000,1.000)	(0.475,0.725,0.975)	(0.725,0.975,1.000)
C_{61}	(450,530,550)	(420,450,500)	(460,480,510)	(150,200,250)	(1000,1200,1400)	(720,758,800)	(360,390,410)	(1200,1300,1500)
C_{62}	(20,25,30)	(10,13,15)	(20,25,30)	(10,15,20)	(45,56,60)	(15,18,20)	(10,12,15)	(40,44,50)
C_{63}	(0.600,0.850,1.000)	(0.200,0.450,0.700)	(0.600,0.850,1.000)	(0.100,0.350,0.600)	(0.600,0.850,1.000)	(0.600,0.850,1.000)	(0.600,0.850,1.000)	(0.500,0.750,1.000)
C_{64}	(0.600,0.850,1.000)	(0.000,0.225,0.475)	(0.500,0.750,1.000)	(0.100,0.350,0.600)	(0.725,0.975,1.000)	(0.500,0.750,1.000)	(0.225,0.475,0.725)	(0.500,0.750,1.000)

Table 4. The aggregated importance values of criteria and sub-criteria

Criterion		Aggregated Weights
C_1		(0.600,0.850,1.000)
	C_{11}	(0.700,0.950,0.975)
	C_{12}	(0.475,0.725,0.975)
	C_{13}	(0.350,0.600,0.850)
	C_{14}	(0.550,0.800,0.950)
	C_{15}	(0.450,0.700,0.950)
	C_{16}	(0.500,0.750,1.000)
C_2		(0.475,0.725,0.975)
	C_{21}	(0.750,1.000,1.000)
	C_{22}	(0.500,0.750,1.000)
	C_{23}	(0.000,0.250,0.500)
	C_{24}	(0.200,0.425,0.675)
	C_{25}	(0.325,0.575,0.825)
C_3		(0.100,0.350,0.600)
	C_{31}	(0.350,0.600,0.850)
	C_{32}	(0.325,0.575,0.825)
	C_{33}	(0.600,0.850,1.000)
	C_{34}	(0.350,0.600,0.850)
C_4		(0.475,0.725,0.975)
	C_{41}	(0.725,0.975,1.000)
	C_{42}	(0.725,0.975,1.000)
	C_{43}	(0.725,0.975,1.000)
	C_{44}	(0.725,0.975,1.000)
C_5		(0.325,0.575,0.825)
	C_{51}	(0.225,0.475,0.725)
	C_{52}	(0.500,0.750,1.000)
	C_{53}	(0.475,0.725,0.975)
	C_{54}	(0.750,1.000,1.000)
C_6		(0.725,0.975,1.000)
	C_{61}	(0.475,0.725,0.975)
	C_{62}	(0.100,0.325,0.575)
	C_{63}	(0.300,0.550,0.700)
	C_{64}	(0.575,0.825,0.975)

Table 5. The transformation values of criteria and sub-criteria

Criterion		Transformation values
C_1		0.771
	C_{11}	0.846
	C_{12}	0.680
	C_{13}	0.580
	C_{14}	0,729
	C_{15}	0.660
	C_{16}	0.700
C_2		0.680
	C_{21}	0.889
	C_{22}	0.700
	C_{23}	0.300
	C_{24}	0.444
	C_{25}	0.560
C_3		0.380
	C_{31}	0.580
	C_{32}	0.560
	C_{33}	0.771
	C_{34}	0.580
C_4		0.680
	C_{41}	0.868
	C_{42}	0.868
	C_{43}	0,868
	C_{44}	0.868
C_5		0.560
	C_{51}	0.480
	C_{52}	0.700
	C_{53}	0.680
	C_{54}	0.889
C_6		0.868
	C_{61}	0.680
	C_{62}	0.364
	C_{63}	0.521
	C_{64}	0.750

The transformation values of normalized fuzzy evaluations are calculated by means of Equation 12. The results are listed in Table 6.

λ values of fuzzy ratings and fuzzy integral values of entire options according to each criterion are calculated by means of Equation (4-7) by setting $g(A_1) = g^1 = RW_1$. The results are listed in Table 7.

Final fuzzy integral values are calculated, and options are ranked according to final fuzzy integral values in decreasing order. The results are listed in Table 8.

Table 8. Final FI values and ranking

Alternatives	FI	Ranking
P_1	0.8602	3
P_2	0.7826	8
P_3	0.8711	1
P_4	0.8276	6
P_5	0.8438	4
P_6	0.8602	2
P_7	0.8367	5
P_8	0.7997	7

Table 6. The transformation values of normalized fuzzy evaluations

Sub Criterion	RI_{1jk}	RI_{2jk}	RI_{3jk}	RI_{4jk}	RI_{5jk}	RI_{6jk}	RI_{7jk}	RI_{8jk}
C_{11}	0.868	0.480	0.868	0.283	0.700	0.771	0.771	0.700
C_{12}	0.852	0.333	0.852	0.333	0.744	0667	0.467	0.667
C_{13}	0.826	0.462	0.703	0.385	0.703	0826	0.703	0.615
C_{14}	0.862	0.138	0.688	0.313	0.761	0.688	0.862	0.688
C_{15}	0.862	0.295	0.688	0.295	0.862	0.761	0.396	0.688
C_{16}	0.836	0.585	0.634	0.366	0.634	0.634	0.718	0.634
C_{21}	0.667	0.667	0.667	0.667	0.667	0.667	0.667	0.667
C_{22}	0.889	0.700	0.889	0.580	0.300	0.868	0.380	0.560
C_{23}	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
C_{24}	0.605	0.395	0.605	0.395	0.605	0.605	0.605	0.605
C_{25}	0.868	0.380	0.700	0.300	0.771	0.889	0.580	0.771
C_{31}	0.855	0.326	0.674	0.543	0.674	0.652	0.674	0.674
C_{32}	0.889	0.465	0.889	0.300	0.868	0.580	0.750	0.700
C_{33}	0.844	0.384	0.815	0.405	0.844	0.815	0.815	0.815
C_{34}	0.878	0.435	0.878	0.308	0.855	0.855	0.878	0.674
C_{41}	0.889	0.480	0.868	0.300	0.889	0.889	0.580	0.700
C_{42}	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
C_{43}	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
C_{44}	0.686	0.405	0.595	0.405	0.686	0.686	0.568	0.595
C_{51}	0.700	0.111	0.700	0.111	0.750	0.868	0.300	0.700
C_{52}	0.857	0.400	0.857	0.375	0.857	0.711	0.857	0.831
C_{53}	0.857	0.600	0.857	0.375	0.857	0.625	0.857	0.625
C_{54}	0.878	0.435	0.855	0.326	0.878	0.878	0.652	0.855
C_{61}	0.721	0.766	0.749	0.946	0.258	0.547	0.818	0.167
C_{62}	0.682	0,924	0.682	0.864	0.165	0.829	0.933	0.327
C_{63}	0.750	0.413	0.750	0.326	0.750	0.750	0.750	0.674
C_{64}	0.229	0.717	0.300	0.620	0.132	0.300	0.520	0.300

Table 7. λ values of fuzzy scales and FI values

	C_1	C_2	C_3	C_4	C_5	C_6
λ	-0.9994	-0.9938	-0.97935	-0.9997	-0.994	-0.97036
P_1	0.730	0.618	0.879	0.859	0.875	0.694
P_2	0.550	0.683	0.441	0.499	0.544	0.804
P_3	0.877	0.827	0.869	0.830	0.856	0.709
P_4	0.372	0.652	0.477	0.498	0.369	0.863
P_5	0.825	0.717	0.856	0.859	0.369	0.498
P_6	0.801	0.853	0.823	0.859	0.867	0.698
P_7	0.834	0.655	0.844	0.577	0.836	0.828
P_8	0.698	0.721	0.787	0.684	0.848	0.492

When the results are examined, P_3, P_6 and P_1 can be thought as the most appropriate projects considering technical, financial and national issues. If P_5 and P_7 are considered, they were expected to be in higher position in ranking since they have high scorings. Their rankings can be explained by investment cost. Both P_5 and P_7 have higher investment cost than the others. Therefore, it can be said that this sub-criterion has an important effect on ranking. Also, it can be emphasized that reasonable costs for projects and other requirements must meet on a common ground for the sustainability of R&D activities.

Previously, several researchers have used different fuzzy MCDM techniques for project selection. These methods possess several advantages such as the consideration of imprecision and vagueness inherent in the problem, but they also incorporate some shortcomings. Defuzzification has been commonly used in fuzzy MCDM methods. Freeling [34] stated that by reducing the whole analysis to a single number, much of the information which has been intentionally kept throughout calculations is lost. Thus, defuzzification might essentially contradict with the key objective of minimizing the loss of information throughout the analysis. Moreover, obtaining pairwise comparisons in widely used techniques such as AHP and ANP may become quite complex especially when the number of attributes and/or alternatives increases. Apart from this, Saaty and Tran [35] claimed that uncertainty in the AHP was successfully remedied by using intermediate values in the 1–9 scale combined with the verbal scale and that seemed to work better to obtain accurate results than using fuzzy AHP. Fuzzy TOPSIS and fuzzy VIKOR assume mutual independence of attributes, which can be highly restrictive for decisions processes that usually incorporate inner dependencies among attributes.

5. DISCUSSIONS AND CONCLUSIONS

Today, due to the rapid globalization, achieving competitive advantage is based on the information. Information is changed into science and technology with research and development studies. The sustainable development of a country is only possible conceivable by expanding the data content and by changing the increasing information into science and technology. Thus, research and development have great importance. Determining the most appropriate R&D project that match up with the organization’s goals is getting much more importance under restricted resources, since the projects that contribute to technical and economic success have a constructive effect. Such projects also accommodate the organization composing a list of preferential projects that will develop the success and will provide a comprehensive extent and strategic way for the organization. R&D project selection constitutes a significant part of project management in order to achieve the desired results and outputs. Therefore, R&D project selection is a challenging process for the organizations, since it includes evaluation of a wide range of factors, including economic, technical, strategic etc. It is also a complex procedure with a characteristic of multi steps, a group of decision-maker, who have diverse ideas and experiences, multiple and conflicting objectives, imprecision in forecasting future achievement and high risk in projects. It can be predicted that a considerable effort needs to determine the best alternative. For this reasons, decision-maker require a scientific guide to select and evaluate R&D projects.

In this study, OWA integrated fuzzy integral method is implemented to select the best R&D project in a company which has a R&D center authorized by Turkish Ministry of Industry and Technology. Selection criteria are determined by means of literature review and experts’ opinions. A hierarchical structure for criteria including 6 main criteria and 27 sub-criteria are constructed. Structuring the criteria in a multi-level hierarchy enables to conduct more effective analysis when a large number of performance attributes are to be considered in the evaluation process. 4 decision-makers and 8 projects take part for selection process. OWA aggregation method is applied to weight decision makers and aggregate their ratings. In project selection process that considers multiple conflicting criteria, determining the weights of criteria, and the ratings of alternatives is difficult. Decision makers attempt to weight criteria and alternatives according to her/his own preference and her/his own past experiences. Nevertheless, such individual knowledge is difficult to gain due to the following causes: (1) decision maker(s) does not have enough time and energy completely understand such problems; (2) decision maker(s) might have limited information and experience to evaluate criteria; and (3) decision maker(s) preferences may change with time. Thus, the use of an appropriate aggregation operator, which reflects the real behavior of the group is essential. OWA implements different aggregation rules by changing the order weights, and it encompasses other aggregation operators.
The results of the analysis provide ranking of alternative R&D projects in the case company. It also shows that technological, environmental, marketing, organizational, national and financial issues should be considered simultaneously in the evaluation process. The proposed method is shown to be efficient, generalizable and practical and it has several significant merits compared to the other methods.

In this study, four experts are provided the evaluations. From a statistical point of view, this number is insufficient. This issue can be stated as a limitation of the study. However, with a rapid increase in competition and restrictions of financial capabilities, R&D projects evaluation becomes crucial for the organizations. Furthermore, interdependency between organization resources and complicated projects make project decisions much more problematic. Thus, the evaluation is conducted by a committee of four decision makers that includes general manager, R&D center director, design team leader and project manager, who are specialists on project management. In order to make a robust decision the use of many more experts in divers disciplines requires the elimination of the outliers by employing an analytical method, which will be addressed in the future researches. Moreover, implementing the proposed methodology to real-world group decision making problems in diverse disciplines and extensions of the proposed methodology by combining both subjective and objective importance weight assessments of the criteria and related sub-criteria might be the subjects of the future researches.

Author Contributions: Conceptualization: M.D.; Material and Methodology: M.D., M.K.; Supervision: M.D.; Visualization: M.K.; Writing-Original Draft: M.D., M.K.; All authors have read and agreed to the published version of manuscript.
Conflict of Interest: No conflict of interest was declared by the authors.
Financial Disclosure: This research was financially supported by Galatasaray University Research Fund Grant Number FOA-2022-1092.

REFERENCES

[1] R. Bhattacharyya, “A Grey Theory Based Multiple Attribute Approach for R&D Project Portfolio Selection,” Fuzzy Information and Engineering, vol. 7, no. 2, pp. 211–225, 2015.

[2] C. Muralidharan, N. Anantharaman, and S. G. Deshmukh, “A multi-criteriagroup decision making model for supplier rating,” The Journal of Supply Chain Management, vol. 38, no. 4, pp. 22–33, 2002.

[3] A. D. Henriksen and A. J. Traynor, “ A practical R&D project-selection scoring tool,” IEEE Transactions on Engineering Management, vol. 46, no. 2, pp. 158-170, 1999.

[4] R. Bhattacharyya, P. Kumar, P. and S. Kar, "Fuzzy R&D portfolio selection of interdependent projects," Computers and Mathematics with Applications, vol. 62, no. 10, pp. 3857-3870, 2011.

[5] B. Feng, J. Ma and Z. P. Fan, "An integrated method for collaborative R&D project selection: Supporting innovative research teams," Expert Systems with Applications, vol. 38, no. 5, pp. 5532-5543, 2011.

[6] K. Khalili-Damghania and S. Sadi-Nezhad, "A decision support system for fuzzy multi-objective multi-period sustainable project selection," Computers & Industrial Engineering, vol. 64, no. 4, pp. 1045-1060, 2013.

[7] K. Khalili-Damghania and S. Sadi-Nezhad, "A hybrid fuzzy multiple criteria group decision making approach for project selection," Applied Soft Computing, vol. 13, no. 1, pp. 339-352, 2013.

[8] F. Hassanzadeh, H. Nemati and M. Sun, "Robust optimization for interactive multiobjective programming with imprecise information applied to R&D project portfolio selection," European Journal of Operational Research, vol. 238, no. 1, pp. 41-53, 2014.

[9] M. N. M. Arratia, I. F. López, S. E. Schaeffer, and L. Cruz-Reyes, "Static R&D project portfolio selection in public organizations," Decision Support Systems, vol. 84, pp. 53-63, 2016.

[10] F. Cluzel, B. Yannou, D. Millet, and Y. Leroy, "Eco-ideation and eco-selection of R&D projects portfolio in complex systems industries," Journal of Cleaner Production, vol. 112, no. 5, pp. 4329-4343, 2016.

[11] A. Hosseini, O. Lædre, B. Andersen, O. Torp, N. Olsson, and J. Lohne, "Selection Criteria for Delivery Methods for Infrastructure Projects," Procedia-Social and Behavioral Sciences, vol. 226, pp. 260-268, 2016.

[12] E. Karasakal and P. Aker, "A multicriteria sorting approach based on data envelopment analysis for R&D project selection problem," Omega, vol. 73, pp. 79-92, 2017.

[13] H. Jafarzadeh, P. Akbari, and B. Abedin, "A methodology for project portfolio selection under criteria prioritisation, uncertainty and projects interdependency – combination of fuzzy QFD and DEA," Expert Systems with Applications, vol. 110, pp. 237-249, 2018.

[14] H. F. Rad and S. M. Rowzan, "Designing a hybrid system dynamic model for analyzing the impact of strategic alignment on project portfolio selection," Simulation Modelling Practice and Theory, vol. 89, pp. 175-194, 2018.

[15] S. Song, F. Yang, and Q. Xia, "Multi-criteria project portfolio selection and scheduling problem based on acceptability analysis," Computers and Industrial Engineering, vol. 135, pp. 793-799, 2019.

[16] F. Liu, Y. W. Chen, J. B. Yang, D. L. Xu, and W. Liu, "Solving multiple- criteria R&D project selection problems with a data-driven evidential reasoning rule," International Journal of Project Management, vol. 37, no. 1, pp. 87-97, 2019.

[17] E. Binici and E. Aksakal, "A new approach to R&D project selection problem and a solution proposal: UTA method," Pamukkale University Journal of Engineering Sciences, vol. 26, no. 1, pp. 211-226, 2020.

[18] V. Mohagheghi, S. M. Mousavi, M. Mojtahedi, S. Newton, "Evaluating large, high-technology project portfolios using a novel interval-valued Pythagorean fuzzy set framework: An automated crane project case study," Expert Systems with Applications, vol. 162, no. 1, 113007, 2020.

[19] P. Liu, B. Zhu, H. Seiti, and L. Yang, "Risk-based decision framework based on R-numbers and best-worst method and its application to research and development project selection," Information Sciences, vol. 571, no. 1, pp. 303-322, 2021.

[20] W. R. W. Mohd and L. Abdullah, "Aggregation methods in group decision making: A decade survey," Informatica (Slovenia), vol. 41, no. 1, pp. 71–86, 2017.

[21] R. R. Yager, "On ordered weighted averaging aggregation operators in multi-criteria decision making," IEEE Transactions on Systems Man and Cybernetics, vol. 18, no. 1, pp. 183–190, 1988.

[22] D. P. Filev and R. R. Yager, "On the issue of obtaining OWA operator weights," Fuzzy Sets and Systems, vol. 94, pp. 157–169, 1998.

[23] M. Dursun, E. E. Karsak, and M. A. Karadayi, "A fuzzy multi-criteria group decision making framework for evaluating health-care waste disposal alternatives," Expert Systems with Applications, vol. 38, no. 9, pp. 11453-11462, 2011.

[24] M. Ying, "Linguistic quantifiers modeled by Sugeno integrals," Artificial Intelligence, vol. 170, pp. 581-606, 2006.

[25] M. Ayub, Choquet and Sugeno Integrals, Master Thesis, Blekinge Institute of Technology, 2009.

[26] G. Choquet, "Theory of capacities," Annales de l'Institut Fourier, vol. 5, pp. 131-295, 1954.

[27] M. Sugeno, Theory of fuzzy integrals and its applications, Thesis, Tokyo Institute of Technology, 1974.

[28] J. M. Keller, J. Osborn, "Training the fuzzy integral," International Journal of Approximate Reasoning, vol. 15, no. 1, pp. 1-24, 1996.

[29] R. Balachandra, J. H. Friar, "Factors for success in r&d projects and new product innovation: a contextual framework," IEEE Transactions on Engineering Management, vol. 44, no. 3, pp. 276-287, 1997.

[30] C. C. Huang, P. Y. Chu, and Y. H. Chiang, "A fuzzy AHP application in government-sponsored R&D project selection," Omega, vol. 36, no. 6, pp. 1038-1052, 2008.

[31] A. S. Pillai, A. Joshi, and K. S. Rao, "Performance measurement of R&D projects in a multi-project, concurrent engineering environment," International Journal of Project Management, vol. 20, no. 2, pp. 165-177, 2002.

[32] G. Jin, S. Sperandio, and P. Girard, "Selection of design project with the consideration of designers' satisfaction factors and collaboration ability," Computers and Industrial Engineering, vol. 131, pp. 66-81, 2019.

[33] J. J. Jiang and G. Klein, "Project selection criteria by strategic orientation," Information and Management, vol. 36, no. 2, pp. 63-75, 1999.

[34] S. Freeling, "Fuzzy sets and decision analysis," IEEE Transactions on Systems, Man, and Cybernetics, vol. 10, pp. 341-354, 1980.

[35] T. L. Saaty and L. T. Tran, "On the invalidity of fuzzifying numerical judgments in the analytic hierarchy process," Mathematical and Computer Modelling, vol. 46, pp. 962-975, 2007.

Research Paper
Academic Platform Journal of Engineering and Smart Systems (APJESS) 11(1), 11-18, 2023
ISSN: 2822-2385
Received: 14-Jul-2022 Accepted: 04-Nov-2022
https://doi.org/10.21541/apjess.1143964

Coding Program Selection using Spherical Fuzzy Analytic Hierarchy and Pythagorean Fuzzy Analytic Hierarchy Processes

*[1]Serap TEPE

[1] Department of Occupational Health and Safety, University of Health Sciences, İstanbul, Türkiye, serap.tepe@sbu.edu.tr

Abstract

Today, coding is not a field that belongs only to software developers; it has become a field of interest to many people from different professions. The coding education designed for elementary school level resulting from the changes made in the curriculum has led to teaching analytical thinking to children. Deciding the most suitable software for children among all the options is an important issue. This paper aims to extend the classical Analytical Hierarchy Process (AHP) and look at the spherical fuzzy analytical hierarchy (SF-AHP) method to show its applicability to the problems of coding software program selection for children through a comparative analysis using Pythagorean AHP (PF-AHP). After performing the analysis by using the proposed method, it was found that technological facilities, diversity, cost and environmental conditions were the most critical factors according to SF-AHP and PF-AHP methodologies. According to these criteria, the educational programming platform 'Tynker' was determined to be the best alternative using both these methods.

Keywords: Multi Criteria Decision Making, AHP, Spherical Fuzzy-AHP, Pythagorean Fuzzy-AHP

1. INTRODUCTION

AHP is one of the most preferred multi-criteria decision-making methods. The hierarchical order in this method was developed by Saaty [1]. The purpose of the decision making is located at the highest level. The main criteria and sub criteria – if any – under the main criteria are located one level lower. Below that there are decision options, namely alternatives. AHP can be easily applied with many criteria and is a very effective method in making group decisions. The flexibility of the result can be easily tested thanks to sensitivity analysis. AHP can make both quantitative and qualitative criteria evaluations in decision making. It can involve the preferences, judgments, intuition and experiences of the group or individual in the decision process. It is one of the most useful multi-criteria, decision-making methods enabling complex problems to be solved using a hierarchical structure.

The decision-making process is a complex process as it involves many different factors. In this process, preferences, intuition, experiences, judgments, opinions, and objective or subjective evaluations can make decision-making more difficult. Therefore, classical logic may be insufficient for decision making. Also, since the human mind is quite complex in terms of mentality and decision making, an approach different from classical logic is required in this process. There is a 'true' or 'false' state in the classical logic system. In this system, it is thought that a third possibility is impossible to realize and such situations are usually called paradoxes. Classical logic has the two values (0, 1), while fuzzy logic has values in the range [0, 1]. The main idea of fuzzy logic is that a proposition can be 'true', 'false', 'very true', 'very false', 'approximately true' or 'approximately false'. In other words, truth is a function that relates values in a set containing infinite numbers of truth values between the classical 'true' and 'false' or numerically to a range of real numbers [0, 1]. This statement is accepted as a result of Zadeh's [2] first work on fuzzy logic. Although the classical fuzzy set theory developed by Zadeh works well to overcome the shortcomings experienced by the decision maker in decision making, the complexity of human decisions and the diversity of linguistic expressions have led researchers to seek other approaches in this area. Therefore, Torra [3] defined multi-fuzzy sets, in other words, fuzzy sets with more than one membership. Then, Rodriguez et al. [4] conducted a series of studies to examine these sets and to enrich the content of linguistic expressions. Thus, it was made possible to use richer expressions in a more flexible and impressive way when comparing two alternatives. Over the years, many studies have been carried out in this area and the studies have made significant contributions to published literature. Studies on fuzzy sets are shown in Figure 1 [5].

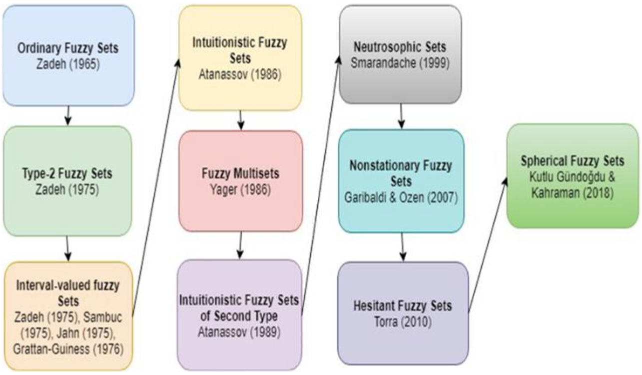

Figure 1. Extensions of Fuzzy Sets

In this study, a decision-making model based on spherical fuzzy sets was developed for the selection of applications to teach children coding. This selection problem involves uncertainty. Coding education, which has been included to start in the elementary school curriculum, gives children an edge in their analytical thinking, creativity and problem-solving skills, as well as success in computer science. Studies have shown that children who learn coding can create more practical solutions to the problems they encounter, and they are better at evaluating the results. Coding education also has a structure that sets goals for success and makes it intriguing for children who achieve these goals step by step. In recent years, developments in the area of coding has led to diversity in user profiles. Platforms have been created for children in the field of coding, and fun and instructive software has been designed to appeal to their level. However, the fact that each software program has different features makes it difficult to choose an appropriate environment for children. It is necessary to determine the objectives of using the software in coding education and to choose the appropriate software program accordingly. Comparison and selection of these software programs is very important and requires the utmost diligence. Educational software should be suitable for the development of the child in a way that they can make progress according to their own pace and knowledge levels. Choosing the right coding software is also very important in terms of contributing to the learning of students who will use the software, achieving the teaching goals, keeping the students' attention focused and boosting their motivation.
In this research, case study included four criteria, three sub criteria under each criterion, and four alternatives were presented. This decision model integrated the analytic hierarchy process (AHP) with spherical fuzzy sets. The difference in this study is that, for the first time, SF-AHP was used to choose from among the platforms that teach coding to children. In addition, the results in this study were cross-checked using the Pythagorean fuzzy AHP method, and the two methods were compared to overcome uncertainty and achieve optimum results. SF-AHP enables decision makers to independently reflect their uncertainty in the decision process by using a linguistic evaluation scale based on spherical fuzzy sets. Following the introduction in Part 1 which summarizes a literature review on fuzzy AHP, this study consists of the following sections: Part 2 includes the proposed multi-criteria decision-making (MCDM) technique and the spherical fuzzy AHP method (SF-AHP). Part 3 applies the SF-AHP method to the problem of selecting a platform to teach coding to children and it includes the comparative analysis of SF-AHP and Pythagorean Fuzzy Analytic Hierarchy Processes (PFAHP), and finally, conclusions are drawn on the findings and some evaluations are made in Part 4.

The notion that 'Everything is a ranking problem' forms the basis for fuzzy logic. In other words, fuzzy logic deals with the degree of occurrence of events rather than with the probability of occurrence. Fuzzy logic uses linguistic variables such as 'cold', 'warm', 'few', 'very few', similar to when one person is talking to another or explaining something. Fuzzy logic can be called the real-life application of mathematics [6]. A fuzzy set is a class of objects that has a continuity of membership degrees. Such a set is characterized by a membership function that assigns a membership degree ranging from zero to one for each object. Fuzzy sets and fuzzy logic are powerful mathematical tools for modeling commonsense reasoning in the decision-making process without complete and precise knowledge of uncertain systems in industry, nature and humanity. Their role is important when applied to complex phenomena that cannot be easily described by traditional mathematical methods, especially when the goal is to find a good approximate solution [7].

Providing a broader framework than classical set theory, fuzzy set theory contributes to the ability to reflect the real world [8]. Modeling using fuzzy sets has proven to be an effective way to formulate decision-making problems when available information is subjective and uncertain [9]. With the increase of type-2 fuzzy logic studies since the late 1990s, fuzzy logic theory, which has been used in fuzzy logic applications up to the current time, is now regarded as type-1 fuzzy logic for the first time in published literature [10]. Fuzzy logic theory is based on computation with fuzzy sets, which is an extension of classical sets called 'sharp sets' in the context of fuzzy logic. In classical set theory, in those cases where each object may or may not be an element of a particular set, the membership of each object in a particular set is determined by a degree, called 'membership degree'. In type-1 fuzzy sets, the membership degree is defined by a definite number within the interval [0,1], whereas in type-2 fuzzy sets, the membership degree is fuzzy in itself and is generally considered to be a secondary membership function. If the secondary membership function is – at most – 1 at each point, it has a type-2 set range. Thus, type-2 fuzzy sets contain a third dimension and an area occupied by some uncertainty, and it provides an extra degree of freedom to overcome those uncertainties. Type-2 fuzzy logic, a new expansion of fuzzy logic, can model uncertainties and reduce their effect due to the fuzzy membership function and its third dimension. When the uncertainties disappear, type-2 fuzzy logic can be reduced to type-1 fuzzy logic.

The concept of a type-2 fuzzy set was introduced by Zadeh as an extension of an ordinary fuzzy set (type-1 fuzzy set). These sets are fuzzy sets whose membership degrees are themselves type-1 fuzzy sets; they are very useful in situations where it is difficult to determine the full membership function for a fuzzy set. Therefore, they are useful in including uncertainty [11]. After Zadeh's (1965) pioneering work, fuzzy set theory has been expanded in several directions [12]. Recently, based on expanded forms of the fuzzy set, Torra proposed a new generalized fuzzy set called the hesitant fuzzy set (HFS), which provides new perspectives for further research on decision making in uncertain environments [13]. HFS provides many advantages compared to the traditional indefinite set and its other extensions, especially in group decision making with anonymity [14]. Torra also defined the complement, union and intersection of HFSs. Torra and Narukawa (2009) presented an extension principle allowing existing operations on fuzzy sets to be generalized to HFSs and described the implementation of this new set in the decision-making framework. Since the possible values of membership degrees in an HFS are random, the HFS is somewhat more natural than any other expansion of the fuzzy set as regards uncertainty and its representation. It should be noted that modeling fuzzy information with other forms of expanded fuzzy sets is based on obtaining single or range values that should include and express the information provided by decision makers (or experts) when determining the membership of an object to another object [15]. As Yu (1973) points out, “When a group of individuals plan to form a company with themselves as shareholders or form a union to increase their total bargaining power, they often find some disagreement among themselves. Conflicts are different from subjective evaluations of emerging decision-making problems”. Since decision makers (or experts) could have different views on alternatives due to their different knowledge or experience, and cannot easily convince each other, it can sometimes be difficult to get a consensus, but there are several possible assessment values. HFS is suitable for solving this problem and is more powerful than any other extended fuzzy set [16]. In intuitionistic fuzzy sets (IFS), the computational complexity is greater because two types of uncertainties are involved. However, when better results are desirable, especially in the diagnosis of medical images where uncertainty is high, it becomes easier to obtain accurate results. Therefore, researchers try to use it in real-time practices [17].

While Zadeh’s fuzzy set theory was modeled to show only the degree of membership defined in the range of [0,1], Atanassov’s intuitionistic fuzzy set theory also defined the degree of non-membership in addition to the membership degree. In the intuitionistic fuzzy set theory, both membership and non-membership degrees are in the range [0,1]. Looking from this point of view, the sum of membership and non-membership degrees in traditional fuzzy set theory is calculated to be 1. However, the sum of these two parameters need not be 1 in intuitionistic fuzzy set theory. The intuitionistic fuzzy set is a powerful tool in case of uncertainty. A prominent feature of the intuitionistic fuzzy set is that it assigns a membership degree and a non-membership degree to each element, and therefore it constitutes an extension of Zadeh’s fuzzy set, which assigns only one membership degree to each element. When published literature was examined, studies related to the method in question included Bustince et al. who defined some intuitionistic fuzzy generators and investigated the presence of equilibrium points and binary points, Szmidt and Kacprzyk’s study of an unlikely type of entropy measurement for A-IFSs, Mondal and Samantaîn’s introduction of the concept of intuitionistic openness grading on fuzzy subsets of a non-empty set and studies for intuitionistic fuzzy topological field definition [18]. In addition, Deschrijver and Kerre established the relationships between A-IFS fuzzy sets, range-valued fuzzy sets and range-valued A-IFSs, while Bustince and Burillo, and Deschrijver and Kerre, investigated the composition of intuitionistic fuzzy relationships. Dudek et al. considered the intuitionistic fuzziness of the concept of sub-hyper quasigroups in a hyper quasigroup and explored some properties of such sub-hyper quasigroups.

In the decision-making process, decision makers can make their own assessment of each of the alternatives. Some factors that affect decision makers in an uncertain environment cause them to be unable to determine exact values. Fuzzy logic is applied to deal with those uncertainties. The Pythagorean fuzzy set is built on two basic functions. These are membership and non-membership functions. Pythagorean fuzzy set logic is more concerned with the uncertainty of these two basic functions. It helps to model the uncertainties and subjective statements of decision makers in the best way [19]. The Pythagorean fuzzy set generalized by Yager is a new tool for overcoming uncertainty given the degree of membership μ meeting the condition μ2 + ν2≤1 and the non-membership value ν. Pythagoras fuzzy sets (PFS) are an effective generalization of the intuitionistic fuzzy set with a membership value and the square sum of these values is less than or equal to 1 [20]. AHP is a powerful and flexible MCDM tool that constructs a complex decision-making problem hierarchically at several different levels considering both qualitative and quantitative features [21]. AHP combines both subjective and objective evaluations in a holistic framework based on ratio scales in simple pairwise comparisons and helps the analyst to organize critical aspects of a problem in a hierarchical structure. MCDM can measure the consistency of the decisions of a decision-maker. Instead of measuring weights, two-way comparisons allow weights of criteria and alternative scores to be derived from comparison matrices. AHP helps decision-makers organize the criteria and sub criteria of a problem in a hierarchical structure similar to a family tree [22]. In the classical method, the evaluations of decision makers are represented as definite numbers. Nevertheless, fuzzy logic provides a mathematical capability that can be used to capture the uncertainties accompanying the human cognitive process in cases where decision makers cannot express their evaluations with definite numbers [23]. Therefore, the original AHP method has been extended to several fuzzy versions with the aim of improvements in spite of missing information and uncertainties.

2. MATERIALS AND METHODS

The proposed spherical fuzzy AHP method in this study consists of several steps described in the following section. The flow chart for the method used in Figure 2 (in part 3) is shown to clearly illustrate the principles of the study.

- Step 1. A hierarchical structure is created.

- Step 2. Two-way comparisons are constructed using spherical fuzzy judgment matrices based on the linguistic terms given in Table 1. Equations (1) and (2) are used to obtain the score indices (SI) in Table 1.

Table 1. Linguistic measures of importance

Linguistic measures of importance used for pairwise comparisons		
	(μ, υ, π)	Score Index (SI)
Absolutely more important (AMI)	(0.9, 0.1, 0.0)	9
Very high importance (VHI)	(0.8, 0.2, 0.1)	7
High importance (HI)	(0.7, 0.3, 0.2)	5
Slightly more important (SMI)	(0.6, 0.4, 0.3)	3
Equally important (EI)	(0.5, 0.4, 0.4)	1
Slightly low importance (SLI)	(0.4, 0.6, 0.3)	1/3
Low importance (LI)	(0.3, 0.7, 0.2)	1/5
Very low importance (VLI)	(0.2, 0.8, 0.1)	1/7
Absolutely low importance (ALI)	(0.1, 0.9, 0.0)	1/9

$$SI = \sqrt{\left|100 * \left[(\mu_{\tilde{A}_s} - \pi_{\tilde{A}_s})^2 - (\upsilon_{\tilde{A}_s} - \pi_{\tilde{A}_s})^2\right]\right|}$$

for AMI, VHI, HI, SMI, and EI (1)

$$\frac{1}{SI} = \frac{1}{\sqrt{\left|100 * \left[(\mu_{\tilde{A}_s} - \pi_{\tilde{A}_s})^2 - (\upsilon_{\tilde{A}_s} - \pi_{\tilde{A}_s})^2\right]\right|}}$$

for EI, SLI, LI, VLI and ALI (2)

- Step 3. The consistency of pairwise comparison matrices is checked.
- Step 4. The spherical fuzzy local weights for criteria and alternatives are calculated.

Using the SWAM operator given in Equation (3), the weight of each alternative is then determined.

$$SWAM_w (A_{SI}, \dots, A_{Sn}) = \left\langle \left[1 - \prod_{i=1}^{n} (1 - \mu^2_{A_{si}})^{wi}\right]^{\frac{1}{2}}, \prod_{i=1}^{n} (\upsilon^{wi}_{A_{si}}), \left[\prod_{i=1}^{n} (1 - \mu^2_{A_{si}})^{wi} - \prod_{i=1}^{n} (1 - \mu^2_{A_{si}} - \pi^2_{A_{si}})^{wi}\right]^{\frac{1}{2}} \right\rangle$$

where $w = 1/n$. (3)

- Step 5. A hierarchical ranking of layers is created to obtain overall weights.

Criterion weights are made fuzzy using equation (4) and the score function (S).
It is normalized by equation (5).
The spherical fuzzy product given by Eq. (6) is applied.

$$S(\tilde{w}_j^s) = \sqrt{\left|100 * \left[(3\mu_{\tilde{A}_s} - \frac{\pi_{\tilde{A}_s}}{2})^2 - (\frac{\upsilon_{\tilde{A}_s}}{2} - \pi_{\tilde{A}_s})^2\right]\right|} \quad (4)$$

$$\bar{w}_j^s = \frac{S(\tilde{w}_j^s)}{\sum_{j=1}^{n} S(\tilde{w}_j^s)} \quad (5)$$

$$\tilde{A}_{sij} = \bar{w}_j^s . \tilde{A}_{s_i} = \left\langle \left(1 - (1 - \mu^2_{\tilde{A}_s})^{\bar{w}_j^s}\right), \upsilon_{\tilde{A}_s}^{\bar{w}_j^s}, \left((1 - \mu^2_{\tilde{A}_s})^{\bar{w}_j^s} - (1 - \mu^2_{\tilde{A}_s} - \pi_{\tilde{A}_s}{}^2)^{\bar{w}_j^s}\right)^{\frac{1}{2}} \right\rangle \ \forall i \quad (6)$$

The final spherical fuzzy AHP score ($\tilde{F}$), for each alternative A_i, is obtained by carrying out the spherical fuzzy arithmetic addition over each global preference weights, as given in Eq. (7)

$$\tilde{F} = \sum_{j=1}^{n} \tilde{A}_{S_{ij}} = \tilde{A}_{S_{i1}} \oplus \tilde{A}_{S_{i2}} \dots \oplus \tilde{A}_{S_{in}} \ \forall i \quad (7)$$

i.e. $\tilde{A}_{S_{11}} \oplus \tilde{A}_{S_{12}} =$

$$\left\langle (\mu^2_{\tilde{A}_{S_{11}}} + \mu^2_{\tilde{A}_{S_{12}}} - \mu^2_{\tilde{A}_{S_{11}}}\mu^2_{\tilde{A}_{S_{12}}})^{1/2}, \upsilon_{\tilde{A}_{S_{11}}}\upsilon_{\tilde{A}_{S_{12}}}, \left((1 - \mu^2_{\tilde{A}_{S_{12}}})\pi^2_{\tilde{A}_{S_{11}}} + (1 - \mu^2_{\tilde{A}_{S_{11}}})\pi^2_{\tilde{A}_{S_{12}}} - \mu^2_{\tilde{A}_{S_{11}}}\mu^2_{\tilde{A}_{S_{12}}}\right)^{1/2} \right\rangle$$

- Step 6. The final score for each alternative is determined using the score function given by Eq. (4).
- Step 7. Alternatives are ranked according to their point scores. The largest value indicates the best solution [24].

3. FINDINGS

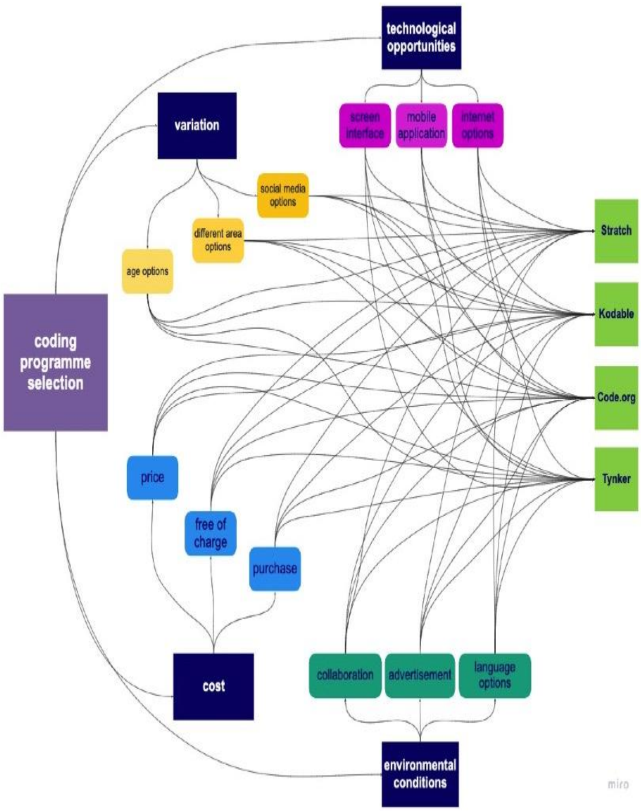

Figure 2. Hierarchical structure for the main and sub criteria

Two-way comparisons are constructed using spherical fuzzy judgment matrices and results are given below. Pairwise comparison of main criteria is given in Table 2.

This study was conducted to compare and select a software program to be used to educate children in coding. A comparison and selection of this software is very important and should be done diligently. Four main criteria and 12 sub-criteria are investigated in the study. The main criteria were determined to be C1: Technology, C2: Diversity, C3: Price and C4: Environmental Factors. Figure 2 shows the hierarchical structure showing the main criteria and sub criteria. The main and sub criteria were evaluated according to the linguistic terms given in Table 1 by the decision-making expert group. Pairwise comparison matrices were calculated according to the corresponding numerical values in the classical AHP method for the linguistic scale given in Table 1. Paired comparisons and the spherical weights obtained are given in Tables 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17 and 18. Table 19 shows the weights of the alternatives according to the spherical fuzzy evaluation. The ranking of the alternatives compared is given in Table 20.

Table 2. Pairwise comparison of main criteria

Criteria		w^s		w
C1	0.77	0.22	0.18	0.37
C2	0.56	0.43	0.29	0.25
C3	0.50	0.49	0.28	0.23
C4	0.34	0.65	0.26	0.15

Using Eq. (4), w^s scores were obtained and the results are given below.

Table 3. Pairwise comparison caused by technological opportunities

C1		w^s		w
C11	0.49	0.48	0.32	0.30
C12	0.39	0.58	0.31	0.24
C13	0.70	0.29	0.24	0.46

Table 4. Pairwise comparison caused by variation

C2		w^s		w
C21	0.71	0.29	0.23	0.43
C22	0.67	0.32	0.27	0.39
C23	0.33	0.66	0.27	0.18

Table 5. Pairwise comparison caused by cost

C3		w^s		w
C31	0.79	0.20	0.18	0.49
C32	0.35	0.63	0.28	0.20
C33	0.53	0.46	0.27	0.31

Table 6. Pairwise comparison caused by environmental conditions

C4		w^s		w
C41	0.38	0.60	0.31	0.22
C42	0.48	0.50	0.31	0.28
C43	0.79	0.20	0.18	0.50

Table 7. Pairwise comparison of alternatives caused by ease of display screen interface

C11		w^s		w
A1	0.67	0.31	0.25	0.32
A2	0.50	0.49	0.27	0.23
A3	0.35	0.63	0.27	0.16
A4	0.60	0.38	0.28	0.29

Table 8. Pairwise comparison of alternatives caused by use of mobile application

C12		w^s		w
A1	0.77	0.22	0.18	0.37
A2	0.64	0.36	0.24	0.29
A3	0.44	0.55	0.29	0.19
A4	0.35	0.64	0.28	0.15

Table 9. Pairwise comparison of alternatives caused by use offline

C13		w^s		w
A1	0.57	0.41	0.30	0.28
A2	0.49	0.49	0.33	0.23
A3	0.61	0.37	0.30	0.30
A4	0.39	0.59	0.30	0.18

Table 10. Pairwise comparison of alternatives caused by age options

C21		w^s		w
A1	0.43	0.54	0.33	0.20
A2	0.54	0.44	0.33	0.26
A3	0.55	0.40	0.35	0.27
A4	0.55	0.40	0.35	0.27

Table 11. Pairwise comparison of alternatives caused by different area options

C22		w^s		w
A1	0.65	0.35	0.25	0.30
A2	0.49	0.51	0.26	0.22
A3	0.71	0.28	0,.23	0.33
A4	0.33	0.65	0.26	0.14

Table 12. Pairwise comparison of alternatives caused by use of social media options

C23		w^s		w
A1	0.44	0.51	0.35	0.21
A2	0.64	0.35	0.28	0.32
A3	0.44	0.51	0.35	0.21
A4	0.54	0.44	0.33	0.26

Table 13. Pairwise comparison of alternatives caused by price

C31		w^s		w
A1	0.39	0.57	0.32	0.17
A2	0.68	0.31	0.23	0.32
A3	0.39	0.57	0.32	0.17
A4	0.71	0.28	0.23	0.34

Table 14. Pairwise comparison of alternatives caused by being free of charge

C32		w^s		w
A1	0.69	0.28	0.26	0.33
A2	0.43	0.57	0.28	0.19
A3	0.69	0.28	0.26	0.33
A4	0.36	0.63	0.28	0.16

Table 15. Pairwise comparison of alternatives caused by opportunity to purchase

C33		w^s		w
A1	0.75	0.24	0.23	0.33
A2	0.31	0.69	0.25	0.13
A3	0.75	0.24	0.23	0.33
A4	0.48	0.53	0.25	0.21

Table 16. Pairwise comparison of alternatives caused by collaboration

C41		w^s		w
A1	0.65	0.35	0.25	0.30
A2	0.35	0.64	0.28	0.15
A3	0.76	0.24	0.21	0.36
A4	0.44	0.55	0.29	0.19

Table 17. Pairwise comparison of alternatives caused by advertisement

C42		w^s		w
A1	0.76	0.24	0.21	0.35
A2	0.32	0.67	0.25	0.14
A3	0. 65	0.35	0.25	0.30
A4	0.48	0.52	0.26	0.22

Table 18. Pairwise comparison of alternatives caused by language options

C43		w^s		w
A1	0.75	0.24	0.23	0.35
A2	0.37	0.61	0.30	0.16
A3	0.66	0.31	0.28	0.30
A4	0.42	0.58	0.28	0.19

Spherical fuzzy weight matrix based on fuzzy approach is given in Table 19.

Table 19. Spherical fuzzy weight matrix based on fuzzy approach

	C11	C12	C13	C14	C21	C22	C23	C24	C31	C32	C33	C34
	0.26	0.19	0.13	0.23	0.20	0.15	0.11	0.18	0.36	0.27	0.19	0.32
A1	0.58	0.67	0.75	0.61	0.65	0.72	0.79	0.68	0.46	0.58	0.69	0.51
	0.38	0.37	0.34	0.39	0.37	0.35	0.32	0.37	0.35	0.35	0.33	0.36
	0.19	0.14	0.10	0.17	0.15	0.11	0.08	0.13	0.26	0.19	0.14	0.23
A2	0.66	0.72	0.79	0.68	0.71	0.77	0.82	0.73	0.57	0.66	0.74	0.60
	0.40	0.38	0.35	0.40	0.38	0.36	0.33	0.37	0.38	0.37	0.34	0.39
	0.17	0.12	0.09	0.15	0.13	0.10	0.07	0.12	0.24	0.18	0.12	0.21
A3	0.69	0.75	0.80	0.71	0.74	0.78	0.83	0.75	0.61	0.69	0.76	0.64
	0.38	0.36	0.33	0.38	0.36	0.34	0.32	0.36	0.37	0.36	0.33	0.37
	0.11	0.08	0.06	0.10	0.09	0.07	0.05	0.08	0.16	0.12	0.08	0.14
A4	0.77	0.81	0.86	0.79	0.81	0.84	0.88	0.82	0.72	0.77	0.82	0.74
	0.34	0.32	0.30	0.34	0.32	0.31	0.28	0.32	0.34	0.32	0.30	0.34

Score values and ranking obtained from SF-AHP approach is given in Table 20.

Table 20. Score values and ranking obtained from SF-AHP Approach

Alternatives	Score Value	Ranking
A1	28.13	4
A2	28.73	3
A3	28.91	2
A4	29.42	1

Tepe et al. (2020) suggested a fuzzy-based risk assessment model to evaluate hazards in a real-case study using PFAHP. Pythagorean AHP and Neutrosophic AHP were successfully proposed in their work. In this study, the proposed methodology was compared with PF-AHP for the coding program selection. Table 21 presents the Pythagorean linguistic scale, which was used for the comparison purpose.

Table 21. Weighting scale for the PF-AHP method [25]

Linguistic terms	PFN equivalents			
	IVPF numbers			
	μ_L	μ_U	V_L	V_U
Certainly Low Importance - CLI	0	0	0.9	1
Very Low Importance - VLI	0.1	0.2	0.8	0.9
Low Importance - LI	0.2	0.35	0.65	0.8
Below Average Importance - BAI	0.35	0.45	0.55	0.65
Average Importance - AI	0.45	0.55	0.45	0.55
Above Average Importance - AAI	0.55	0.65	0.35	0.45
High Importance - HI	0.65	0.8	0.2	0.35
Very High Importance - VHI	0.8	0.9	0.1	0.2
Certainly High Importance - CHI	0.9	1	0	0
Exactly Equal - EE	0.197	0.197	0.197	0.197

The results obtained according to the PF-AHP method are given in Table 22. According to the results obtained from this method, alternative A4 is in first place.

Table 22. Score values and ranking obtained from the PF-AHP approach

Alternatives	Score Value	Ranking
A1	0.118	2
A2	0.116	3
A3	0.100	4
A4	0.148	1

According to the SF-AHP method, the ranking was A4, A3, A2, A1, and according to the PF-AHP method, it was A4, A1, A2, A3. The coding program named Tynker – represented by A4 – is in first place in both methods. The main reason for the difference in rankings is the different assumptions for the two theories. The comparison of the rankings according to both methods is given in Table 23.

Table 23. Comparative ranking values

Alternatives	SF-AHP Ranking	PF-AHP Ranking
A4	1	1
A3	2	4
A2	3	3
A1	4	2

4. DISCUSSION AND CONCLUSION

Children will be able to make better use of their problem-solving skills on issues they will encounter throughout their educational life thanks to the coding knowledge they learn at an early age. Coding software programs designed according to the developmental levels of children aim their presentation to children by using motivational methods that operate through play instead of teaching coding directly. Today, experts are trying to design coding software in a way that is less complex and can be enjoyed by children. There are many parameters to be considered in these studies. In this study, treating the problem as Multi-Criteria Decision Making allows more accurate decisions to be made, as it includes many dimensions simultaneously.

Ease of user interface, availability of a mobile application, availability of the program when it is offline, choosing designs suitable for the age levels of the children, as well as many other criteria such as the program's pay/free/purchase options or language options are the topics that software developers should consider. The aforementioned criteria – and more – have been generated from the problems and experiences encountered in coding program selection for children. In this study, these parameters were determined as the main criteria and sub-criteria, and leading brands in the sector were compared according to these criteria.

In the study, the problem of coding program selection for children was successfully solved with SF-AHP and compared by PF-AHP cross-checking. Addressing the problem as SF and PF allows for more precise and more flexible assessments. In addition, in this way, human subjective evaluations can be easily adapted to the process.

Some differences were observed in the rankings due to the different assumptions between both methods and the linguistic scales they used. The use of fuzzy logic in this study eased the evaluation process, which is difficult for decision makers because of the differences in coding program selection criteria and measurements. The educational programming platform 'Tynker' was determined to be the best alternative using both these methods.

In future studies, SF-AHP can be compared with other multi-criteria decision-making extensions, such as intuitionistic fuzzy or hesitant fuzzy sets. In addition, the methodology suggested can be used in evaluation processes for different problems and its robustness can also be tested for different decision-making problems.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study has received no financial support.

REFERENCES

[1] Saaty, T. L., (1986), Axiomatic Foundation of the Analytic Hierarchy Process, Management Science, 32 (7), 841-855.

[2] Keskenler M.F. ve Keskenler E.F., (2017). Bulanık Mantığın Tarihi Gelişimi, Takvim-i Vekayi, 5(1),1-10.

[3] Torra, V., (2010). Hesitant Fuzzy Sets, International Journal of Intelligent Systems, 25,529–539.

[4] Rodriguez, R.M., Martinez, L. ve Herrera, F., (2013). A Group Decision Making Model Dealing with Comparative Linguistic Expressions Based on Hesitant Fuzzy Linguistic Term Sets, Information Sciences, 241,28-42.

[5] Kutlu Gündoğdu, F., Kahraman, C. (2019). A Novel Fuzzy TOPSIS Method Using Emerging Interval-Valued Spherical Fuzzy Sets. Engineering Applications of Artificial Intelligence 85, 307–323.

[6] Zadeh, L. A. (1975). Fuzzy Logic and Approximate Reasoning. Synthese, 30 (3-4), 407-428.

[7] Bojadziev G., Bojadziev M. (1998). Fuzzy Sets, Fuzzy Logic, Applications, World Scientific, London.

[8] Ertuğrul, İ., Tuş, A. (2007). Interactive Fuzzy Linear Programming and an Application Samplat a Textile Firm. Fuzzy Optimization and Decision Making, 6(1), 29-49.

[9] Zimmermann, H. J. (1992). Methods and Applications of Fuzzy Mathematical Programming. In an Introduction to Fuzzy Logic Applications n Intelligent Systems 97-120. Springer, Boston, MA.

[10] Wu, D., Mendel, J. M. (2008). A Vector Similarity Measure for Linguistic Approximation: Interval Type-2 and Type-1 Fuzzy Sets. Information Sciences, 178(2), 381-402.

[11] Castillo, O., Melin, P., Kacprzyk, J., Pedrycz, W. (2007). Type-2 Fuzzy Logic: Theory and Applications. IEEE International Conference on Granular Computing (GRC 2007),145-147. IEEE.

[12] Xu, Z. (2014). Hesitant Fuzzy Sets Theory (Vol. 314). Cham: Springer International Publishing.

[13] Torra, V. (2010). Hesitant Fuzzy Sets. International Journal of Intelligent Systems, 25(6), 529- 539.

[14] Tepe, S., Kaya, I. (2019) A Fuzzy-Based Risk Assessment Model for Evaluations of Hazards with a Real-Case Study, Human and Ecological Risk Assessment: An International Journal, 26(2), 512-537, DOI: 10.1080/10807039.2018.1521262

[15] Rodriguez, R. M., Martinez, L., Herrera, F. (2011). Hesitant Fuzzy Linguistic Term Sets for Decision Making. IEEE Transactions on Fuzzy Systems, 20(1), 109-119.

[16] Wang, F., Li, X., Chen, X. (2014). Hesitant Fuzzy Soft Set and Its Applications in Multicriteria Decision Making. Journal of Applied Mathematics.

[17] Bustince, H., Burillo, P. (1996). Vague Sets are Intuitionistic Fuzzy Sets. Fuzzy Sets and Systems,79(3), 403-405.

[18] Mondal, T. K., Samanta, S. K. (1999). Topology of Interval-Valued Fuzzy Sets. Indian Journal of Pure and Applied Mathematics, 30, 23-29.

[19] Tepe, S., Kaya, I. (2018). A New Risk Assessment Methodology by Using Pythagorean Fuzzy Analytic Hierarchy Process. 12th International Conference on Challenges in Industrial Engineering and Operations Management, 110.

[20] Yager, R. R. (2013). Pythagorean Fuzzy Subsets. In 2013 Joint IFSA World Congress And NAFIPS Annual Meeting (IFSA/NAFIPS) , 57-61. IEEE.

[21] Lee, A. H., Chen, W. C., Chang, C. J. (2008). A Fuzzy AHP and BSC Approach for Evaluating Performance of IT Department in the Manufacturing Industry in Taiwan. Expert Systems with Applications, 34(1), 96-107.

[22] Kumar, N. V., Ganesh, L. S. (1996). An Empirical Analysis of the Use of the Analytic Hierarchy Process for Estimating Membership Values in a Fuzzy Set. Fuzzy Sets and Systems, 82(1), 1-16.

[23] Kahraman C., Kaya I. (2010). A Fuzzy Multicriteria Methodology for Selection Among Energy Alternatives. Expert Systems with Applications, 37(9), 6270–6281

[24] Kutlu Gündoğdu, F., Kahraman, C. (2020). A Novel Spherical Fuzzy Analytic Hierarchy Process and Its Renewable Energy Application. Soft Computing 24, 4607–4621 https://doi.org/10.1007/s00500-019-04222-w

[25] Ilbahar, E., Karaşan, A., Cebi, S., Kahraman, C. (2018). A Novel Approach to Risk Assessment for Occupational Health and Safety Using Pythagorean Fuzzy AHP Fuzzy Inference System. Safety Science, 103, 124-136.

Research Paper
Academic Platform Journal of Engineering and Smart Systems (APJESS) 11(1), 19-26, 2023
ISSN: 2822-2385
Received: 24-Jul-2022 Accepted: 05-Dec-2022
https://doi.org/10.21541/apjess.1137177

Forecasting the Impact of Vaccination on Daily Cases in Türkiye for Covid-19

*[1]Enes YILDIZ, [2]Muhammed Mustafa KELEK, [3]Fatih Onur HOCAOĞLU, [4]Yüksel OĞUZ

[1] Department of Electrical and Electronic Engineering, Afyon Kocatepe University, Afyon, Türkiye, enesyildiz@aku.edu.tr
[2] Department of Electrical and Electronic Engineering, Afyon Kocatepe University, Afyon, Türkiye, mmustafakelek@aku.edu.tr
[3] Department of Electrical and Electronic Engineering, Afyon Kocatepe University, Afyon, Türkiye, fohocaoglu@gmail.com
[4] Department of Electrical and Electronic Engineering, Afyon Kocatepe University, Afyon, Türkiye, yukseloguz@aku.edu.tr

Abstract

In this study, it is aimed to investigate the effect of the vaccine on the cases in the fight against Covid-19, which threatens the whole world. The number of Covid-19 cases, which were tried to be reduced with various precautions all over the world and in Türkiye, has become a new hope with the start of vaccination. The increase in the effect of the vaccination, which started in January 2021, brought the need to examine the vaccination rate in three groups as slow, medium and fast. In this study, different scenarios were tried in the number of vaccinations applied in Türkiye, and the daily number of cases until December 2021 was forecasted by Artificial Neural Networks (ANN). The effect of restrictions and vaccination on the number of Covid-19 cases was investigated. Different training algorithms were used and the best success rate was found with the comparison method. Accurate forecasting of cases will let policy makers to take precautions on time. Moreover, the effect of vaccination on cases should be investigated.

Keywords: Covid-19, Forecasting, Artificial Intelligence, Artificial Neural Networks (ANN), Daily Case.

1. INTRODUCTION

New studies and developments are constantly being carried out in the fight against the coronavirus (Covid-19) pandemic, which has been affecting worldwide for about two years. The Covid-19 epidemic, which emerged in Wuhan, on December 1, 2019, has spread worldwide over time. When the disease was seen in other countries, the World Health Organization (WHO) declared a pandemic on January 30, 2020 [1,2]. A new state of panic has occurred in the world with the confirmation of Italy's first case on January 31, 2020. WHO declared that Europe is the epicenter of the Covid-19 crisis on March 13, 2020. The deaths in Italy on March 19, 2020, leaving behind China, where the disease started, brought about the danger of the disease and the need to find treatment as soon as possible.

The precautions at the beginning of the pandemic are mostly mask, distance and cleanliness. In addition, various restrictions have been introduced. Human mobility was reduced with various restrictions to prevent the spread of the pandemic. Thus, it aimed to increase the protection of people with weakened immunity against the possibility of contamination. Although the restrictions seem to be beneficial in reducing the risk of transmission, they affected negatively in many areas such as the country's economy, people's lifestyles, education systems, etc. The states applied some restrictions against the possibility of the collapse of the health systems when the number of seriously ill patients increased. The first Covid-19 case was detected in a Turkish citizen who returned from a European trip in Türkiye on the night of 10 March 2020. The first Covid-19 case seen in Türkiye has brought some restrictions. Serious restrictions have been started to be considered due to reasons such as lack of information about the virus, the health infrastructure not being ready for Covid-19, and the lack of certain treatment methods. Most of the countries tried to prevent the epidemic by restricting mobility at the beginning of the pandemic. Restrictions slowed the pace of the epidemic and reduced the number of daily cases. Although restrictions reduce the risk of transmission, they cannot eliminate the disease. Thus, some vaccine studies developed for the treatment of the disease. Vaccine studies, which have been actively implemented, are becoming widespread day by day. It has been observed that some precautions such as the obligation to wear masks in the open air have been removed in some countries where vaccination is sufficient. Looking at this information, it is understood that the vaccine is the most important factor in the fight against Covid-19.

In this study, the effect of vaccination and restriction on the number of daily cases was investigated. The daily number of cases was forecasted by considering the weekend & evening curfews, partial & full closure, and controlled normalization periods applied from March 2020 to July 2021. The success rates obtained using different training functions were compared for these estimations. The effect of Covid-19 vaccination was included in the study with the start of vaccination in Türkiye on January 13, 2021. The purpose of this study; is by determining the number of cases for the future, reduce the hospital density, and direct the restrictions to be taken according to the number of cases. In addition, it is to raise people's awareness by explaining the effect of vaccination on the number of cases.

2. LITERATURE REVIEW

The lack of information about the Covid-19 allowed many studies. As a result of each research, new various findings were obtained. Daniel mentions the damage of Covid-19 to education. He aimed to minimize these damages caused by Covid-19 and ensure the education sector's continuity with his proposal [3]. When Covid-19 first appeared in Wuhan, it could not determine the diagnosis of Covid-19 quickly due to reasons such as the world was not ready for such an epidemic, the necessary precautions were not taken, and the epidemic spread rapidly. Alazab et al. diagnosed Covid-19 disease using Deep Convolution Neural Network (CNN). They completed the detection process by obtaining an F-score between 95-99% in their data consisting of 1000 chest X-rays. In addition, using 3 different forecasting algorithms, they estimated the number of patients who will get Covid-19 disease in 7 days [4,5].

Najmul Hasan used a hybrid structure consisting of Ensemble Empirical Mode Decomposition (EEMD) and ANN for Covid-19 case detection. He examined the period between 22 January and 18 May 2020. In his examination, he decomposed the signals with EEMD and separated them from their noise. After this process, he trained with ANN. The result of his training gave better results than traditional methods [6]. Ardabili et al. estimate the number of Covid-19 cases globally with the Grey Wolf Optimizer based ANN. They used the cases for training between January 22 and September 15, 2020, and the number of cases between September 16 and October 15, 2020, for testing. They obtained 6.23 Mean Absolute Percentage Error (MAPE) in their training and 13.15 MAPE results in the test process [7].

Ozen et al. estimated the number of cases for the USA using the Python and R programming languages. They compared the error rates of algorithms such as polynomial regression and linear regression. As a result, they suggested that the estimations should be made with polynomial regression since the error rate of the linear regression algorithm was low [8]. Ankaralı et al. forecasted the number of intensive care beds and respiratory devices for April 2020 with Gompertz and Time-series models. They made an estimation of the number of intensive care patients per day for a month [9]. Rustam and friends forecast the number of Covid-19 cases using the MLS model in their study named Covid-19 Future Forecasting Using Supervised Machine Learning Models. Standard estimation methods such as Linear Regression (LR), Support Vector Machine (SVM), and Exponential Smoothing (ES) were also used in their estimations [10].

Sahai et al. made predictions for some countries such as the USA, Brazil, India, Russia, and Spain. They used the ARIMA model and the Hannan and Rissanen algorithm [11]. The IHME Covid-19 health service utilization forecasting team estimated the number of beds, the number of intensive care unit's beds, and the number of intubated devices in the health infrastructure depending on the Covid-19 disease using a statistical method [12]. Turan et al., In their study, estimated the 5-day COVID-19 Death Numbers in Turkey with ANN. Their study using the ANFIS model predicted the number of deaths in the next 5 days with a 96% accuracy rate [13]. Selvi and Başer, in their study, tried to predict the weekly death numbers for the future by using Facebook's Prophet model. They made their predictions for 15 different periods [14]. Namusudra at al. in their study proposes a novel Nonlinear Autoregressive (NAR) Neural Network Time Series (NAR-NNTS) model for forecasting COVID-19 cases. The results showed that NAR-NNTS model trained with LM training algorithm performs better than other models for COVID-19 epidemiological data prediction [15]. Eroğlu uses artificial neural network (ANN) and deep learning models to predict Covid-19 cases 7 days in advance. It was also found that ANN was successful in Covid-19 case prediction [16]. Fanelli and Piazza analyze the temporal dynamics of the coronavirus disease 2019 outbreak in China, Italy, and France in the time window. Their study's first aim is to provide officials with realistic estimates for the time and magnitude of the epidemic peak, i.e., the maximum number of infected individuals [17].

3. MATERIALS AND METHODS

3.1. Artificial Neural Network Model

Artificial Neural Networks (ANN) is a system that imitates the working structure of the human brain and is inspired by the nervous system [18,19, 20]. The ANN is the definition of functions such as thinking like a human, making decisions, analyzing, and comparing to machines. The machines also enter the learning phase like humans and gain experience with the help of ANN [21, 22, 23]. The multi-layered ANN structure is given in Figure 1.

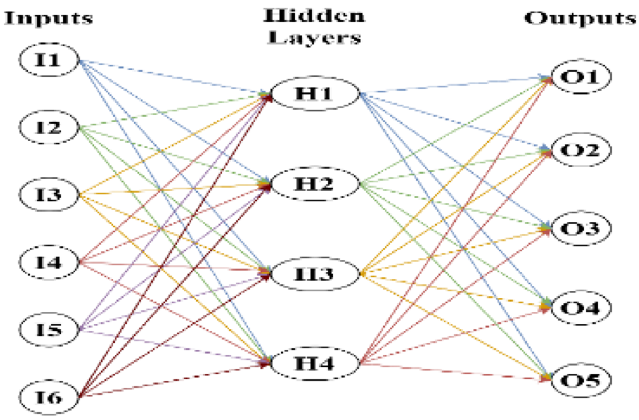

Figure 1. Multi-layer ANN network structure

Various activation functions are used in ANN to teach complex data better. Logarithmic-Sigmoid (Logsig), Tangent-Sigmoid (Tansig), and Purelin are the most basic three activation functions in ANN. Logsig function is the most used activation function. The definition range of this function is in the range [0 1] and exhibits a non-linear variation in this range. The definition range of the Tansig is

[-1 1]. The most important difference between the Tansig and the Logsig function is that it is also defined in negative regions. Purelin is the activation function in which the output value changes linearly according to the input values. The definition range is [-1 1]. The input and output curves of the activation functions are given in Figure 2 [24].

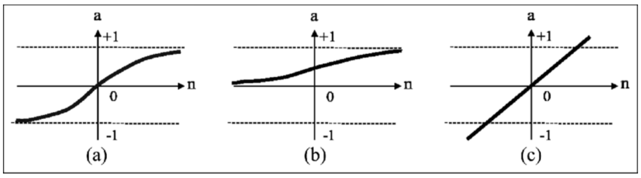

Figure 2. Input-output curves of activation functions (a: tansig b: logsig c: purelin)

It is aimed to reduce training time and increase training performance by using more than one training function. Thus, Levenberg-Marquardt Backpropagation (Trainlm), Gradient Descent with Momentum and Adaptive Learning rate Backpropagation (Traingdx), Conjugate Gradient Backpropagation (Traincgb), and Resilient Backpropagation (Trainrp) were used as training functions in the study [25].

Trainlm: It is known as Luvenberg-Marquardt backpropagation, which is frequently encountered in ANN applications. It works with the principle of updating the bias and weights according to the Luvenberg-Marquardt optimization. Although it needs more memory, it is one of the most preferred training functions.

Traingdx: It is a training function with variable learning rate and backpropagation. It is advantageous in terms of variable learning speed.

Traincgb: Powell/Beale is a training function which has restart backpropagation. weights and biases are updated according to the Powell/Beale spread.

Trainrp: It is a network training function that updates the weight and bias values according to the flexible backpropagation algorithm (Rprop). The soft backpropagation training algorithm is a successful function in eliminating the detrimental effects of the sizes of the partial derivatives [25].

3.2. Data

The data used in this study were taken from the official data announced by the Ministry of Health of the Republic of Türkiye [26]. All symptomatic and non-symptomatic case numbers were used in this study. At the beginning of the epidemic, the Ministry of Health announced the number of patients showing the symptoms of the disease until November 2020 in Türkiye. Therefore, the estimated case numbers were used for the number of asymptomatic patients between March 2020 and November 2020.

4. EXPERIMENTAL STUDY AND DISCUSSION

To examine the effect of vaccination on daily cases a neural network model was built. The model has six inputs, four hidden layers and just output. The factors that trigger the daily number of cases were chosen as input data. These factors were the restriction factor, the total number of tests, the number of daily applied tests, daily applied number of first-dose and second-dose vaccines, the total number of vaccines applied. It is expected that the number of daily cases will decrease when the restrictions or the number of vaccinations is intense. In addition, the need for Covid-19 testing was used as an input with the thought that contact with positive cases could be high. The output data of the designed algorithm were the number of daily cases. The estimated number of immunized people may be far from the real values since the protection of the applied vaccines, how many antibodies the recovered cases have, or the duration of immunity against the disease are not known exactly. The immunity period of those who had the disease was accepted as about three months. The mean time between the first dose and the second dose of vaccine was assumed as 14 days and all vaccines were choosing one type. Considering that the first dose of the vaccines provides 70% and the second dose 80% antibodies, the case of lasting three months of immunity was examined.

It was carried out with the Feed-Forward Backprop Network type in ANN for prediction and training. The data announced until 29 July 2021 were used for training and the period until between August and December 2021 was used for testing. Data from 30 July to 24 August were used for testing. The daily case numbers were estimated in the Network Toolbox interface in the MATLAB. The purpose of using more than one training function algorithm is to shorten the training time and to increase the performance. The validation values of the training functions of ANN were given in Table 1.

Table 1. Training functions and their performance used in ANN

Function Name	Validation: R	All: R
Trainlm	0.8781	0.8737
Traingdx	0.9957	0.9943
Traincgb	0.9981	0.9975
Trainrp	0.9946	0.9943

Feed-Forward Backpropagation network type and Mean Square Error (MSE) were used for all training functions [24]. Test results are given in Table 2.

Table 2. Test results in ANN

Function Name	MSE (Normalized Value)
Trainlm	0.8781
Traingdx	0.9957
Traincgb	0.9981
Trainrp	0.9946

Traincgb training function has the most successful validation rate. In addition, the validation values of Gradient Descent with Momentum and Adaptive Learning rate Backpropagation (Traingdx) and Levenberg-Marquardt Backpropagation (Trainrp) training functions were close to

Traincgb. The data were normalized and trained. The comparison of daily case numbers with estimated and actual data with the Trainlm function as shown Figure 3. As a result of the training, the validation value of the Trainlm function was calculated as 87.81%.

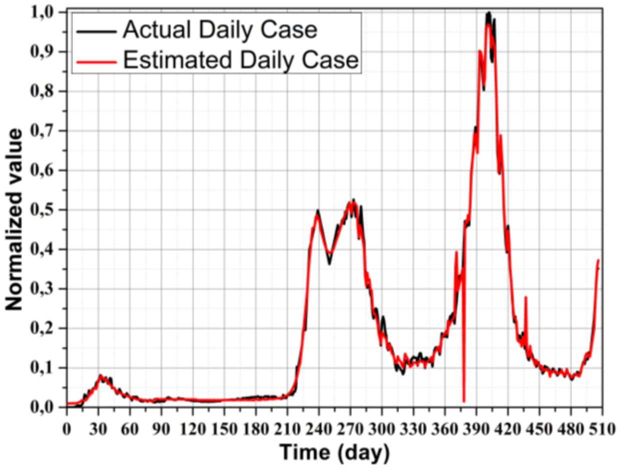

Figure 3. The comparison of daily case numbers with estimated and actual data with the Trainlm.

The vaccination process started on January 13, 2021, while it aimed to reduce the risk of transmission with various restrictions in the early days of the epidemic. After that, it is expected that herd immunity will increase rapidly and the number of cases will decrease. It was observed that there was a decrease in the vaccination rate due to some reasons. The algorithm was trained with the help of the training functions of the data announced until July 29, 2021. The daily number of cases was estimated according to the high, normal and low vaccination rate until November 2021.

The high vaccination status has been compared to the period when the number of vaccines applied from the past to the present is the highest. It also indicates that more and more vaccines will be made every day in the future. The normal vaccination status is the continuation of vaccination close to the rates that have occurred in the last weeks. Low vaccination status is the gradual decrease in the number of vaccinations. The numbers of high, normal, and low vaccination status used in the estimates are shown in Figure 4.

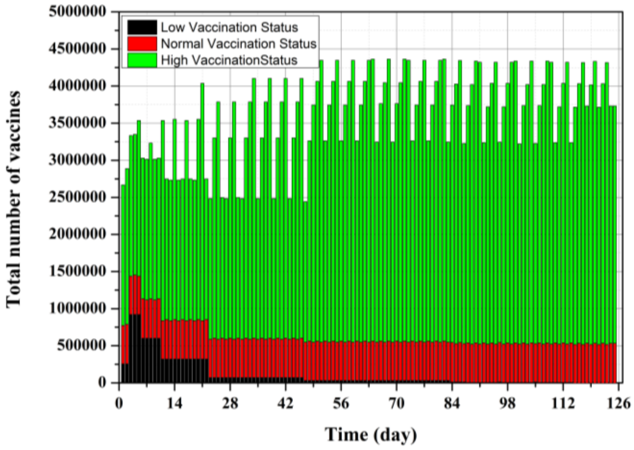

Figure 4. The total number of vaccines

The total number of vaccinations between August and December is given in Figure 4. The daily case numbers were estimated according to the vaccine amounts indicated in Figure 4. The vaccination status was estimated until November 2021 according to the application of low, normal and high vaccines. The daily case numbers were estimated with different training functions and the vaccination status was assumed as between 20 July and 29 July. The estimated number of daily cases by four different functions was given in Figure 5.

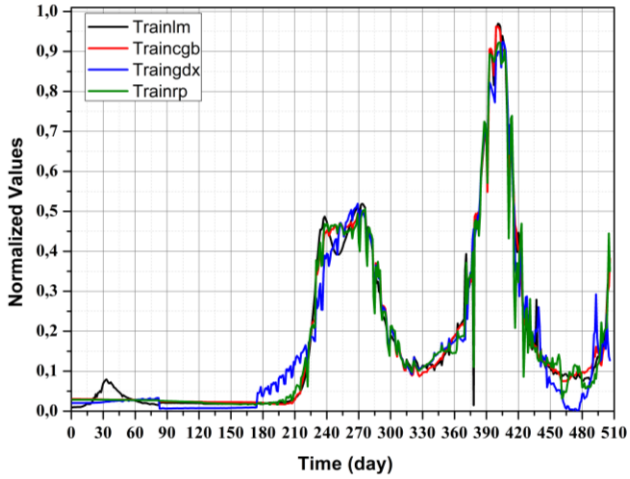

Figure 5. The estimated number of daily cases by four different functions.

The potential number of daily cases was estimated with the Traincgb function according to the low and high vaccination status, and it shown in Figure 6.

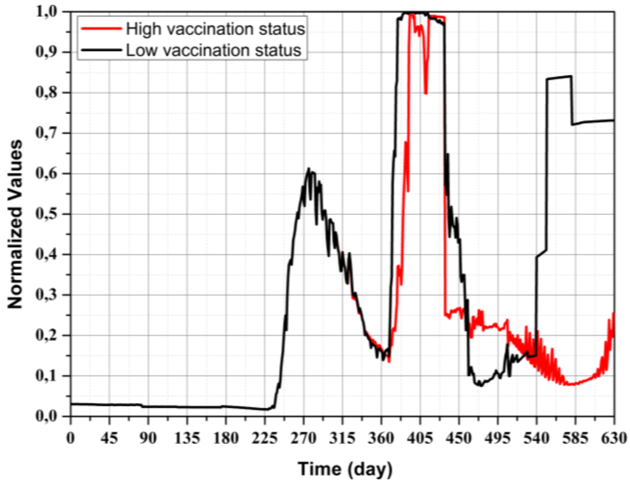

Figure 6. Daily case number estimation by low and high vaccination status of Traincgb function.

It is expected that the immunity will be directly proportional with the increase in the number of vaccinations. It is thought that the number of daily cases will decrease with the increase of immunity. Other input data were kept constant to display the effect of the vaccine in the estimates clearly. The estimation of the change in the number of daily cases of the Traingdx training function when vaccination status is high is shown in Figure 7.

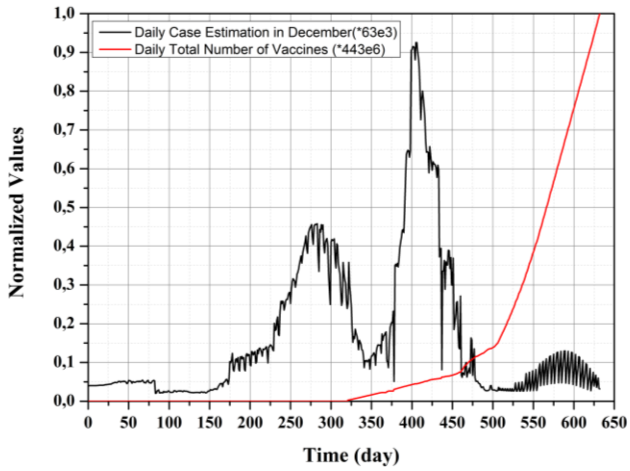

Figure 7. The estimation number of daily cases of the Traingdx training function

There were serious decreases in the number of daily cases, when vaccination was high. The reason for the sudden increase in the number of cases in late November and early December (between 500 and 625 units on the chart) is that the immunity period in vaccination is considered to be three months and the third dose of vaccines is not taken into account. It is expected that the daily number of cases will be around 2000 – 3000 if the total amount of first and second dose vaccination at the beginning of December is 440 million. The number of 3000 cases in December is estimated in the chart, since the third dose of vaccines is not taken into account and the immunity period is accepted as 3 months. Thus, the importance of the 3rd dose vaccine is also revealed. It is thought that the number of daily cases will decrease without the need for restrictions when enough vaccination is done. The effect of the restriction when the vaccination status is normal with the Traincgb training function is given in Figure 8. The use of different training algorithms allows the training functions to be compared with each other. The number of cases announced by the Ministry of Health in July and the daily number of cases estimated by the designed algorithms were given in Table 3.

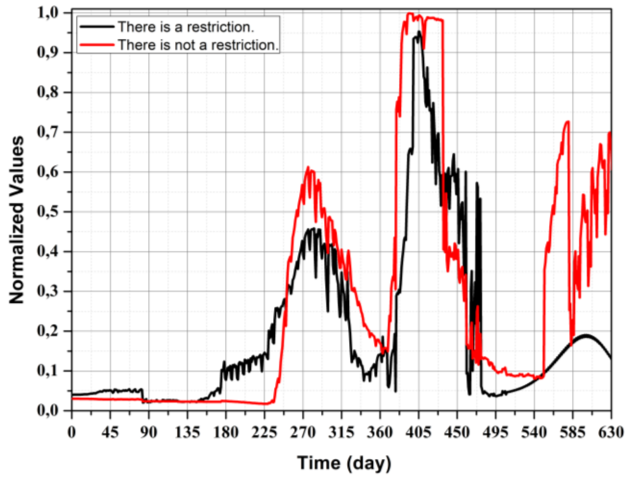

Figure 8. Estimation of the number of daily cases by Restriction Status with Traincgb Training Function.

Table 3. The estimated and announced daily number of cases in July

Date	The Announced Number of Cases	Estimated Number of Cases			
		Trainlm	Traingdx	Traincgb	Trainrp
10.07.2021	5530	5419	3681	6807	3984
11.07.2021	5261	5434	4353	6822	3722
12.07.2021	5404	5994	4608	7162	3902
13.07.2021	6285	6665	5609	7714	4548
14.07.2021	6907	8089	7653	8690	4696
15.07.2021	7304	7344	13614	8592	4414
16.07.2021	6918	10608	13864	10179	5861
17.07.2021	7666	8481	23387	9315	5112
28.07.2021	7680	8769	12828	9262	7164
19.07.2021	7667	8757	10750	8888	7481
20.07.2021	8780	7167	9837	7484	7816
21.07.2021	8151	7054	7758	7214	9993
22.07.2021	9586	9217	7772	8909	14009
23.07.2021	11094	10219	11426	9711	10830
24.07.2021	12381	10985	12609	10080	12005
25.07.2021	14230	11791	11942	10437	12660
26.07.2021	16809	16255	11189	15894	13082
27.07.2021	19761	19129	20833	18763	13123
28.07.2021	22291	22312	15194	19700	19021
29.07.2021	22161	22498	11618	24113	28060

Table 4. Daily case number estimates with training functions for November and December

Date	Daily Number of Case Estimates											
	Vaccination status: High				Vaccination status: Low				Vaccination status: Normal			
	Trainlm	Traingdx	Traincgb	Trainrp	Trainlm	Traingdx	Traincgb	Trainrp	Trainlm	Traingdx	Traincgb	Trainrp
09.11.2021	7623	4878	6645	5286	23958	59212	45998	12084	12022	11317	8024	28414
10.11.2021	4605	6655	7402	5391	23251	59140	46006	12058	12263	11475	8179	29488
11.11.2021	4512	2149	6240	8701	22476	58813	45992	7509	12462	11133	8223	28071
12.11.2021	6141	3396	6730	5526	21929	58980	46024	7509	12717	11261	8392	29103
13.11.2021	5258	4451	7346	5091	21291	58896	46031	5677	12919	10914	8441	27633
14.11.2021	3994	6102	8718	4960	20676	58807	46038	11961	13189	11013	8625	28623
15.11.2021	3955	5947	9227	4853	20083	58715	46046	18247	13393	10662	8680	27111
16.11.2021	4652	1904	6683	8946	19511	58618	46053	11916	13678	10734	8880	28060
17.11.2021	6474	3002	7681	5931	18961	58516	46059	11894	13883	10380	8940	26516
18.11.2021	9340	3912	8902	5014	18431	58409	46066	11872	14180	10425	9159	27425
19.11.2021	4543	5338	11610	4540	17922	58296	46073	11851	14387	10070	9226	25859
20.11.2021	4669	1717	7251	8954	17432	58179	46080	18139	14697	10089	9465	26730
21.11.2021	6463	2698	8932	6351	17022	58225	46095	11826	14904	9734	9538	25152
22.11.2021	9600	3499	10923	5086	16556	58106	46100	11806	15225	9729	9799	25985
23.11.2021	4019	4714	15057	4318	16109	57982	46104	11787	15431	9375	9879	24406
24.11.2021	6366	2475	10406	6723	15679	57852	46109	11768	15763	9348	10164	25203
25.11.2021	9590	3196	13194	5219	15266	57716	46113	11749	15969	8997	10252	23633
26.11.2021	4649	4237	13409	4207	14870	57574	46118	11731	16310	8951	10564	24395
27.11.2021	6186	2263	12421	7108	14489	57426	46122	11713	16513	8603	10659	22842
28.11.2021	9356	2908	16070	5419	14123	57272	46126	11696	16864	8539	10999	23569
29.11.2021	4642	3777	15834	4153	13772	57110	46130	11679	17064	8197	11103	22042
30.11.2021	5955	2064	15016	7482	13447	56940	46133	11664	17423	8119	11474	22737
01.12.2021	5866	2003	15918	7591	13122	56765	46137	11648	17714	7904	11731	22317
02.12.2021	7623	4878	6645	5286	23958	59212	45998	12084	12022	11317	8024	28414

The correlation coefficients between the obtained estimation results and the announced number of daily cases are Trainlm: 97.23%, Traingdx: 46.42%, Traincgb: 94.26% and Trainrp: 89.61%. As can be seen from the correlation coefficients, the best estimation results for July were obtained with the Trainlm Function. Since the beginning of the pandemic, the best accuracy rate from March 2020 to July 2021 has been achieved with the Traincgb training function, at approximately 98% access rate. Estimates for November and December 2021, taking into account different vaccination status and there is no restriction, were given in Table 4.

As can be seen in Table 4, it is seen that there is a serious increase in the number of cases when vaccination status is low and a decrease in the number of daily cases when the vaccination status is high. The input values such as the number of tests performed per day and the restriction factor were kept constant and the effect of the vaccine on the daily number of cases were only changed while estimating the daily number of cases. It is seen that the number of cases will decrease without any restrictions during periods of high vaccination status. The effect of the restrictions for the two situations where the vaccination status was normal and low were examined and the results were given in Table 5.

Table 5. The effect of restriction on estimated daily case numbers with the Trainrp function

Date	Vaccination Status High	Vaccination Status Normal
09.11.2021	5776	4850
10.11.2021	5750	4733
11.11.2021	5698	4770
12.11.2021	5701	4556
13.11.2021	5677	4845
14.11.2021	5653	4923
15.11.2021	5630	4995
16.11.2021	5608	5291
17.11.2021	5586	5229
18.11.2021	5564	4912
19.11.2021	5543	4860
20.11.2021	5523	4871
21.11.2021	5518	4890
22.11.2021	5498	4738
23.11.2021	5479	4691
24.11.2021	5460	4732
25.11.2021	5441	4826
26.11.2021	5423	4872
27.11.2021	5405	4923
28.11.2021	5388	4850
29.11.2021	5371	4859
30.11.2021	5356	4805
01.12.2021	5340	4860
02.12.2021	5776	4850

Restrictions have had a significant impact during periods of low vaccination status. Estimation made in daily case numbers shows that vaccination has a significant effect on the number of cases. When the vaccination status is high, there is no need for restrictions. As a result of this study, the estimated number of people who became immune according to the amount of vaccination in December is shown in Table 6.

Table 6. Estimated number of immunized people

Date	Vaccination Status High	Vaccination Status Normal	Vaccination Status Low
02.12.2021	75582935	69429669	63154480

In this study, it is aimed to see the effect of the vaccine on the number of cases and the effect of restrictions. In addition, as a result of the training, it aims to guide socialization by estimating the number of cases in the coming months. When the tables are examined, intensive vaccination creates a serious decrease in the number of daily cases. Reducing vaccination has an adverse effect on the daily number of cases. When the estimations examined in Table 4 and Table 5, there is no need for restriction in case the vaccination is high. Thus, it shows the importance of vaccination.

5. CONCLUSION

In this study, it is aimed to predict the number of Covid-19 cases that may occur in the coming months and the effect of the vaccine on the number of cases. Considering the effect of vaccination and restrictions, daily case numbers were estimated with different training functions. The estimated and the actual number of daily cases may be different. This difference mostly coming from some reasons such as the impact of people's social lives, mutating the virus or people give up the necessary precautions. Restrictions may come or abrogate by estimating the number of cases in the coming months according to the status of the vaccination numbers. This will help countries to be more prepared for emergencies that may occur.

This study examined the success rates of the network created for estimation. It has been observed that the success rate of the network created with the "Traincgb" training function is higher than the others in both the training and testing stages.

This study has anticipated a reference for future studies, like the number of patients estimation, etc. In future studies using the same data, the ANN model can be compared with other algorithms, and the success rates of the algorithms on estimation can be compared. In addition, especially the effects of the mutation that the virus has undergone can be added to future studies.

Author contributions: In the study, Author 1 contributed to the creation and implementation of the model, Author 2 contributed to the design and literature review, Author 3 contributed to the evaluation of the results obtained, and Author 4 contributed to the writing, supervision and execution of the data.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study has received no financial support.

REFERENCES

[1] World Health Organization (WHO). "Coronavirus disease 2019 (COVID-19) Situation Report – 62" Accessed on: June 25, 2021. https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200322-sitrep-62-covid-19.pdf?sfvrsn=755c76cd_2

[2] NTV TV Channel. "World Health Organization declared international emergency for Corona virus" Accessed on: January. 13, 2022. https://www.ntv.com.tr/galeri/dunya/corona-virusu-icin-dunya-saglik-orgutu-uluslararasi-acil-durum-ilan-etti-sars-be,3O3Hubz-NUOgO3ymqTqtBg

[3] S.J. Daniel "Education and the COVID-19 pandemic". Prospects, 2020, ch. 49(1), pp. 91–96.

[4] E. Cengiz, C. Yılmaz and H. Kahraman. "Classification of Human and Vehicles with The Deep Learning Based on Transfer Learning Method". Düzce Üniversitesi Bilim ve Teknoloji Dergisi, 2021, ch. 9(3), pp. 215-225.

[5] M. Alazab et all, "COVID-19 prediction and detection using deep learning". International Journal of Computer Information Systems and Industrial Management Applications, 2020, ch. 12(1), pp. 168-181.

[6] N. Hasan, "A methodological approach for predicting COVID-19 epidemic using EEMD-ANN hybrid model". Internet of things, 2020, ch. 11(100228), pp. 1-10.

[7] S Ardabili et all, "Coronavirus Disease (COVID-19) Global Prediction Using Hybrid Artificial Intelligence Method of ANN Trained with Grey Wolf Optimizer", 2020 IEEE 3rd International Conference and Workshop in Óbuda on Electrical and Power Engineering, 19 November 2020 Budapest, Hungary, Accessed on: July. 05, 2021.

[8] N.S. Özen, S. Saraç and M. Koyuncu, "COVID-19 Vakalarının Makine Öğrenmesi Algoritmaları ile Tahmini: Amerika Birleşik Devletleri Örneği". Avrupa Bilim ve Teknoloji Dergisi, 2021, ch. 22, pp. 134-139.

[9] H. Ankaralı, S. Ankaralı "Forecasting of the Number of Intensive Care Beds and Hospital Capacity for COVID-19 Outbreak in Turkey Until the End of April". Türk Yoğun Bakım Dergisi, 2020, ch. 18(1), pp. 22-30.

[10] F. Rustam et all, "COVID-19 Future Forecasting Using Supervised Machine Learning Models". IEEE Access, 2020, ch. 8(1), pp. 101489-101499.

[11] A.K. Sahai et all, "ARIMA modelling & forecasting of COVID-19 in top five affected countries". Diabetes & Metabolic Syndrome: Clinical Research & Reviews, 2020, ch. 14(5), pp.1419-1427.

[12] IHME COVID-19 health service utilization forecasting team. "Forecasting COVID-19 impact on hospital bed-days, ICU-days, ventilator-days and deaths by US state in the next 4 months". MedRxiv The Preprint Server for Health Sciences, 2020, Accessed on: Feb. 12, 2021.

[13] T. Turan , G. Turan and U. Köse , "Uyarlamalı Ağ Tabanlı Bulanık Mantık Çıkarım Sistemi ve Yapay Sinir Ağları ile Türkiye'deki COVID-19 Vefat Sayısının Tahmin Edilmesi", Bilişim Teknolojileri Dergisi, 2022, ch. 15(2), pp. 97-105.

[14] O. Sevli, V. G. Başer, "COVID-19 Salgınına Yönelik Zaman Serisi Verileri ile Prophet Model Kullanarak Makine Öğrenmesi Temelli Vaka Tahminlemesi", Avrupa Bilim ve Teknoloji Dergisi, 2020, ch. (19), pp. 827-835.

[15] S. Namasudra et all, "Nonlinear Neural Network Based Forecasting Model for Predicting COVID-19 Cases", Neural Process Lett, 2021, https://doi.org/10.1007/s11063-021-10495-w

[16] Y. Eroğlu, "Forecasting Models For Covid-19 Cases Of Turkey Using Artificial Neural Networks And Deep Learning", Journal of Industrial Engineering, 2020, ch.. 31(3), pp. 354-372.

[17] D. Fanelli, F. Piazza, "Analysis And Forecast of COVID-19 Spreading In China, Italy And France", Chaos, Solitons & Fractals, 2020, ch. 134, pp. 1-5.

[18] N. Delgrange et all, "Neural networks for prediction of ultrafiltration transmembrane pressure–application to drinking water production". Journal of membrane science, 1998, ch. 150(1), pp. 111-123.

[19] E. Cengiz et all "Pedestrian and Vehicles Detection with ResNet in Aerial Images". In 4th International Symposium on Innovative Approaches in Engineering and Natural Sciences, Samsun, Türkiye, 22 December 2019.

[20] M.M. Kelek et al, "RLBP Metodu ile Mamografi Görüntülerinin İncelenmesi ve Sınıflandırılması". Afyon Kocatepe Üniversitesi Uluslararası Mühendislik Teknolojileri ve Uygulamalı Bilimler Dergisi, 2021, ch. 4(2), pp. 59-64.

[21] Ö. Civalek, "The Analysis of Time Dependent Deformation in R.C. Members By Artificial Neural Network". Pamukkale Üniversitesi Mühendislik Dergisi, 1997, ch. 3(2), pp. 331-335.

[22] R. Ata, "Akhisar Bölgesi için Ortalama Rüzgar Hızlarına Bağlı Rüzgar Esme Sürelerinin Yapay Sinir Ağları ile Tahmini". Pamukkale Üniversitesi Mühendislik Dergisi, 2014, ch. 20(5), pp. 162-165.

[23] S. J. Taylor and B. Letham, "Forecasting at scale," Am. Stat., 2018, ch. 72(1), pp. 37–45.

[24] H. Altun, K.M. Curtis, "Exploiting the statistical characteristic of the speech signals for an improved neural learning in a MLP neural network". Neural Networks for Signal Processing VIII. Proceedings of the 1998 IEEE Signal Processing Society Workshop, Cambridge, UK, 2 September 1998.

[25] E. Yıldız, N. Çetinkaya "Elektrik Güç Sistemlerindeki Kaçak Kullanımların Tahmini", Journal of Investigations on Engineering and Technology, 2022, ch. 5(1), pp. 1-10.

[26] Ministry of Health of the Republic of Türkiye. "Website for Covid-19". Accessed on: January 13, 2021 https://covid19.saglik.gov.tr/.

Research Paper
Academic Platform Journal of Engineering and Smart Systems (APJESS) 11(1), 27-34, 2023
ISSN: 2822-2385
Received: 09-Mar-2022 Accepted: 16-Dec-2022
https://doi.org/10.21541/apjess.1084875

Cascade Proportional Derivative Controller for A Flexible Link Robot Manipulator using the Bees Algorithm

*[1]Mehmet Sefa GÜMÜŞ, [2]Abdullah ÇAKAN, [3]Mete KALYONCU

[1] Department of Mechanical Engineering, Konya Technical University, Konya, Türkiye, msgumus@ktun.edu.tr
[2] Department of Mechanical Engineering, Konya Technical University, Konya, Türkiye, acakan@ktun.edu.tr
[3] Department of Mechanical Engineering, Konya Technical University, Konya, Türkiye, mkalyoncu@ktun.edu.tr

Abstract

In this study, a flexible robot arm model and the design of its controller are introduced. The robot arm consists of a single flexible link. It is desired to control the circular position of the robot arm and the vibration of the tip point. Cascade proportional derivative controller was used to control the position and reduce the tip vibration. Controller gains were found using The Bees Algorithm. The weighted function of system responses such as settling time, maximum overshoot and steady-state error is used as a performance criterion while searching for the best parameters. In addition, controller gains were obtained with the genetic algorithm to evaluate the working performance of The Bees Algorithm. It has been observed that the Cascade PD controller, whose gains are optimized by The Bees Algorithm, successfully controls the flexible robot arm system and reduces the vibration of the tip point.

Keywords: The Bees Algorithm; Flexible Link; Cascade PID

1. INTRODUCTION

In recent years, the use of flexible structures has been increasing in many applications, especially due to their lightweight and lower cost. Especially in the field of aerospace and robotics, many elements are modeled as flexible since structures are desired to be light and quickly movable [1]. Controlling flexible structures is more complicated than rigid systems. Flexible structures require a higher-level control system due to their oscillations. For this reason, studies on the control of flexible structures have gained importance [2, 3].

Different controllers are used in flexible link control [4, 5]. PID controllers are one of the most used structures in controlling systems, thanks to their efficiency and durability [6-9]. It is very important to set the gains correctly in the design of the PID controller [10, 11]. There are many proposed methods for adjusting the coefficients of the PID controller. These methods can be divided into three parts: analytical, empirical, and optimization. Analytical methods try to determine the gains using root-locus curves. On the other hand, empirical methods such as Ziegler-Nichols or Cohen Coon's, try to obtain the gains by making an approach according to the experimentally obtained results [12-14]. However, these methods may be insufficient in some cases in fine-tuning the gains. Generally, in more complex systems, gains are tried to be obtained by using methods such as genetic algorithms and particle swarm optimization [15-18].

The Bees Algorithm is a swarm-based algorithm that mimics the behavior of bees. There are many studies in which the gains of PID controllers are successfully optimized with The Bees Algorithm [19, 20].

There are various approaches proposed for the control of flexible systems in the literature. Generally, open-loop applications cannot provide the desired level of control for flexible systems [21]. Especially depending on the configuration of the system, a more complex control system is needed due to the change of some parameters such as damping or natural frequency [22]. PID [23, 24], LQR [25, 26], and Fuzzy [27] controllers are used to control the flexible systems.

Since there are two output values in the system modeled in this study, it is not appropriate to control the system with a normal PID controller. A hierarchical PID controller was applied to control the flexible link [24]. In addition, a cascade fuzzy controller is also applied to the system [28]. In this study, it is aimed to control the flexible robot arm manipulator with the cascade PD controller. The coefficients of the controller are optimized with The Bees Algorithm. In addition, the controller gains are also found with the Genetic Algorithm in order to observe the performance of The Bees

Algorithm. Response of the system with two proposed controllers were compared.

2. FLEXIBLE LINK SYSTEM

The study was carried out on the linearized state-space model of an experimental flexible link setup designed by Quanser and using frequently in control studies shown in Figure 1.

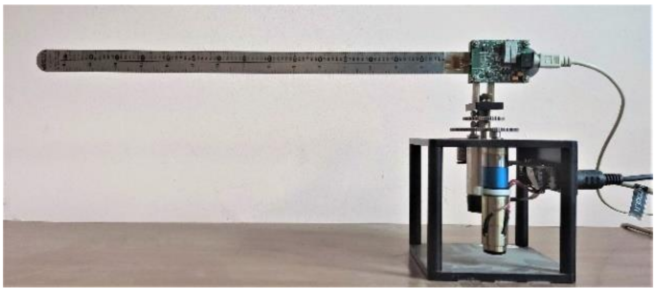

Figure 1. Experimental setup.

A flexible link has been tried to be controlled by using a servo motor. It is assumed that the weight is distributed along its length. An encoder was used to measure the position of the link, and a strain-gage was used to measure the tip vibration of the flexible link. These data are defined as the outputs of the system. The position of the link is defined as "θ" and the tip vibration of the link is defined as "α". The system is shown schematically in Figure 2.

The mathematical model of the system is specified in the user manual of the Quanser flexible link. The dynamic model of the flexible link system can be obtained using the Euler – Lagrange formula [29].

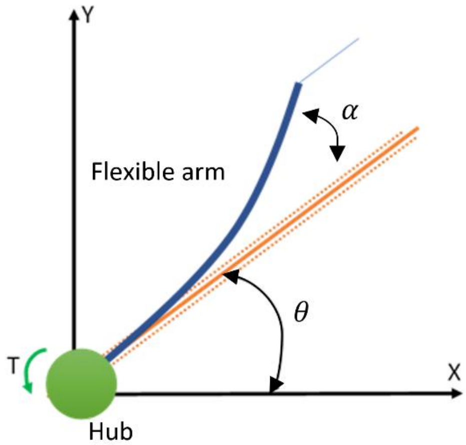

Figure 2. Schematic view of the flexible link

The potential energy and kinetic energy of the system in terms of theta and alpha variables can be defined as shown in Eq. 1 and 2. The stiffness of the link is used in the potential energy equation and the rotational moments of inertia of the hub and the link are used in the kinetic energy equations.

$$V_{P.E} = \frac{1}{2} k_{stiff} \alpha^2 \tag{1}$$

$$\begin{aligned} V_{K.E} &= V_{K.E\,(link)} + V_{K.E\,(hub)} \\ V_{K.E} &= \frac{1}{2} J_{link} (\dot{\theta} + \dot{\alpha})^2 + \frac{1}{2} J_{hub} \dot{\theta}^2 \end{aligned} \tag{2}$$

With these equations, the Lagrange function can be formed as follows.

$$\begin{aligned} L &= V_{K.E} - V_{P.E} \\ L &= \left(\frac{1}{2} J_{link} (\dot{\theta} + \dot{\alpha})^2 + \frac{1}{2} J_{hub} \dot{\theta}^2\right) - \left(\frac{1}{2} k_{stiff} \alpha^2\right) \end{aligned} \tag{3}$$

If partial derivatives are taken according to generalized coordinates, the following equations are obtained. "τ" used in the equations was stated as the output torque of the servomotor, and "b_{eq}" was stated as the equivalent viscous damping coefficient.

$$\frac{\delta}{\delta t}\left(\frac{\delta L}{\delta \dot{\theta}}\right) - \frac{\delta L}{\delta \theta} = \tau - b_{eq} \dot{\theta} \tag{4}$$

$$\frac{\delta}{\delta t}\left(\frac{\delta L}{\delta \dot{\alpha}}\right) - \frac{\delta L}{\delta \alpha} = 0 \tag{5}$$

Using Eq. 4 and 5, the dynamic equations of the system can be obtained as follows.

$$J_{link}(\ddot{\theta} + \ddot{\alpha}) + J_{hub} \ddot{\theta} = \tau + b_{eq} \dot{\theta} \tag{6}$$

$$J_{link}(\ddot{\theta} + \ddot{\alpha}) + k_{stiff} \alpha = 0 \tag{7}$$

The output torque of the servomotor can be expressed as shown in Eq. 8.

$$\tau = \eta_m \eta_g k_t k_g I_m \tag{8}$$

η_m and η_g represent the efficiency of the motor and the gear, respectively. "k_t" is the torque constant, and "k_g" is the gear ratio. "I_m" represents the armature current of the motor. The armature current, on the other hand, can be expressed in terms of controlled voltage using the Kirchhoff rules as shown in Eq. 9.

$$I_m = \frac{V_m - k_t k_m \dot{\theta}}{R_m} \tag{9}$$

"V_m" indicates the voltage supplied to the motor, and "R_m" indicates the electrical resistance of the armature.

Substituting Eq. 8 and 9 into Eq. 6, the dynamic model of the system can be expressed with the following equations.

$$\begin{aligned} J_{link}(\ddot{\theta} + \ddot{\alpha}) + J_{hub} \ddot{\theta} \\ = \eta_m \eta_g k_t k_g \left(\frac{V_m - k_t k_m \dot{\theta}}{R_m}\right) + b_{eq} \dot{\theta} \end{aligned} \tag{10}$$

$$J_{link}(\ddot{\theta} + \ddot{\alpha}) + k_{stiff} \alpha = 0 \tag{11}$$

Arranging Eq. 6 and 7, the state space model of the system can be expressed as shown in Figure 3. The state-space model is arranged as the following equations according to the inputs of the system "u", and the outputs of the system "y" . A, B, C, and D matrices of the system provided in the user manual are shown in Eq. 12.

$$\begin{bmatrix}\dot{\theta}\\ \dot{\alpha}\\ \ddot{\theta}\\ \ddot{\alpha}\end{bmatrix}=\begin{bmatrix}0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\\ 0 & \dfrac{k_{stiff}}{J_{hub}} & \dfrac{-\eta_m\eta_g k_t k_m {k_g}^2+b_{eq}R_m}{J_{hub}R_m} & 0\\ 0 & \dfrac{k_{stiff}(J_{hub}+J_{link})}{J_{hub}J_{link}} & \dfrac{\eta_m\eta_g k_t k_m {k_g}^2+b_{eq}R_m}{J_{hub}R_m} & 0\end{bmatrix}\begin{bmatrix}\theta\\ \alpha\\ \dot{\theta}\\ \dot{\alpha}\end{bmatrix}+\begin{bmatrix}0\\ 0\\ \dfrac{\eta_m\eta_g k_t k_g}{J_{hub}R_m}\\ \dfrac{-\eta_m\eta_g k_t k_g}{J_{hub}R_m}\end{bmatrix}V_m$$

Figure 3. State-space presentation of the flexible link

$$\dot{x}=Ax+Bu \qquad (12)$$
$$y=Cx+Du$$

$$A=\begin{bmatrix}0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\\ 0 & 623{,}74 & -40{,}32 & 0\\ 0 & -965{,}34 & 40{,}32 & 0\end{bmatrix}$$

$$B=\begin{bmatrix}0\\ 0\\ 61{,}63\\ -61{,}63\end{bmatrix}, \qquad (13)$$

$$C=\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\end{bmatrix}, \quad D=\begin{bmatrix}0\\ 0\end{bmatrix}$$

3. CASCADE PROPORTIONAL DERIVATIVE CONTROLLER

Cascade control consists of the use of two control loops. The first control loop provides the reference point for the second control loop [30].

The outer or primary loop uses the sensor of the variable to be controlled. This is the dominant loop that provides the intended control. The inner or secondary loop uses the second variable sensor to be controlled and drives the second controller to keep this variable at a certain value.

Cascade control is generally advantageous if the dynamics of the inner loop are faster than the dynamics of the outer loop. When the inner loop is not significantly faster than the outer loop, the advantages of cascading control are reduced. Moreover, if the inner loop is set aggressively, it may even cause instability in the system by creating the risk of interaction between the two loops [33].In a single loop PID control system that has low stiffness, it will be difficult to meet the requirements when the level of experimental loads is very high relative to the stiffness of the system. It is therefore unlikely to achieve a very high quality of control [34]. In Cascade control systems, the secondary (internal) circuit is the acceleration loop of the system; the primary (external) circuit can be expressed as a position control loop [35]. In this study, the tip vibration is used as the feedback of the secondary loop, and the position of the link is used as the feedback of the first loop. The primary and the secondary controllers are named as PD-1 and PD-2, respectively. When the reference value is set as the position of the link, the external controller initiates the motion providing a reference to the controller in the secondary loop that controls the tip vibration of the link.

The output of the secondary controller provides the necessary voltage to the motor. The control system block diagram used in the study is shared in Figure 4. In the trials conducted during the study, it was observed that the integration process in the PID controller had not a positive effect on the control of the system. For this reason, the controller was defined as a proportional derivative.

4. CASCADE PD CONTROLLER OPTIMIZATION

4.1. Genetic Algorithm

Genetic algorithms are evolutionary algorithms that optimize functions by modeling the biological process, first introduced by John Holland in 1975 [34]. While GA parameters represent genes in the biology, the aggregated set of parameters constitutes the chromosome. Each individual of the Gas which are the candidates of the solution, is represented in the form of chromosomes. This set of candidate solutions is also called the population. The fitness of the population is maximized or minimized within certain rules. Each new generation is obtained by combining survivors into sequences created by random information exchange [35, 36]. The genetic algorithm is a commonly used method to find controller gains [8, 37-38]. The suitable gains of the PD controller were found by the genetic algorithm using the parameters in Table 1.

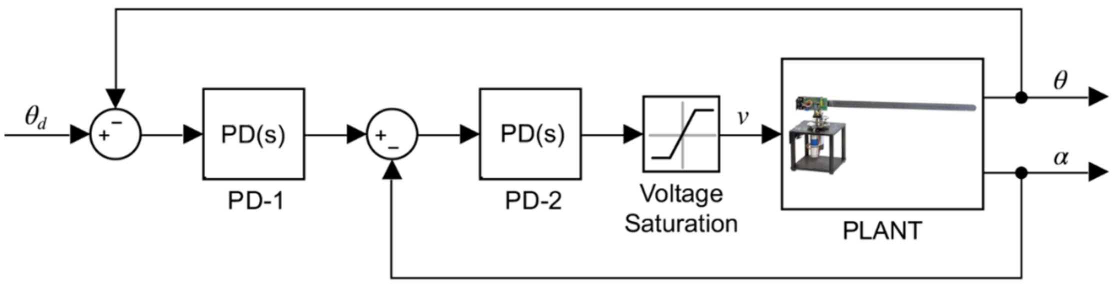

Figure 4. Cascade PD control system

Table 1. Genetic Algorithm parameters

Parameters	Values
Generation number	25
Population size	40
Elite count	10
Crossover fraction	0.6

4.2. The Bees Algorithm

The Bees Algorithm (BA) was first proposed by DT Pham et al. in 2006, the behavior of bees searching for resources such as nectar and water by using swarm intelligence to learn, remember, and transfer the knowledge [39-43]. Pham and Kalyoncu, who designed fuzzy logic and PID controllers with the bees algorithm for the control of a robotic arm, laid the foundations of the studies in this field [24]. Kalyoncu et al. observed that the controllers whose parameters were determined by The Bees Algorithm compared to the traditional methods in position and balance control gave better results [44-47]. Baronti et al. analysed of the search mechanisms of The Bees Algorithm [48]. The flowchart is shown in Figure 5, pseudo code is shown in Figure 6.

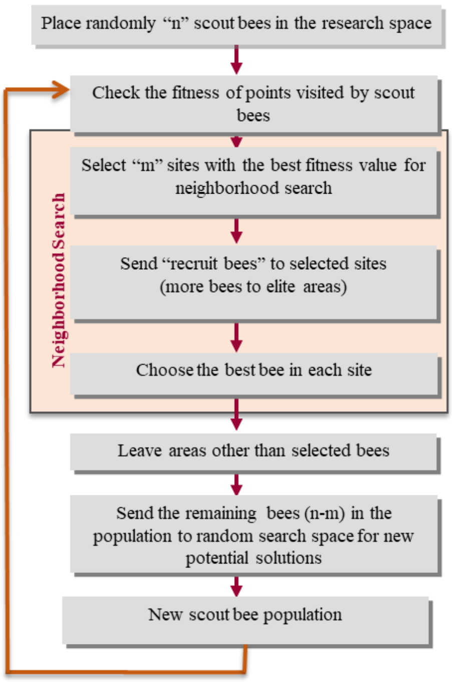

Figure 5. Flowchart of the Bees Algorithm

1. Initialise population with random solutions.
2. Evaluate fitness of the population.
3. While (stopping criteria not met) //Forming new population.
4. Select elite bees.
5. Select sites for neighbourhood search.
6. Recruit bees around selected sites and evaluate fitness.
7. Select the fittest bee from each site.
8. Assign remaining bees to search randomly and evaluate their fitness.
9. End While

Figure 6. Pseudo code of The Bees Algorithm

Table 2. The Bees Algorithm parameters

Parameters	Values
Number of iteration "itr"	25
Number of scout bees "n"	20
Number of suitable regions "m"	8
Number of the best regions "e"	5
Number of bees sent to the best elite region "nep"	10
Number of bees sent to the region "nsp"	7
Region size "ngh"	0.01

The bees algorithm contains many parameters such as the number of scout bees (n), the number of the most suitable regions selected from n visited points (m), the number of the best regions in the m selected regions (e), the number of bees sent to the best elite region (nep), the remaining are the number of bees sent to the region (nsp), the region size (ngh), and the number of iteration (itr). The parameters used in the optimization process are given in Table 2.

4.3. Tuning Cascade PD Controller

The input of the system is the voltage of the servomotor. The proportional controller gains (K_P^1, K_P^2) and derivative controller gains (K_D^1, K_D^2) of the outer and the inner loop of the control system are the parameters that determine the performance of the system. The main goal is to find controller gains that will minimize the performance index for a control input. The performance index was created by considering the weighted summation of rising time (t_r), settling time (t_s), peak time (t_p), maximum overshoot (p_{max}), steady state error (e_{ss}), and matrix norm (α_{norm}) as stated in Eq. 14 [23].

$$\begin{aligned} P &= P_\theta + P_\alpha \\ P_\theta &= 10t_r + 6t_s + 6.5t_p + 0.1|p_{max}| + 4.4|e_{ss}| \\ P_\alpha &= 0.1\alpha_{norm} + 3.3t_s + 50t_p + 0.8|p_{max}| + 1500|e_{ss}| \end{aligned} \tag{14}$$

In this study, the control system and the state-space model of the flexible link are set up in MATLAB/Simulink environment. The related controller coefficients were defined as variables. The response of the system to the control input was evaluated. The range in which the controller gains are sought is given in Table 3. The Bees Algorithm was composed in the MATLAB environment. The system was operated using the parameters suggested by the bees sent in each iteration. The results were stored, and the next iteration was prepared. In this way, the most suitable controller gains that will minimize the fitness function have been obtained with The Bees Algorithm.

Table 3. Optimization ranges of PD controller gains

Gains	Minimum	Maximum
Kp^{PD-1}	0	5
Kd^{PD-1}	0	1
Kp^{PD-2}	0	5
Kd^{PD-2}	0	1

5. STABILITY ANALYSIS

Stability analysis is a standard requirement for control systems to avoid loss of control. Stability can be analyzed by looking at the eigenvalues of A matrix of state-space representation. Many techniques are available for obtaining state-space representations of dynamic systems. MATLAB platform lets you analyze the dynamics of systems and extract system models in the form of the state-space matrices A, B, C, and D according to selected input and outputs. The closed control system shown in Figure 4. including PD controllers is defined as a state-space model by using MATLAB. Obtained *A* matrices including optimized PD controllers by using The Bees Algorithm and Genetic Algorithm are given in Eq. 15 and Eq. 16 respectively.

$$A_{BA} = \begin{bmatrix} -100 & 0 & -0.1763 & 0 & 0 & 0 \\ -13.18 & -100 & -0.3661 & -0.1318 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ -4967 & -6163 & -138 & 574.1 & -40.32 & 0 \\ 4967 & 6163 & 138 & -915.7 & 40.32 & 0 \end{bmatrix} \quad (15)$$

$$A_{GA} = \begin{bmatrix} -100 & 0 & -0.3268 & 0 & 0 & 0 \\ -195.7 & -100 & -6.462 & -1.957 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ -16100 & -6163 & -531.5 & 462.8 & -40.32 & 0 \\ 16100 & 6163 & 531.5 & -804.4 & 40.32 & 0 \end{bmatrix} \quad (16)$$

Eigenvalues of the obtained *A* matrices are the roots of the characteristic equation [49]. As seen in Table 4. all eigenvalues have negative real parts. This means that all closed-loop poles of the control system which contains optimized PD controllers using The Bees Algorithm and Genetic Algorithm are in the left-half plane. The controlled system is therefore stable.

Table 4. Eigenvalues of *A* matrices.

Eigenvalues of A_{BA}	Eigenvalues of A_{GA}
$-99.8487 + 1.4641i$	$-98.1218 + 7.6902i$
$-99.8487 - 1.4641i$	$-98.1218 - 7.6902i$
$-8.9633 + 21.9158i$	$-8.4908 + 21.2097i$
$-8.9633 - 21.9158i$	$-8.4908 - 21.2097i$
-19.2677	-3.4269
-3.4285	-23.6679

6. SIMULATION RESULTS

Controller gains found by The Bees Algorithm and Genetic Algorithm are shown in Table 5. The gains of the proportional controller were very close to each other. However, a difference was observed between the gains of the derivative controller gains.

The responses of the systems found with two different algorithms are shared in Table 6. The settling and rising times of the system for theta angle were very close to each other. However, when the tip point vibrations are evaluated, it is observed The Bees Algorithm achieves better results.

Table 5. GA and BA optimization results

Gains	Genetic Algorithm	The Bees Algorithm
Kp^{PD-1}	2,9752	2,6019
Kd^{PD-1}	0,0033	0,0018
Kp^{PD-2}	0,6547	0,6741
Kd^{PD-2}	0,0196	0,0013

Table 6. Performance criteria of controllers

Time Responses	GA Controller	BA Controller
θ, Rise Time (t_r) [s]	0.6846	0.6968
θ, Settling Time (t_s) [s]	1.1891	1.2310
θ, Maximum Peak [%]	0	0
θ, Steady State Error (e_{ss})	0	0
α, Norm	14.9806	10.6592
α, Settling Time (t_s) [s]	0.8473	0.9444
α, Peak Time (t_p) [s]	0.0609	0.0805
α, Maximum Peak [deg]	3.5952	2.6088
α, Steady State Error (e_{ss})	0	0

The convergences of two different algorithms in the iterations are shown in Figure 7. When the curves are examined, it is seen that while the Genetic Algorithm converges faster, the fitness value obtained by The Bees Algorithm is more successful than the Genetic Algorithm.

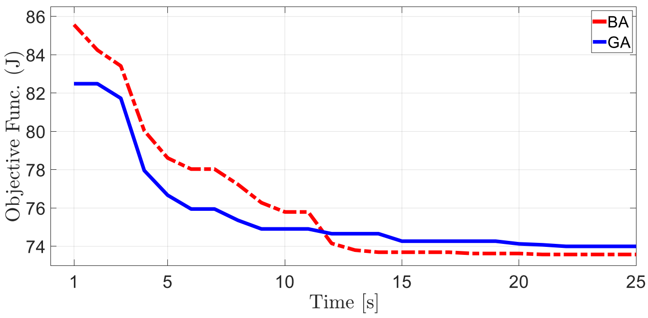

Figure 7. Convergence performance of GA, BA

In addition, according to the supplied voltage of the motor shown in Figure 8 and Figure 9, it is seen that the controller obtained with BA provides a more efficient control with less energy consumption.

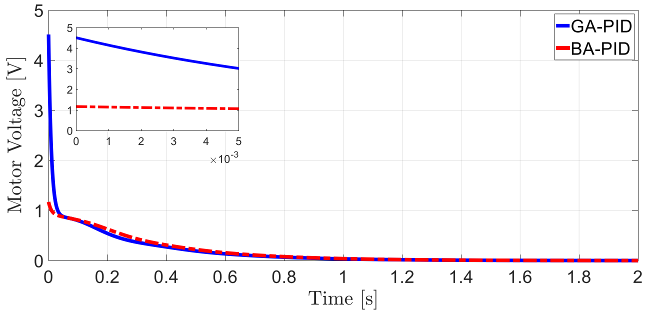

Figure 8. Motor voltages for 30° reference position.

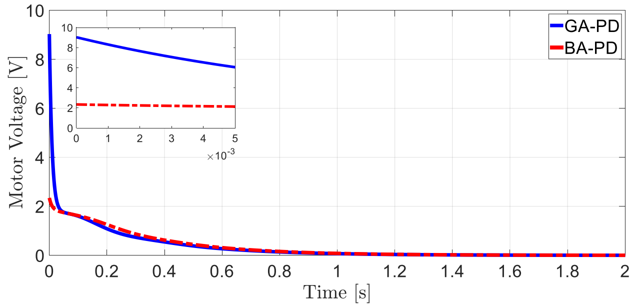

Figure 9. Motor voltages for 60° reference position.

It is seen that BA and GA have obtained close results in position control in Figure 10 and Figure 11, but BA is more successful in tip vibration shown in Figure 12 and Figure 13.

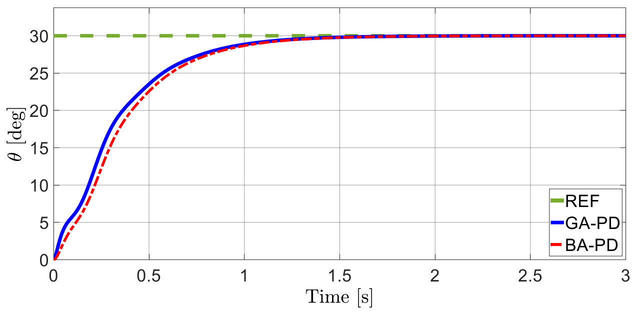

Figure 10. Position result for 30° reference position.

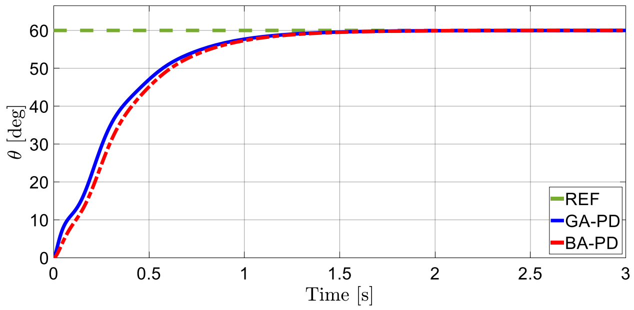

Figure 11. Position result for 60° reference position.

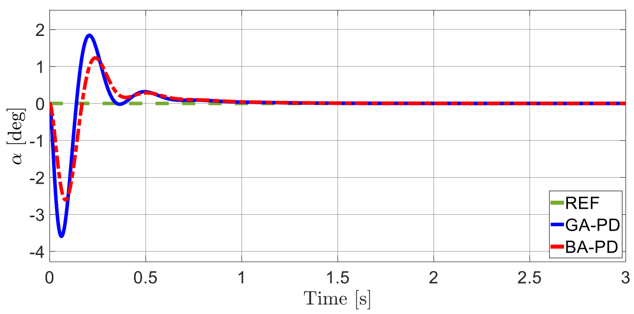

Figure 12. Tip vibration result for 30° reference position.

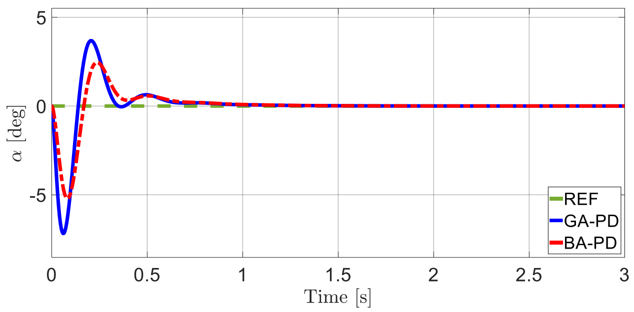

Figure 13. Tip vibration result for 60° reference position.

7. CONCLUSION

In this study, a model of a flexible robot manipulator arm was created. A cascade PD controller was used to control the position and tip point vibration. The gains of the proposed PD controller have been successfully found by Genetic Algorithm and The Bees Algorithm. It has been observed that The Bees Algorithm founds the controller gains with better fitness values than the Genetic Algorithm. When the response of the systems suggested by different algorithms was examined, it was observed that the tip point vibration level was reduced. In addition, the decrease in the motor voltage with The Bees Algorithm leads to lower energy consumption. I was observed that the tip point vibration level was successfully suppressed with a sufficient position control.

Author Contributions: Gumus M.S. performed the analysis and wrote the paper. Cakan A. designed the model and made the stability analysis. Kalyoncu M. conceived the study and contributed to the optimization.
Conflict of Interest: No conflict of interest was declared by the authors.
Financial Disclosure: The authors declared that this study has received no financial support.

REFERENCES

[1] S. Xu, G. Sun, and Z. Li, "Finite frequency vibration suppression for space flexible structures in tip position control," International Journal of Control, Automation, and Systems, vol. 16, no. 3, pp. 1021-1029, 2018.

[2] B. Altıner, A. Delibaşı, and B. Erol, "Modeling and control of flexible link manipulators for unmodeled dynamics effect," Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering, vol. 233, no. 3, pp. 245-263, 2019.

[3] X. Lang, C. J. Damaren, and X. Cao, "Hybrid frequency domain control for large flexible structures," Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, vol. 233, no. 11, pp. 4272-4283, 2019.

[4] Bhaskarwar T, Hawari HF, Nor NBM, Chile RH, Waghmare D, Aole S, "Sliding Mode Controller with Generalized Extended State Observer for Single Link Flexible Manipulator," Applied Sciences, vol 12, no 6, 3079, 2022.

[5] Zhou X, Wang H, Tian Y, "Adaptive boundary iterative learning vibration control using disturbance observers for a rigid–flexible manipulator system with distributed disturbances and input constraints," Journal of Vibration and Control, vol 28 no.11-12, pp. 1324-1340, 2022.

[6] M.-T. Ho and Y.-W. Tu, "PID controller design for a flexible-link manipulator," in Proceedings of the 44th IEEE Conference on Decision and Control, 2005: IEEE, pp. 6841-6846.

[7] A. Izadbakhsh and S. Khorashadizadeh, "Single-loop PID controller design for electrical flexible-joint robots," Journal of the Brazilian Society of Mechanical Sciences and Engineering, vol. 42, no. 2, pp. 1-12, 2020.

[8] S. K. Pradhan and B. Subudhi, "Position control of a flexible manipulator using a new nonlinear self-tuning PID controller," IEEE/CAA Journal of Automatica Sinica, vol. 7, no. 1, pp. 136-149, 2018.

[9] P. Sarkhel, N. Banerjee, and N. B. Hui, "Fuzzy logic-based tuning of PID controller to control flexible manipulators," SN Applied Sciences, vol. 2, pp. 1-11, 2020.

[10] A. Urbaś, J. Kłosiński, and K. Augustynek, "The influence of the PID controller settings on the motion of a truck-mounted crane with a flexible boom and friction in joints," Control Engineering Practice, vol. 103, p. 104610, 2020.

[11] H. Açikgöz, Ö. F. Keçecioğlu, M. Güneş, And M. Şekkeli, "Öz Ayarlamalı Bulanık-Pid Denetleyici İle Hidrolik Türbinin Benzetim Çalışması," Academic Platform Journal Of Engineering And Science, Vol. 3, No. 1, Pp. 7-15, 2015.

[12] R. Aisuwarya and Y. Hidayati, "Implementation of ziegler-nichols PID tuning method on stabilizing temperature of hot-water dispenser," in 2019 16th International Conference on Quality in Research (QIR): International Symposium on Electrical and Computer Engineering, 2019: IEEE, pp. 1-5.

[13] K. S. Chia, "Ziegler-nichols based proportional-integral-derivative controller for a line tracking robot," Indonesian journal of electrical engineering and computer science, vol. 9, no. 1, pp. 221-226, 2018.

[14] J. Fišer and P. Zítek, "PID controller tuning via dominant pole placement in comparison with ziegler-nichols tuning," IFAC-PapersOnLine, vol. 52, no. 18, pp. 43-48, 2019.

[15] N. I. M. Azmi, N. M. Yahya, H. J. Fu, and W. A. W. Yusoff, "Optimization of the PID-PD parameters of the overhead crane control system by using PSO algorithm," in MATEC Web of Conferences, 2019, vol. 255: EDP Sciences, p. 04001.

[16] M. A. Ibrahim, A. K. Mahmood, and N. S. Sultan, "Optimal PID controller of a brushless DC motor using genetic algorithm," Int J Pow Elec & Dri Syst ISSN, vol. 2088, no. 8694, p. 8694, 2019.

[17] H. Suwoyo, Y. Tian, C. Deng, and A. Adriansyah, "Improving a wall-following robot performance with a PID-genetic algorithm controller," in 2018 5th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI), 2018: IEEE, pp. 314-318.

[18] Z. Xiang, D. Ji, H. Zhang, H. Wu, and Y. Li, "A simple PID-based strategy for particle swarm optimization algorithm," Information Sciences, vol. 502, pp. 558-574, 2019.

[19] M. Arif Şen, M. Tinkir, and M. Kalyoncu, "Optimisation of a PID controller for a two-floor structure under earthquake excitation based on the bees algorithm," Journal of Low Frequency Noise, Vibration and Active Control, vol. 37, no. 1, pp. 107-127, 2018.

[20] E. A. Esleman, G. Önal, and M. Kalyoncu, "Optimal PID and fuzzy logic based position controller design of an overhead crane using the Bees Algorithm," SN Applied Sciences, vol. 3, no. 10, pp. 1-13, 2021.

[21] C. Conker, H. Yavuz, and H. H. Bilgic, "A review of command shaping techniques for elimination of residual vibrations in flexible-joint manipulators," Journal of Vibroengineering, vol. 18, no. 5, pp. 2947-2958, 2016.

[22] D. K. Thomsen, R. Søe-Knudsen, O. Balling, and X. Zhang, "Vibration control of industrial robot arms by multi-mode time-varying input shaping," Mechanism and Machine Theory, vol. 155, p. 104072, 2021.

[23] T. Mansour, A. Konno, and M. Uchiyama, "Modified PID control of a single-link flexible robot," Advanced Robotics, vol. 22, no. 4, pp. 433-449, 2008.

[24] D. Pham, E. Koç, M. Kalyoncu, and M. Tınkır, "Hierarchical PID controller design for a flexible link robot manipulator using The Bees Algorithm," Methods (eg. genetic algorithm), vol. 25, p. 32, 2008.

[25] H. H. Bilgic, M. A. Sen, A. Yapici, H. Yavuz, and M. Kalyoncu, "Meta-heuristic tuning of the LQR weighting matrices using various objective functions on an experimental flexible arm under the effects of disturbance," Arabian Journal for Science and Engineering, pp. 1-14, 2021.

[26] Ü. Önen, A. Çakan, and I. Ilhan, "Performance comparison of optimization algorithms in LQR controller design for a nonlinear system," Turkish Journal of Electrical Engineering & Computer Sciences, vol. 27, no. 3, pp. 1938-1953, 2019.

[27] C. Sun, H. Gao, W. He, and Y. Yu, "Fuzzy neural network control of a flexible robotic manipulator using assumed mode method," IEEE Transactions on Neural Networks and Learning Systems, vol. 29, no. 11, pp. 5214-5227, 2018.

[28] İ. H. Akyüz, Z. Bingül, And S. Kizir, "Cascade fuzzy logic control of a single-link flexible-joint manipulator," Turkish Journal of Electrical Engineering & Computer Sciences, vol. 20, no. 5, pp. 713-726, 2012.

[29] I. Tijani, R. Akmeliawati, A. A. Muthalif, and A. Legowo, "Optimization of PID controller for Flexible link system using a Pareto-based Multi-Objective differential (PMODE) evolution," in 2011 4th International Conference on Mechatronics (ICOM), 2011: IEEE, pp. 1-6.

[30] W. Bolton, Instrumentation and control systems. Newnes, 2021.

[31] Y. Hu, C. Chen, H. Wu, and C. Song, "Study on structural optimization design and cascade PID control of maglev actuator for active vibration isolation system," Journal of Vibration and Control, vol. 24, no. 10, pp. 1829-1847, 2018.

[32] J. Liu, Y. Li, Y. Zhang, Q. Gao, and B. Zuo, "Dynamics and control of a parallel mechanism for active vibration isolation in space station," Nonlinear Dynamics, vol. 76, no. 3, pp. 1737-1751, 2014.

[33] B.-J. Yang, A. Calise, J. Craig, and M. Whorton, "Adaptive control for a microgravity vibration isolation system," in AIAA guidance, navigation, and control conference and exhibit, 2005, p. 6071.

[34] H. John, "Holland. genetic algorithms," Scientific american, vol. 267, no. 1, pp. 44-50, 1992.

[35] P. J. Angeline, "Evolution revolution: An introduction to the special track on genetic and evolutionary programming," IEEE Intelligent Systems, vol. 10, no. 03, pp. 6-10, 1995.

[36] A. Sadık, A. Kahraman, And R. Şahin, "Determination Of Optimum Pinch Point Temperature Difference Depending on Heat Source Temperature and Organic Fluid with Genetic Algorithm," Academic Platform Journal of Engineering and Smart Systems, vol. 10, no. 1, pp. 19-29..

[37] J. Zhang, J. Zhuang, and H. Du, "Self-organizing genetic algorithm based tuning of PID controllers," Information Sciences, vol. 179, no. 7, pp. 1007-1018, 2009.

[38] A. Mirzal, S. Yoshii, and M. Furukawa, "PID parameters optimization by using genetic algorithm," arXiv preprint arXiv:1204.0885, 2012.

[39] D. Karaboga, "An idea based on honey bee swarm for numerical optimization," Technical report-tr06, Erciyes university, engineering faculty, computer …, 2005.

[40] D. Karaboga and B. Akay, "A comparative study of artificial bee colony algorithm," Applied mathematics and computation, vol. 214, no. 1, pp. 108-132, 2009.

[41] D. Pham, A. Ghanbarzadeh, E. Koc, and S. Otri, "Application of the bees algorithm to the training of radial basis function networks for control chart pattern recognition," in Proceedings of 5th CIRP international seminar on intelligent computation in manufacturing engineering (CIRP ICME'06), Ischia, Italy, 2006, pp. 711-716.

[42] D. Pham, A. J. Soroka, A. Ghanbarzadeh, E. Koc, S. Otri, and M. Packianather, "Optimising neural networks for identification of wood defects using the bees algorithm," in 2006 4th IEEE International Conference on Industrial Informatics, 2006: IEEE, pp. 1346-1351.

[43] D. T. Pham, A. Ghanbarzadeh, E. Koç, S. Otri, S. Rahim, and M. Zaidi, "The bees algorithm—a novel tool for complex optimisation problems," in Intelligent production machines and systems: Elsevier, 2006, pp. 454-459.

[44] V. Bakırcıoğlu, M. Şen, and M. Kalyoncu, "Dört Ayaklı Robotun Bir Bacağı İçin PID Kontrolcü Tasarımı ve Arı Algoritması Kullanarak Optimizasyonu," Uluslararası katılımlı 17. Makina Teorisi Sempozyumu (UMTS 2015), pp. 661-665.

[45] D. Pham and M. Kalyoncu, "Optimisation of a fuzzy logic controller for a flexible single-link robot arm using the Bees Algorithm," in 2009 7th IEEE International Conference on Industrial Informatics, 2009: IEEE, pp. 475-480.

[46] M. A. Şen, V. Bakırcıoğlu, and M. Kalyoncu, "Performances comparison of the bees algorithm and genetic algorithm for PID controller tuning," in Proceedings of the 5th International Conference on Mechatronics and Control Engineering, 2016, pp. 126-130.

[47] M. A. Sen and M. Kalyoncu, "Optimisation of a PID controller for an inverted pendulum using The Bees Algorithm," in Applied Mechanics and Materials, 2015, vol. 789: Trans Tech Publ, pp. 1039-1044.

[48] Baronti, L., Castellani, M., & Pham, D. T. "An analysis of the search mechanisms of the bees algorithm," in Swarm and Evolutionary Computation, 2020, vol. 59, 100746.

[49] K. Ogata, "Modern Control Engineering," in Prentice Hall, Vol. 5, 2010.

Research Paper
Academic Platform Journal of Engineering and Smart Systems (APJESS) 11(1), 35-40, 2023
ISSN: 2822-2385
Received: 15-Nov-2022 Accepted: 20-Dec-2022
https://doi.org/10.21541/apjess.1205309

Implementation of Fuzzy Linear Programming Approach for More Accurate Demand Forecasting in a Make-to-Stock Company

*[1]Çağatay TEKE

[1] Department of Industrial Engineering, Bayburt University, Bayburt, Türkiye, cagatayteke@bayburt.edu.tr

Abstract

Demand forecasting is of crucial importance for make-to-stock companies because product demand is uncertain and it changes with time. Fuzzy linear programming (FLP) can be an optimum approach for such uncertain situations. In this study, the FLP model was used for more accurate demand forecasting in a make-to-stock company. Demand forecasting study was carried out according to the FLP method and linear programming (LP) method. Solutions of FLP and LP were compared in terms of imputed shortage cost, inventory carrying cost, and net profit. Results show that the applied FLP method is more advantageous than LP as it provides a 67% decrease in costs and a 15% increase in net profit.

Keywords: Demand Forecasting; Fuzzy Linear Programming; Make-to-Stock.

1. INTRODUCTION

Determination of product demand is very important in terms of production planning since companies make the production plan according to product demand. On the other hand, demand amounts in make-to-stock companies can't be known precisely. Therefore, they make the production plan in accordance with the estimated demand value.

Make-to-stock companies aim to forecast the product demand with a minimum error as more realistic demand forecasting enables to decrease in the inventory carrying cost and imputed shortage cost. In addition, when companies achieve this aim, costs based on the deterioration of product inventory decline. However, improving demand forecast accuracy is a difficult issue because product demand is unknown and it varies from period to period. Thus, fuzzy logic is a suitable approach to deal with decision problems involving such uncertainties and linear programming (LP) [1]. Zimmermann introduced a fuzzy approach regarding LP problems in 1974. In addition, Lai and Hwang, Tong Shaocheng, Buckley, among others, cope with the fact that all parameters are fuzzy [2].

When evaluated similar studies, Azizi et al. [3] developed adaptive neuro fuzzy inference system to predict the throughput of production systems. It was used because of factors include uncertainty such as set up time and demand. It was applied in tile industry. Obtained results revealed that adaptive neuro fuzzy inference system is appropriate for prediction of throughput in uncertainty. Worapradya and Thanakijkasem [4] developed a model with hierarchical genetic algorithm to optimize the steel production. Figueroa-Garcia et al. [5] used fuzzy linear programming (FLP) and interval fuzzy set approach for mixed production planning problem. Torabi et al. [6] used fuzzy hierarchical production planning approach for solving multi-level production planning problem. Bilgen [7] utilized fuzzy mathematical programming approach for production and distribution planning problem. Ertuğrul and Tuş [8] investigated the interactive FLP approach by utilizing Zimmermann, Werners, Chanas and Verdegay approaches. Their application was performed in the textile industry.

In recent years, FLP has been used in areas such as finance, energy, and transportation [9-15]. In the literature, no study has been found in which FLP has been compared with classical LP in the demand forecasting problem of a make-to-stock company. In this respect, it is expected that this study will make a significant contribution to the literature.

In this paper, production planning problem in a make-to-stock company was investigated and a demand forecasting study was conducted. FLP approach was used to forecast the product demand accurately. Because of the fact that both objective function and constraints include uncertainty, Zimmerman's approach was used. Estimated product demands were obtained from the models of classical LP and FLP. Production planning was performed for each model by using these demand values for three periods. Results were compared with the aspect of inventory carrying cost, imputed shortage cost, and net profit.

2. FUZZY SETS

In classical sets, there are two states, 0 and 1. In other words, an element either belongs to a set or doesn't [16]. For instance, it is supposed that there is a car. The headlights, air conditioner and windscreen wiper of the car are out of service. However, the engine of the car is running and it is moving. In that case, it can't be reached a conclusion that either the car is out of order exactly or it runs precisely. Therefore, it is more suitable to characterize the car as a slight level failed and middle level failed. As is also understood from this example, an element can belong to a set with any value between 0 and 1. This value is entitled as the degree of membership and symbolized with "μ" for fuzzy sets fundamental to fuzzy logic. Also, degrees of membership are expressed with membership functions.

It can be propounded that there are three basic reasons for using fuzzy logic. The first of these is subjectivity. Judgements related to a situation can vary from person to person. For example, we assume there are three age sets; young, middle and old. While thirty age belongs to 'young' set for a person, it belongs to 'middle' set for another person. Secondly, whole elements of a set can't belong to it with the same degree of membership. In addition, an element can belong to sets more than one [17]. Thirdly, real world problems include many variables. Each variable's effect to problem and interactions among them can't be determined exactly. In other words, this is very difficult to model this type of problems. Thus, fuzzy logic can be an ideal approach for solving them.

For instance, it is presumed that there are five sets about temperature; very low, low, middle, high and very high. In this case, we have five fuzzy sets and five membership functions. These are illustrated below:

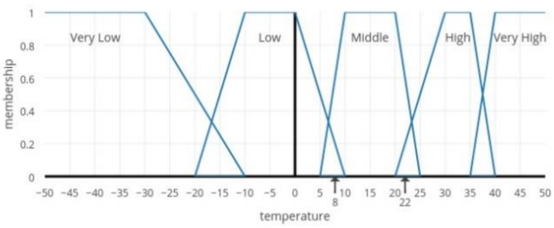

Figure 1. Fuzzy sets and membership functions

As shown in Figure 1, each element of a set can't belong to it with the same degree of membership. For example, whereas 15C° belongs to 'middle' set with 1 degree of membership, 8C° belongs to it with 0.4 degree. Also, 22C° belongs to 'high' set with 0.2 degree of membership and 'middle' set with 0.6 degree. In other words, it belongs to two sets.

In fuzzy logic, triangular and trapezoidal membership functions are used generally. Additionally, membership functions such as gaussian and sigmoid are also available. While determining to suitable membership function for a problem, capability of representation the data in it of membership function must be taken into account [18].

3. FUZZY LINEAR PROGRAMMING

3.1. Linear Programming (LP)

LP is a type of mathematical programming. The aim of mathematical programming is to determine the extremum point of a function under some constraints. Both objective function and constraints are linear in LP [19]. LP model can be loosely formulated as follows:

$$\begin{aligned} &Max\ C^T x \\ &subject\ to \\ &Ax \le b \\ &x \ge 0 \end{aligned} \qquad (1)$$

in which x represents the vector of variables, C is the vector of coefficients in objective function, $(.)^T$ is the matrix transpose, A is a matrix of coefficients in constraints, b is a vector of right-hand sides of the constraints. The expression to be max or min is called objective function.

LP is of crucial importance and it is used in many fields such as engineering and economy [20]. LP problems can be solved with LINDO optimization software. If the objective function, right-hand sides or coefficients of constraints are uncertain, LP isn't appropriate to solve the problem.

Many types of FLP were formed. Some methods were developed for converting them to LP. Finally, they were solved with optimization software [21].

3.2. Fuzzy Linear Programming (FLP)

Sometimes, coefficient of the variable belongs to a problem depends on other parameters. Also, it can't be evaluated exactly and can determine subjectively. Thus, coefficients in problem can include uncertainty. In this case, classical LP falls behind with the solution of the problem. FLP can be an ideal approach for such problems [22]. Formulation of the FLP model can be considered as follows:

$$\begin{aligned} &Max\tilde{Z} = \tilde{C}^T x \\ &subject\ to \\ &\tilde{A}x \tilde{\le} \tilde{b} \\ &x \ge 0 \end{aligned} \qquad (2)$$

in which tilde (~) is fuzzy symbol differently from LP model. To solve this problem, it is necessary to find the probability distribution of the optional objective function Z. To deal with this problem, fuzzy constraints and fuzzy objective function convert into crisp ones [23].

3.3. Zimmermann Method

This method is one of the FLP models. Both objective function and constraints are fuzzy in this method. An FLP model developed by Zimmermann is indicated as follows [21]:

$$C^T x \tilde{\geq} b_0$$
$$(Ax)_i \tilde{\leq} b_i \tag{3}$$
$$x \geq 0 \quad i = 1, 2, \dots, m$$

A symmetrical model in which the objective function becomes a constraint is the inequality. To arrive at a general formulation, this inequality is converted into matrix form as follows:

$$-C^T x \tilde{\leq} -b_0 \tag{4}$$

in which

$$B = \begin{bmatrix} -C \\ A_i \end{bmatrix} \quad b = \begin{bmatrix} -b_0 \\ b_i \end{bmatrix} \tag{5}$$

The constraint's inequalities mean "as small as or equal to" can be allowed to violate right-hand side b by expanding a value. The degree of violation is represented by membership function as:

$$\mu_0(x) = \begin{Bmatrix} 0 & , if\, Cx \leq b_0 - d_0 \\ 1 - \dfrac{b_0 - Cx}{d_0} & , if\, b_0 - d_0 \leq Cx \leq b_0 \\ 1 & , if\, Cx \leq b_0 \end{Bmatrix} \tag{6}$$

$$\mu_i(x) = \begin{Bmatrix} 0 & , if\, (Ax_i) \geq b_i + d_i \\ 1 - \dfrac{(Ax)_i - b_i}{d_i} & , if\, b_i \leq (Ax)_i \leq b_i + d_i \\ 1 & , if\, (Ax)_i \leq b_i \end{Bmatrix} \tag{7}$$

in which d is a matrix of admissible violation. This problem can be expressed as follows using an auxiliary variable represented by λ:

$$\mu_0(x) \geq \lambda$$
$$\mu_i(x) \geq \lambda \tag{8}$$
$$\lambda \in [0,1]$$

Then, the problem can be stated as LP as follows:

$$Max\, \lambda$$
$$s.t.$$
$$\mu_0(x) \geq \lambda \tag{9}$$
$$\mu_i(x) \geq \lambda$$
$$\lambda \in [0,1]$$

This problem is illustrated by the membership functions of the fuzzy objective function and fuzzy constraints as follows:

$$Max\, \lambda$$
$$s.t.$$
$$1 - \frac{b_0 - Cx}{d_0} \geq \lambda$$
$$1 - \frac{(Ax)_i - b_i}{d_i} \geq \lambda, \ \forall i \tag{10}$$
$$\lambda \in [0,1]$$
$$x \geq 0$$

The final form of the FLP model is obtained after some simplifications as follows:

$$Max\, \lambda$$
$$s.t.$$
$$C^T x - \lambda d_0 \geq b_0 - d_0$$
$$(Ax)_i + \lambda d_i \leq b_i + d_i, \ \forall i \tag{11}$$
$$\lambda \in [0,1]$$
$$x \geq 0$$

4. IMPLEMENTATION

Demand forecasting study was conducted with data obtained from a make-to-stock company. The problem was built as FLP model because demand of the product types and expected profit are uncertain. Solution of this model gave estimated demand values for each product type per month to maximize the total profit. Since the company follows make-to-stock strategy, estimated demand values are equal to production amounts. Production data and constraints are given in Table 1.

4.1. Classical LP Model and Solution

Problem was modelled as monthly basis by using related data in Table 1. The classical LP model of the problem is given Eq. (12).

Table 1. Application data

Variables for products	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
Profits (TRY per tonne)	1509	1509	503	1509	1006	503	1509	1006	503
Expected demands (tonne per month)	25	100	150	30	150	200	30	250	80
Tolerances for demands (tonne per month)	5	50	40	5	40	50	5	40	20
Labor usage (hour per tonne)	0.333	0.333	0.333	0.283	0.283	0.283	0.3	0.3	0.3
Expected profit (TRY)					1,200,000				
Tolerance for profit (TRY)					200,000				
Monthly production capacity (tonne)					1150				
Monthly labor capacity (hour)					364				

$$
\begin{aligned}
&Max\ 1509x_1 + 1509x_2 + 503x_3 + 1509x_4 + 1006x_5 + 503x_6 + 1509x_7 + 1006x_8 + 503x_9\\
&subject\ to\\
&x_1 \geq 25\\
&x_2 \geq 100\\
&x_3 \geq 150\\
&x_4 \geq 30\\
&x_5 \geq 150\\
&x_6 \geq 200\\
&x_7 \geq 30\\
&x_8 \geq 250\\
&x_9 \geq 80\\
&0.333x_1 + 0.333x_2 + 0.333x_3 + 0.283x_4 + 0.283x_5 + 0.283x_6 + 0.3x_7 + 0.3x_8 + 0.3x_9 \leq 364\\
&x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 \leq 1150\\
&x_i \geq 0\\
&i = 1,2,\ldots,9
\end{aligned}
\tag{12}
$$

$$
\begin{aligned}
&Max\ \lambda\\
&subject\ to\\
&1509x_1 + 1509x_2 + 503x_3 + 1509x_4 + 1006x_5 + 503x_6 + 1509x_7 + 1006x_8 + 503x_9 - 200{,}000\lambda \geq 1{,}000{,}000\\
&x_1 + 5\lambda \leq 30\\
&x_2 + 50\lambda \leq 150\\
&x_3 + 40\lambda \leq 190\\
&x_4 + 5\lambda \leq 35\\
&x_5 + 40\lambda \leq 190\\
&x_6 + 50\lambda \leq 250\\
&x_7 + 5\lambda \leq 35\\
&x_8 + 40\lambda \leq 290\\
&x_9 + 20\lambda \leq 100\\
&0.333x_1 + 0.333x_2 + 0.333x_3 + 0.283x_4 + 0.283x_5 + 0.283x_6 + 0.3x_7 + 0.3x_8 + 0.3x_9 \leq 364\\
&x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 \leq 1150\\
&\lambda \in [0,1]\\
&x_i \geq 0 \qquad i = 1,2,\ldots,9
\end{aligned}
\tag{13}
$$

LINDO optimization software was used to solve the LP model of the problem. The relevant solution is given in Table 2.

Table 2. Results of LP model

Variable	Value	Reduced Cost
Objective Function	1,101,570 TRY	-
X_1	160	0
X_2	100	0
X_3	150	0
X_4	30	0
X_5	150	0
X_6	200	0
X_7	30	0
X_8	250	0
X_9	80	0

4.2. FLP Model and Solution

Problem was modelled as monthly basis by using related data in Table 1. The FLP model of the problem is given Eq. (13).

LINDO software was used to solve the FLP model of the problem. The relevant solution is given in Table 3.

Table 3. Results of FLP model

Variable	Value	Reduced Cost
λ	0.234	0
X_1	28.832	0
X_2	138.321	0
X_3	180.657	0
X_4	33.832	0
X_5	180.657	0
X_6	177.885	0
X_7	33.832	0
X_8	280.657	0
X_9	95.329	0

4.3. Comparison Between FLP and LP

Quarterly production plans of each model were made by using estimated demand values obtained from LP and FLP.

Outputs of production plans were compared in terms of inventory carrying cost, imputed shortage cost and net profit.

The company can carry inventory maximum 3 months because of the deterioration problem of products. Monthly inventory carrying cost for the company is 12% of product profit per tonne. The company practices back order strategy. If it meets back orders next month, imputed shortage cost for stock-out products is equal to 50% of unit profit. If it meets after two months, the cost is equal to 75% of unit profit. Otherwise, the cost is equal to unit profit.

Production plans of LP and FLP are shown in Table 4 and Table 5.

Table 4. Production planning of LP model

	P (t-2)	D (t-2)	IS (t-2)	P (t-1)	D (t-1)	IS (t-1)	P (t)	D (t)	IS (t)	Descriptions
X_1	160	30	130 (I)	160	27	263 (I)	160	29	394 (I)	**t**: Time period (month), **P**: Production (tonne),
X_2	100	120	20_0 (S)	100	113	20_1+13_0 (S)	100	138	$20_2+13_1+38_0$ (S)	**D**: Demand (tonne), **IS**: Inventory Status, **I**: Inventory, **S**: Stock-out
X_3	150	147	3 (I)	150	149	4 (I)	150	162	8_0 (S)	**20_0**: 20 items can't be met in this period, they can be met next period.
X_4	30	28	2 (I)	30	33	1_0 (S)	30	31	-	
X_5	150	160	10_0 (S)	150	152	10_1+2_0 (S)	150	157	$10_2+2_1+7_0$ (S)	**$20_2+13_1+38_0$**: 20 items are stock-out since two period, 13 items are stock-out since one period and 38 items are stock-out in last period.
X_6	200	190	10 (I)	200	195	15 (I)	200	184	31 (I)	**Profit Status**
X_7	30	31	1_0 (S)	30	32	1_1+2_0 (S)	30	34	$1_2+2_1+4_0$ (S)	Total Profit = $\sum_{x=1}^{9}$ Estimated production amount x Unit profit
X_8	250	257	7_0 (S)	250	261	7_1+11_0 (S)	250	260	$7_2+11_1+10_0$ (S)	Net Profit = Total Profit – (Inventory carrying cost + Imputed shortage cost)
X_9	80	83	3_0 (S)	80	84	3_1+4_0 (S)	80	89	$3_2+4_1+9_0$ (S)	Net Profit = 1,101,570 - (146,673.84 + 123,863.75) = 831,032.4 TRY

Table 5. Production planning of FLP model

	P (t-2)	D (t-2)	IS (t-2)	P (t-1)	D (t-1)	IS (t-1)	P (t)	D (t)	IS (t)	Net Profit
X_1	28.832	30	1.168_0 (S)	28.832	27	0.664 (I)	28.832	29	0.496 (I)	
X_2	138.321	120	18.321 (I)	138.321	113	43.642 (I)	138.321	138	43.963 (I)	
X_3	180.657	147	33.657 (I)	180.657	149	65.314 (I)	180.657	162	83.971 (I)	
X_4	33.832	28	5.832 (I)	33.832	33	6.664 (I)	33.832	31	9.496 (I)	
X_5	180.657	160	20.657 (I)	180.657	152	49.314 (I)	180.657	157	72.971 (I)	958,115.4 TRY
X_6	177.885	190	12.115_0 (S)	177.885	195	12.115_1 $+17.115_0$ (S)	177.885	184	12.115_2 $+17.115_1+6.115_0$ (S)	
X_7	33.832	31	2.832 (I)	33.832	32	4.664 (I)	33.832	34	4.496 (I)	
X_8	280.657	257	23.657 (I)	280.657	261	43.314 (I)	280.657	260	63.971 (I)	
X_9	95.329	83	12.329 (I)	95.329	84	23.658 (I)	95.329	89	29.987 (I)	

5. CONCLUSION

In this paper, demand forecasting problem of a make-to-stock company was addressed. Because the company follows make-to-stock strategy, it needs estimated product demand values to develop a production planning. However, product demand cannot be known precisely and it varies from period to period. Because of this uncertainty, fuzzy logic can be an ideal approach for estimating the product demand with a minimum error.

As estimation of product demand was more accurate, Zimmerman's FLP approach was used. Amount of production for each product type was obtained from the solutions of FLP and LP. Output of production plans based on solutions of FLP and LP models were compared in terms of costs and net profit. Results showed that when fuzzy logic and LP was used together, product demands were forecasted more accurately. Therefore, inventory carrying cost and imputed shortage cost reduced by 67% totally and also net profit increased by 15%.

Author contributions: Concept – Ç.T.; Data Collection &/or Processing – Ç.T.; Literature Search – Ç.T.; Writing – Ç.T.
Conflict of Interest: No conflict of interest was declared by the author.
Financial Disclosure: The author declared that this study has received no financial support.

REFERENCES

[1] S. M. Guu and Y. K. Wu, "Two-phase approach for solving the fuzzy linear programming problems", Fuzzy Sets and Systems, vol. 107, pp. 191-195, 1999.

[2] A. N. Gani, C. Duraisamy, and C. Veeramani, "A note on fuzzy linear programming problem using L-R fuzzy number", International Journal of Algorithms, Computing and Mathematics, vol. 3, pp. 93-106, 2009.

[3] A. Azizi, A. Y. Ali, and L. W. Ping, "Modelling production uncertainties using the adaptive neuro-fuzzy inference system", South African Journal of Industrial Engineering, vol. 26, no. 1, pp. 224-234, 2015.

[4] K. Worapradya and P. Thanakijkasem, "Optimising steel production schedules via a hierarchical genetic algorithm", South African Journal of Industrial Engineering, vol. 25, no. 2, pp. 209-221, 2014.

[5] J. C. Figueroa-García, D. Kalenatic, and C. A. Lopez-Bello, "Multi-period mixed production planning with uncertain demands: fuzzy and interval fuzzy sets approach", Fuzzy Sets and Systems, vol. 206, pp. 21-38, 2012.

[6] S. A. Torabi, M. Ebadian, and R. Tanha, "Fuzzy hierarchical production planning (with a case study)", Fuzzy Sets and Systems, vol. 161, no. 11, pp. 1511-1529, 2010.

[7] B. Bilgen, "Application of fuzzy mathematical programming approach to the production allocation and distribution supply chain network problem", Expert Systems with Applications, vol. 37, no. 6, pp. 4488-4495, 2010.

[8] I. Ertuğrul and A. Tuş, "Interactive fuzzy linear programming and an application sample at a textile firm", Fuzzy Optimization and Decision Making, vol. 6, no. 1, pp. 29-49, 2007.

[9] S. Akbaş, T. E. Dalkilic, and T. G. Aksoy, "A study on portfolio selection based on fuzzy linear programming", International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems, vol. 30, no. 2, pp. 211-230, 2022.

[10] D. Yin, "Application of interval valued fuzzy linear programming for stock portfolio optimization", Applied Mathematics, vol. 9, pp.101-113, 2018.

[11] Ş. Emeç and G. Akkaya, "Developing a new optimization energy model using fuzzy linear programming", Journal of Intelligent and Fuzzy Systems, vol. 40, pp. 9529–9542, 2021.

[12] P. Sefeedpari, S. Rafiee, M. Sharifi, and A. Akram, "Detecting the best optimal dairy cattle herd sizes based on energy consumption using fuzzy linear programming model", Iranian Journal of Biosystem Engineering, vol. 49, no. 1, pp. 149-159, 2018.

[13] I. U. Khan, and F. Rafique, "Minimum-cost capacitated fuzzy network, fuzzy linear programming formulation, and perspective data analytics to minimize the operations cost of American airlines", Soft Computing, vol. 25, pp. 1411–1429, 2021.

[14] E. Escobar-Gómez, J. L. Camas-Anzueto, S. Velázquez-Trujillo, H. Hernández-de-León, R. Grajales-Coutiño, E. Chandomí-Castellanos, and H. Guerra-Crespo, "A linear programming model with fuzzy arc for route optimization in the urban road network", Sustainability, vol. 11, no. 23, pp. 6665, 2019.

[15] A. Güler and H. Bircan, "Fuzzy linear programming and an application in BIMS production facility", Turkish Studies - Economy, vol. 16, no. 2, pp. 823-837, 2021.

[16] G. Chen and T. T. Pham, Introduction to Fuzzy Sets, Fuzzy Logic and Fuzzy Control Systems. Boca Raton: CRC Press, 2001.

[17] B. Yıldız, Artificial Intelligence in Financial Analysis, Detay Publishing, 2009.

[18] M. Mutingi and C. Mbohwa, "A fuzzy-based particle swarm optimisation approach for task assignment in home healthcare", South African Journal of Industrial Engineering, vol. 25, no. 3, pp. 84-95, 2014.

[19] E. Dervişoğlu, "Fuzzy linear programming: review and implementation", Master thesis, Sabanci University Institute of Engineering and Science, Istanbul, 2005.

[20] J. L. Verdegay, "Progress on fuzzy mathematical programming: A personal perspective", Fuzzy Sets and Systems, vol. 281, pp. 219-226, 2015.

[21] C. S. Lee and C. G. Wen, "River assimilative capacity analysis via fuzzy linear programming", Fuzzy Sets and Systems, vol. 79, pp. 191-201, 1996.

[22] J. Ren and T. B. Sheridan, Optimization with Fuzzy Linear Programming and Fuzzy Knowledge Base, IEEE 3rd International Fuzzy Systems Conference, pp. 1389-1393, Orlando, 1994.

[23] R. R. Gasimov and K. Yenilmez, "Solving fuzzy linear programming problems with linear membership functions", Turkish Journal of Mathematics, vol. 26, no. 4, pp. 375-396, 2002.