...::KENT AKADEMİSİ | URBAN ACADEMY

Volume: 18 Issue: 4 - 2025 | Cilt: 18 Sayı 4 - 2025

ARTICLE INFO | MAKALE KUNYESI

Article Type: Research Article | Araştırma Makalesi
Submission Date | Gönderilme Tarihi: 25.10.2024
Admission Date | Kabul Tarihi: 08.05.2025

CITATION INFO | ATIF KÜNYESİ

Ünal, A. U. (2025). An Analysis on the Transition of Autonomous Port Systems in Turkish Ports Operating in the Marmara Region, *Kent Akademisi Dergisi*, *18*(4):2063-2082. https://doi.org/10.35674/kent.1573158

An Analysis on the Transition of Autonomous Port Systems in Turkish Ports Operating in the Marmara Region

Marmara Bölgesi'nde Faaliyet Gösteren Türk Limanlarında Otonom Liman Sistemlerine Geçiş Sürecine İlişkin Bir Analiz

Ali Umut ÜNAL[1]

Öz

Otonom limanlar, son dönemlerde yapay zekânın gelişimi tercih edilmeye başlanmış yeni nesil liman yönetim türüdür. Aynı zamanda evrak işlemleri ve her türlü yük bilgi takibinin otomatik olarak takip edildiği ve istenildiğinde anlık veri verilebildiği sistemleri barındırmaktadır. Otonom limanlara olan yönelim, ağırlıklı olarak Avrupa limanlarında başlamış olup, tüm dünya limanlarının bu yeni liman yönetim türüne geçişleri gerçekleşmektedir. İnsan faktörünün merkezci yaklaşımını değiştirerek, otomasyonun ön plana çıkmasını ve operasyonlarda hata paylarını azaltmayı hedeflemektedir. Yapay zekâ tarafından yapılan hızlı analizler sayesinde, beklemelerde azalmalar ve verimlilikte artışlar olduğu görülmüştür. İnsan faktörünün iş gücünden beyin gücüne doğru evrildiği bu sistemde, insan kontrolünde olan operasyon ekipmanları, birçok iş kazası riskini ortadan kaldırmakta ve olası tehlike durumlarında can kaybı ve yaralanmaları ciddi anlamda azaltmaktadır. Türk limanlarının otonom liman sistemine geçişleri esnasında, hangi avantajlar ve dezavantajlar ile karşı karşıya kalacaklarını belirlemeleri gerekmektedir.

Bu çalışmanın amacı, Marmara Bölgesi'nde faaliyet gösteren limanların otonom liman yönetimine geçiş sürecinde, altyapı ve ekipmanlarının durumuna göre elde edebilecekleri avantaj ve dezavantajları belirlemektir. Bu avantaj ve dezavantajları tespit edilmesi için limancılık sektöründe faaliyet gösteren uzmanların değerlendirmelerinde, SWOT analizi yöntemi kullanılmıştır. Bu çalışma, gelecekte yapılacak olan otonom liman projelerine altyapı oluşturmayı hedeflemektedir. Limanlar için otonom liman sisteminin düşük maliyetlerle, kesintisiz ve sürekli hizmet sunmanın önemli faydalar sağladığı; altyapı yatırımları, internet altyapısı ve siber saldırıların ise ciddi tehditler olduğu görülmektedir.

Anahtar Kelimeler: Deniz İşletmeciliği, Deniz Ulaşımı, Limanlar, Liman Yönetimi, Otonom Liman

ABSTRACT

Autonomous ports represent a novel generation of port management systems that have recently come to the fore in the context of the development of artificial intelligence. These systems automate the monitoring of paperwork and cargo information, ensuring the provision of real-time data upon request. The adoption of autonomous port management systems has emerged predominantly in European ports, and it is anticipated that all global ports will transition to this novel port management paradigm. The objective of this transition is to minimize operational errors by shifting from a human-centric approach to a more automated one. The utilization of artificial intelligence has been observed to facilitate rapid analyses, leading to the identification of reductions in waiting times and productivity increases. In this system, the human factor evolves from labor power to brain power, and human-controlled operation equipment eliminates the risk of many work accidents and significantly reduces the loss of life and injuries in possibly dangerous situations. Turkish ports must assess the potential advantages and disadvantages that they will encounter during their transition to the autonomous port system.

The objective of this study is to ascertain the merits and demerits that ports operating within the Marmara Region can attain by the condition of their infrastructure and equipment during the transition to autonomous port management. To this end, a SWOT analysis was conducted, encompassing evaluations from experts in the port sector. The objective of this study is to establish an infrastructure for prospective autonomous port initiatives. The autonomous port system offers significant benefits, including the provision of uninterrupted and continuous service at low cost. However, it is also important to acknowledge the potential challenges posed by infrastructure investments, internet infrastructure and cyber-attacks.

Keywords: Maritime Management, Maritime Transport, Port, Port Management, Autonomous Port

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INTRODUCTION

Ports fulfill a dual function, serving to facilitate the handling of commercial cargo whilst also acting as pivotal hubs for economic activity. The intensifying competitive landscape within the port industry has prompted the development of automated terminals. The objective of this development is threefold: firstly, to reduce operating costs; secondly, to enhance operational efficiency; and third, to improve occupational safety and environmental sustainability (Park et al., 2022). As global maritime trade and cargo volumes at port terminals have increased, cargo handling operations have become a significant factor in reducing ship turnaround time (Park et al., 2021). In the contemporary era, seafaring vessels are required to possess specific attributes to facilitate the process of docking and loading/unloading in port facilities. The harbor length, depth, and quay length represent critical dimensions that play a pivotal role in this regard (Arıcan et al., 2020). It is important to note that not all ports can accommodate high-tonnage ships, which can lead to costs exceeding those of smaller vessels (Arıcan, 2023).

The role of port management is of great consequence in determining the competitiveness of ports, which is closely linked to the reliability of port services (Duvallet et al., 2023). In the context of evolving global trade dynamics, ports are gaining prominence as pivotal nodes in the global maritime container transport network. This has necessitated enhanced efficiency and cost optimization in operations (Yu, 2024). Operations taking place in autonomous ports represent a significant advance in the maritime industry. These operations leverage emerging technologies to enhance efficiency, safety and sustainability (Min, 2022).

The port of Rotterdam, widely regarded as the most significant port in Europe, is at the vanguard of integrating autonomous technologies and intelligent port initiatives, mirroring a broader tendency towards automation and digitalization in the maritime industry (Razmjooei et al., 2023). The term "autonomous port" is used to describe a port where all operational activities are automated. The implementation of autonomous port technology has led to a decline in the number of personnel required for operational activities, as well as a decrease in the volume of written documentation generated by humans.

The transition of autonomous ports towards smart ports, facilitated by the integration of digital technologies and autonomous systems, represents a substantial advancement in the domain of commercial ports worldwide (Makkawan and Muangpan, 2021). Autonomous ports are distinguished by intelligent navigation, automation, and reduced reliance on manual labor, thereby facilitating a transition toward more efficient and technologically advanced operations (Chang et al., 2022). The advent of unmanned operations in port management constitutes a substantial departure from the mere technological development that has hitherto characterized this field. The advancement of autonomous management systems in the maritime industry, including ports, is associated with the concept of Maritime 4.0, which underscores the significance of digitalization and ship management (Sullivan et al., 2021). The integration of Artificial Intelligence (AI) within these systems plays a pivotal role in facilitating digital transformations in ports, enabling the transition of tasks to digital domains and enhancing the capabilities of autonomous operations within port areas. The utilization of artificial intelligence in the digitalization of autonomous ports is identified as a pivotal and instrumental factor in enhancing operational procedures and business efficiency within port operations (Ghazaleh, 2023). In addition, ports such as the autonomous port of San Pedro in the USA are adapting to recent trends in green and sustainable port operations, thereby contributing to environmental protection activities (Kadio, 2023). The incorporation of environmentally conscious practices within port operations, with a particular emphasis on sustainability, corporate social responsibility, and legal compliance, is becoming increasingly crucial (Casaca and Lyridis, 2022).

The integration of autonomous systems within port management structures necessitates a comprehensive reassessment of prevailing port management practices (Ngoc et al., 2021). The advent of these technologies has the potential to facilitate real-time monitoring, control and decision-making processes, thereby enhancing the efficiency of port operations (Zahid et al., 2021). However, it is crucial to recognize the imperative for robust security measures in the integration of autonomous systems within port operations. This is due to the inherent risks associated with cyber-physical systems, as highlighted by Zahid et al. (2021).

The present study will evaluate the potential benefits and challenges of Turkish ports in the transition to an autonomous port system through the application of a SWOT analysis, incorporating the opinions of experts. The study will then present recommendations for the port sector. This comprehensive assessment is intended to provide an important roadmap for Türkiye, enabling the country to enhance its competitiveness in the maritime sector and prepare for the future of ports.

The subsequent section provides a comprehensive delineation of the configuration of the present study. Firstly, an overview of the general structure of autonomous ports is presented, along with a concise examination of autonomous ports on a global scale. Additionally, a brief analysis of the advantages and disadvantages associated with autonomous ports is offered. The subsequent section details the methodology employed in this study, including the employment of a SWOT analysis. The findings section will evaluate the scenarios that Turkish ports will encounter during their transition to autonomous port management. This evaluation will be conducted by experts with experience in the port sector using the SWOT analysis method. The discussion will be determined under four main headings. The conclusions of the SWOT analysis for Turkish ports are presented and discussed, and the study is concluded with a summary of its contributions to future research.

1. Autonomous Port Concept

Autonomous ports are defined by their integration of technological innovation, operational efficiency and environmental sustainability in the domain of port management. This paradigm shift in port operations is driven by the increasing adoption of digitalization and smart infrastructure in the global logistics and transport sectors.

The enhanced risk-free decision-making capabilities of autonomous port equipment facilitate more effective and productive operations, enhance service profitability through the provision of a secure operational environment, and facilitate the assurance of cargo and handling equipment safety, particularly personnel safety (Hong et al., 2023). As Duan et al. (2023) have demonstrated, the optimization of the operation timing of automated guided vehicles and automated stacking cranes in autonomous container terminals can significantly improve the efficiency of equipment utilization, thereby contributing to energy saving and emission reduction in line with the goal of efficient use of resources and the creation of environmentally friendly ports. The port of Rotterdam, and more specifically the Maasvlakte 2 terminal, represents the pinnacle of automation in the European port network. A similar increase in automation levels has been observed at other major ports, including those in Hamburg, Antwerp, Barcelona, Algeciras, London, Liverpool and Thamesport (Sdoukopoulos et al., 2019).

The implementation of automated processes in port operations has been shown to enhance safety and efficiency, thereby facilitating more effective and high-capacity planning (Jones, 2022). The utilization of Digital Twin (DT) technology facilitates a more efficacious deployment of autonomous technologies, thereby enabling a rapid assessment of the situation and the capacity for immediate decision-making (Toygar, 2024). The integration of these two transformative technologies has the potential to create a more sustainable, efficient and safe port operation through the automation of port operations and the improvement of these operations through simulations (Toygar, 2024). Molavi

et al. (2020) have identified four main operational areas and sub-areas that underpin the concept of a smart port. These four areas are as follows: Area 1, operations, comprising three sub-areas: efficiency, automation and smart infrastructure systems; Area 2, environment, comprising four sub-areas: environmental management systems, emissions and pollution control, waste management and water management; Area 3, energy, comprising three sub-areas: efficient energy consumption, generation and use of renewable energy sources and energy management; and Area 4, safety and security, comprising three sub-areas: safety management systems, security management systems and unified monitoring and optimization systems.

The advantages of autonomous ports are manifold. These include increased operational efficiency, enhanced safety through sophisticated collision avoidance systems, and a reduction in greenhouse gas emissions (Hirata, 2024). The transition to autonomous ports is congruent with the overarching Industry 4.0 trend in the maritime sector, emphasizing the imperative of comprehending and mitigating the risks associated with heightened degrees of autonomy in maritime transportation (Sano, 2023). The vulnerability of shipments during customs inspections and the social production of container space emphasizes the necessity for robust security measures in autonomous port operations (Amro et al., 2021). The necessity for compliance with autonomous port regulations specific to each port is underscored by the importance of energy management optimization and solutions for marine pollution in ports, which are vital for reducing environmental risks (Öztürk et al., 2019). In a study conducted by Al-Fatlawi and Motlak (2023), the enhanced productivity and high performance of smart ports for a more sustainable environment were investigated.

A significant disadvantage is the liability issue, which may impede the full commercial implementation of autonomous inland shipping. A comprehensive evaluation of the prevailing legal framework is imperative to ascertain its applicability to novel autonomous systems (Domenighini, 2024). In the field of control theory, the identifiability of linear port Hamiltonian systems poses a considerable challenge, with the potential to influence the effectiveness of autonomous port operations (Medianu and Lefèvre, 2021). The environmental impact of autonomous ports gives rise to concerns about sustainability and ecological footprint, particularly concerning air pollution from energy generation sources such as autonomous generator sets (Tarnapowicz and German-Galkin, 2016). In the domain of cyber security, the growing reliance on autonomous systems in ports necessitates the implementation of robust cyber security measures to safeguard against potential cyber threats and attacks (Yağdereli et al., 2015). The integration of autonomous vehicles and logistics systems into port operations poses novel challenges concerning system optimization and uncertainty management (Castaneda et al., 2022).

The autonomization of port operations and operational changes in port management and port employee interactions have resulted in an immediate response to the 'new normal' imposed by the Coronavirus Disease 2019 (COVID-19) pandemic. These developments have precipitated a rapid evolution in port management practices, digitalization, automation and recently approved port management models, intending to sustain and enhance the resilience of maritime supply chains (Notteboom et al., 2021).

As the maritime industry adopts the principles and practices of Industry 4.0, autonomous port indicators and performance metrics will be pivotal elements in the transition to smart and digital ports, reflecting a global shift towards modernizing port infrastructure (Makkawan and Muangpan, 2021). The assessment of navigational risks in port approach maneuvers, employing a combination of expert judgment and machine learning, will facilitate the enhancement of safety protocols for autonomous port operations (Serra et al., 2022). The restriction of human access in the development of fully autonomous port cargo handling facilities can enhance the safety guarantees inherent to autonomous port environments (Castaneda et al., 2022).

The implementation of cloud-based tools and technologies, including artificial intelligence, the Internet of Things (IoT), and autonomous driving, plays a significant role in optimizing port operations and enhancing overall efficiency (Cho and Lee, 2020). The potential applications are numerous and include the operation of fully autonomous ports, autonomous cranes for loading and unloading containers, autonomous vehicles for transporting containers, Global Positioning System (GPS) tracking for cargo, the monitoring of the origin of goods, the establishment of seamless communication with trucks, trains and cars along the supply chain, the implementation of real-time surveillance of ports, and the reduction of labor and operating costs (Lesniewska et al., 2019).

To ensure the safe and efficient operation of autonomous systems in ports, it is imperative to employ data-driven methodologies incorporating machine learning and artificial intelligence. This is vital for sustaining the relevance of these technologies and for the development of new port maneuvering guidelines, as well as for the overall maneuvering of autonomous vessels in port environments (Lee et al., 2021). The management of emerging technologies in post-Brexit ports, including the adoption of fully automated ports, autonomous cranes, vehicles, GPS tracking and real-time surveillance, has introduced complexities that require robust regulatory frameworks and strategic planning (Lee et al., 2021). These issues must be addressed in a timely and effective manner (Lesniewska et al., 2019).

The issue of the Battery Management System (BMS) employed in the equipment utilized in autonomous ports is a significant one and one which merits consideration in light of the challenging safety and reliability standards that must be met (Momete, 2018). Moreover, digital technologies such as Blockchain for ports, Blockchain Distributed Ledger Technology (DLT) and data-enabling technologies have become of significant importance for small and medium-sized ports. To effectively navigate the evolving market landscape and the digital transition that lies ahead, small and medium-sized ports must adopt a more agile and responsive approach. (Feng and Notteboom, 2013).

The issue of cybersecurity risks in the context of autonomous and remotely controlled vessels has been the subject of considerable analysis, which has underscored the vital importance of effective cyber threat management to guarantee the safe operation of autonomous systems in ports (Kavallieratos and Katsikas, 2020). As the maritime industry undergoes a transition towards autonomous operations, the vulnerability of port facilities and vessels to cyber-attacks becomes a significant concern, emphasizing the necessity for robust cybersecurity measures to protect autonomous systems (Kapalidis et al., 2022). Moreover, the psychological ramifications of the transition to autonomous maritime operations, including in harbors, necessitate meticulous consideration (Tam et al., 2021). The utilization of drones for port security, as an illustration, highlights the imperative for thorough risk assessment and mitigation strategies (Abkal et al., 2020). It is imperative to enhance the training standards for maritime personnel, ensuring a comprehensive understanding of maritime conventions and optimizing communication techniques within the port environment (Arıcan, 2024).

2. Method

SWOT analysis is a valuable strategic planning tool that enables organizations to assess their internal and external environment. Through the identification of the organization's strengths, weaknesses, opportunities and threats, it is possible to develop strategies that are both informed and conducive to increasing competitiveness and sustainability. Despite its inherent limitations, the efficacy of SWOT analysis can be augmented through integration with other strategic planning instruments. A comprehensive approach to SWOT analysis facilitates more effective decision-making and contributes to organizational success.

The SWOT analysis is a strategic planning tool that is employed to evaluate the internal and external factors that may potentially impact an organization's performance and competitiveness. A SWOT analysis involves a comparison of an organization's internal strengths and potential areas for

improvement with the external opportunities and threats identified through environmental scanning. In essence, a SWOT analysis is a strategic planning tool that is employed to evaluate both internal and external factors that may affect an organization's performance and competitiveness (Özan et al., 2015).

Furthermore, experts are also consulted in other studies on autonomous ports. Akgül and Gençer (2017) developed a series of open-ended questions on the concept of smart port in their study titled 'Smart Port: Opportunities and Threats'. These questions were distributed to key stakeholders in the sector, and the data obtained were presented for their evaluation. Çalışkan (2020) conducted a study to evaluate the challenges faced in the transformation of ports into smart ports. In the study, the Interpretive Structural Model (ISM) method was employed in conjunction with expert opinions to identify and analyze potential challenges related to this transformation. Makkawan and Muangpan (2021) conducted a study on a conceptual model for smart port performance and smart port indicators in Thailand. During the study, the researchers conducted in-depth interviews with participant observers and conducted a comprehensive review of the relevant literature. Gürsoy and Hatunoğlu (2022) employed a purposive sampling method to select port employees as the sample in their exploratory research on the awareness of applications for smart port structuring. A face-to-face survey was conducted to collect data on this subject. In a separate study, Park et al. (2023) conducted a SWOT analysis on the simulation and operating costs of autonomous vehicle loading systems in Ro-Ro ports.

In the present study, online interviews were conducted with experts who have been working in the port sector for a minimum of eight years and were invited to offer their valuable opinions on the transformation of the existing port system into an autonomous port system. The participants are primarily operating in ports in the Marmara Region, and no distinction was made based on terminals in the port sector. To ensure a comprehensive representation, nine experts were selected to cover all terminals. Participants were invited to offer their opinions in four main categories, under the SWOT analysis method. This entailed a reflection on the current situation of their ports and the conveyance of their sectoral experiences. The opinions expressed by the participants were summarised and weighted, and are presented in the evaluation section. Table 1 provides a summary of general information about the experts who participated in this study.

Table 1. General Information of the Experts

Expert	Position	Professional Experience (Year)	Level of Education
Expert 1	Operation Manager	8 years	Master Degree
Expert 2	Planning Manager	9 years	Master Degree
Expert 3	Operation Manager	8 years	Undergraduate
Expert 4	Personnel Manager	12 years	Master Degree
Expert 5	Planning Manager	11 years	Master Degree
Expert 6	Operation Manager	15 years	Undergraduate
Expert 7	Technical Manager	9 years	Undergraduate
Expert 8	Personnel Manager	13 years	Master Degree
Expert 9	Technical Manager	11 years	Undergraduate

A methodology incorporating SWOT analysis has been developed to evaluate Turkish ports concerning autonomous ports. The overarching objective of the methodology is to examine the infrastructure and

superstructure of ports operating within the Marmara Region, irrespective of the nature of the cargo. The methodology for evaluating autonomous ports for Turkish ports is illustrated in Figure 1.

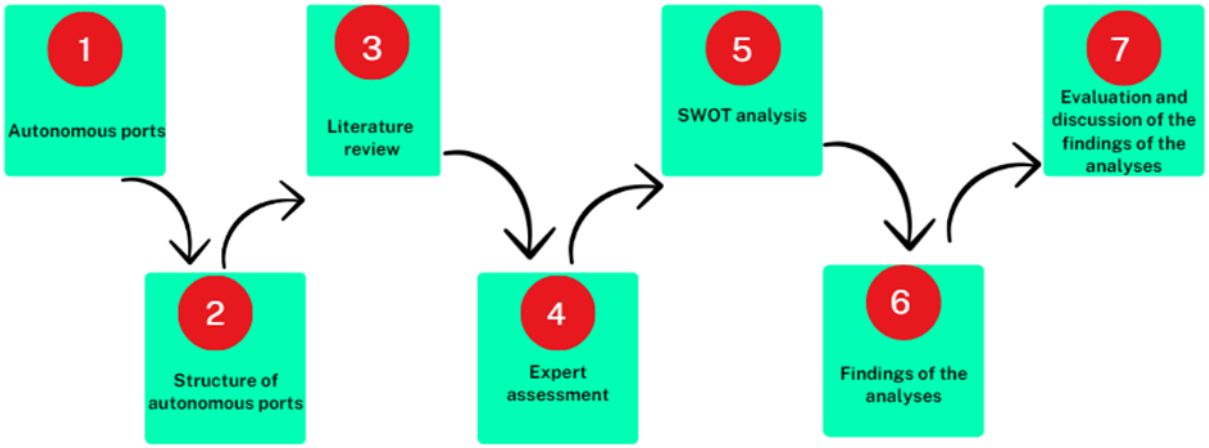

Figure 1. Autonomous Port Assessment Flow Diagram for Turkish Ports

3. Findings

In the course of the interviews conducted with nine experts on the transition of Turkish ports to autonomous ports, the infrastructure and superstructure systems of the ports were evaluated, and the experts were asked to adopt an unbiased approach. The experts subsequently reported their evaluations in the light of their own experiences under four main headings in mutual online interviews. The data obtained were weighted and presented below under the four main headings.

3.1. Strengths

• High Operational Efficiency: The advent of autonomous ports has been demonstrated to engender a reduction in handling costs, an enhancement in operational efficiency, and an acceleration in handling times through automation and optimized processes. The continuous measurement and control systems of autonomous ports ensure the regular measurement and optimization of energy consumption. A further benefit is the reduction in emissions, which is achieved through a decrease in carbon emissions.

• Enhanced Safety: Autonomous equipment and systems offer a more secure working environment by reducing the incidence of human error and incorporating safety measures such as collision avoidance systems.

• Improving Security: In the context of the withdrawal of personnel from operation and storage areas in autonomous ports, there will be a reduction in personnel mobility. Consequently, the withdrawal will result in enhanced security, which can be more readily controlled and monitored. The installation of cameras equipped with motion sensors will facilitate more effective control of unauthorized access to the sites.

• Sustainability: It is imperative to ensure that operations are conducted in an environmentally sustainable manner. This objective can be realized through the optimization of energy consumption, the reduction of emissions, and the utilization of green energy sources.

• Personnel Safety: The automation of hazardous tasks and the removal of personnel from high-risk environments has been demonstrated to enhance personnel safety. The number of personnel involved in hazardous operations conducted within the scope of the services provided by autonomous

ports will be significantly reduced, thereby enhancing the safety of the personnel. As the risk of accidents to personnel decreases, an increase in trust and loyalty to the work will be observed.

- Service Profitability: The impact of the initiative was twofold: firstly, it increased the service profitability of the ports; secondly, it led to an increase in productivity and a cost reduction.

- Resilience: It reduces the fragility of supply chains by ensuring the continuity of operations even in crises such as COVID-19. Even in similar pandemics and national-international crises, ports will be able to ensure the continuity of operations thanks to their autonomous infrastructure.

- 24/7 Operation: It has been demonstrated that the implementation of such technology enables ports to provide uninterrupted service by reducing dependence on manpower. A recent significant demand made by ships to ports is the requirement for 24/7 service. In this context, autonomous ports emerge as a pivotal element, capable of handling substantial loads in information entry and subsequent operations with efficiency.

- Reduced Human Error: In the context of autonomous port operations, delays caused by human error will be eliminated as operations involving the transfer of cargo from in-port activities to ship-based activities will be monitored by artificial intelligence.

- Advanced Monitoring Systems: In autonomous port systems, the movement of cargo is subject to comprehensive and continuous monitoring, from the moment of its arrival at the port until its departure. This information is updated instantaneously, and the system can generate reports upon request. Consequently, the port can respond to the demands of its customers, particularly those of the agency and shipowner.

3.2. Weaknesses

- High Initial Cost: The establishment of autonomous port infrastructure and the conversion of existing systems necessitate a substantial capital investment. Moreover, a significant expense is incurred in the integration of existing systems into autonomous port systems. Consequently, ports will need to allocate substantial resources to facilitate these transitions.

- Applicability for Small and Medium-Sized Ports: The transition to autonomous technologies has the potential to present financial and technical challenges for small and medium-sized ports. For Turkish ports with smaller and medium-sized capacities, this transition will result in increased costs.

- Loss of Labour Force: The advent of automation has the potential to result in the elimination of certain employment opportunities and an increase in unemployment rates. The transition to autonomous ports is likely to increase unemployment rates, particularly among unskilled workers, thereby giving rise to unemployment-related issues.

- Legal and Regulatory Challenges: Existing legal frameworks providing a regulatory framework for autonomous port operations may be inadequate and may require new regulations. The prevailing legal framework is centered on the human labor force, and it may be the case that such regulations are inadequate in the event of accidents and potential loss of life resulting from the operation of unmanned systems within autonomous ports.

- Cyber Security Risks: The utilization of autonomous systems may render operations and data integrity vulnerable to cyber-attacks, which have the potential to jeopardize the systems' functionality. Internet connections must be secure and protected against all kinds of cyber-attacks in a continuous and up-to-date manner. A comparative analysis reveals that Türkiye is lagging behind European countries concerning internet infrastructure and speed. In the event of an internet outage, the

disconnection of unmanned equipment in autonomous ports has the potential to induce significant operational disruptions within the port.

- Maintenance and Repair Difficulties: The maintenance and repair of autonomous equipment may require expertise and specialized equipment. The fact that the equipment in the infrastructures of autonomous ports is mainly imported, the need for foreign operators to provide training for their use, the arrival of teams from abroad for maintenance and repair operations in the first place and the procurement of spare parts from abroad will cause significant expenditures. In the event of a malfunction, the procurement of parts from abroad can also result in significant delays and financial losses for the port.

- Handling Damaged Containers: In autonomous port systems, the condition of the cargo in cargo operations is monitored by camera systems. However, the capacity of artificial intelligence to recognize superficial damages, especially in container loads, may be limited when scanning the photographic system to detect possible damages. Consequently, intervention in containers with low damage may be delayed in container cargo handling operations.

3.3. Opportunities

- Technological Advances: Advancements in artificial intelligence, the Internet of Things (IoT), autonomous driving and cloud technologies present opportunities to further optimize port operations and increase efficiency.

- New Job Opportunities: The advent of autonomous ports has the potential to generate novel employment opportunities, including roles such as technologists, data analysts and cyber security experts. Consequently, the emergence of new employment opportunities in these fields is likely to give rise to novel business lines.

- Competitive Advantage: The transition of Turkish ports to autonomous port management will enable them to execute operations with the same efficiency and performance as other ports worldwide. This will result in an increase in their market share and a positive change in cargo handling rates. The decline in time spent in ports and the enhancement of operational efficiency is anticipated to result in a shift in the ports of call for transit cargoes, thereby augmenting the demand for Turkish ports.

- Data-Driven Decision Making: The utilization of autonomous systems has been demonstrated to enhance decision-making processes through the aggregation and examination of data. The handling of cargo and the provision of services to ships are meticulously documented. Conducting more precise and comprehensive analyses based on the gathered data will enable the organization to make informed decisions regarding the allocation of resources to prospective areas of development for the port.

- Block Chain and Data Provisioning Technologies: The advent of blockchain and data provisioning technologies has precipitated a worldwide development in technology. Consequently, autonomous ports will be capable of reporting on every moment of port operations using these technologies. These technologies have the potential to enhance transparency, traceability and security in port operations.

- Use of Electrical Equipment: The utilization of green energy sources and the integration of electrical equipment have been demonstrated to enhance sustainability and reduce costs. The effective use of electrical energy at optimal levels within the infrastructure and superstructures of Turkish ports is poised to garner significant public attention, signifying a substantial shift that will lead

to substantial cost reductions in the contemporary context, where sustainability stands as a paramount concern.

3.4. Threats

- Cyber Attacks: Autonomous port systems have the potential to be vulnerable to cyber attacks, which can jeopardize operations and data security. However, as demonstrated by global cyberattacks, firewalls can be breached by both mass and individual attacks, resulting in the theft of confidential commercial data.

- Environmental Conditions: Türkiye is located within a seismic zone, a fact that is due to the country's geological structure. The potential for seismic activity and the consequent risk of damage to infrastructure and operational equipment is a perpetual concern. Furthermore, severe weather conditions or natural disasters have the potential to disrupt autonomous port operations.

- Workforce Adaptation: Even though pivotal operations in autonomous ports are conducted by machines, there will invariably be a requirement for a workforce to intervene in operations. Existing employees may encounter challenges in adapting to this novel technology. This suggests a potential risk of personnel with adaptation difficulties being left behind in the transition to the new system.

- Regulatory Compliance: Legal and regulatory uncertainties about autonomous ports have the potential to impede the adoption of this technology and engender additional costs. In the event of injury, incapacity, or loss of life of personnel during operations, the addressee will be the artificial intelligence that manages the equipment or the operators who remotely control the equipment.

- Financial Risks: The initiation of autonomous port development projects demands considerable financial investment, encompassing infrastructure and superstructure equipment. Maintenance and operational expenses are also substantial. The timeframe for the return of these costs as operating profit may be protracted, extending over a considerable period. Consequently, the payback period may be significantly extended beyond initial expectations.

- Public Acceptance: The working principle of autonomous ports and the concept of artificial intelligence is still approached with prejudice in societies. The transition to autonomous ports may encounter resistance from the public due to concerns regarding job loss and security, primarily due to the fear of employee displacement, the potential for security vulnerabilities, and the uncertainty surrounding the implications of such a shift.

All the results obtained are summarised in Figure 2.

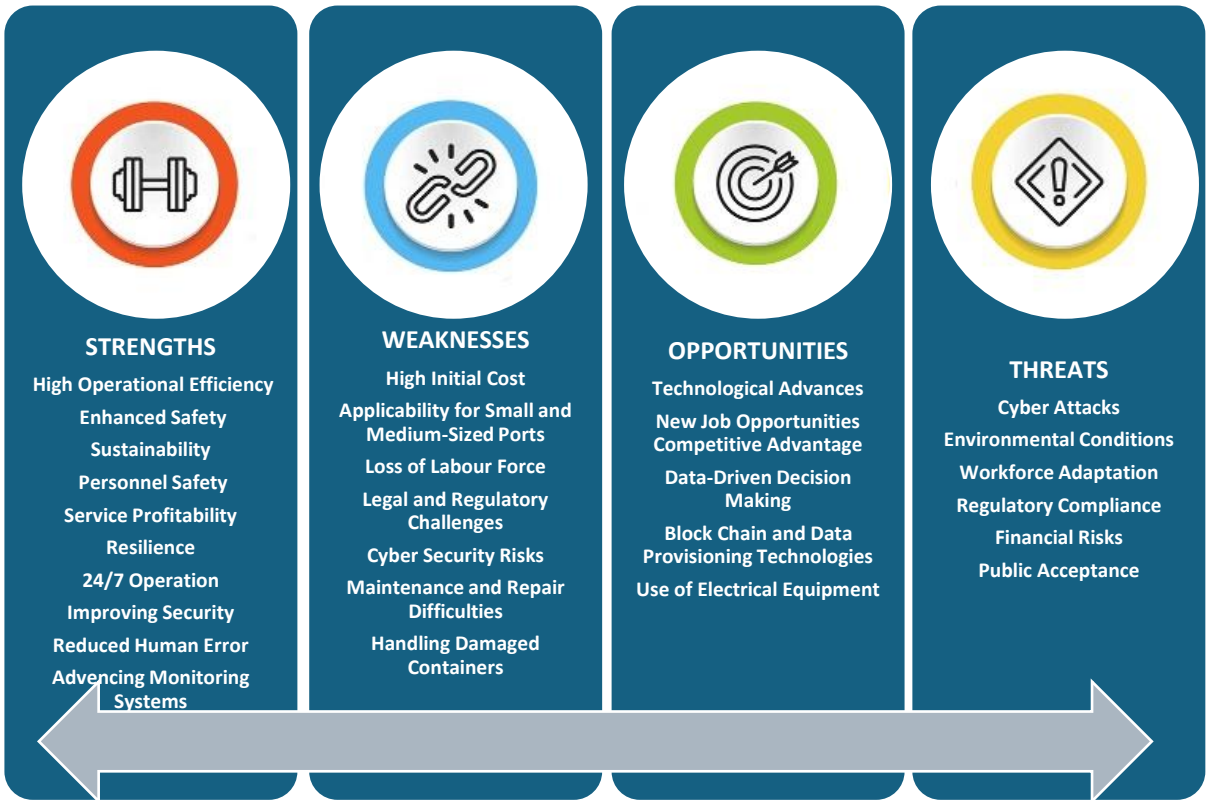

Figure 2. Swot Analysis for Turkish Ports

4. Discussion

The SWOT analysis produced anticipated results in terms of strengths and opportunities, and the experts' expectations regarding autonomous ports and general conclusions have been obtained. However, it is important to note that the identified weaknesses and threats only apply to ports operating in the Marmara Region. A notable weakness pertains to legal and regulatory challenges, with it being emphasized that the prevailing Turkish legislation does not presently provide an infrastructure for the operation of autonomous ports.

It was observed that considerable challenges would emerge in establishing legal obligations and identifying relevant parties in the event of an incident. Another significant vulnerability identified pertains to the risk of cyber security breaches, necessitating the implementation of a robust and advanced internet infrastructure. It is evident that the internet infrastructure of Türkiye is lagging behind that of other countries, and the prevalence of internet speed and interruption problems poses a grave concern for ports. In the event of an interruption to the internet connection or inadequate cyber security measures, the port's operating system is susceptible to failure, which may result in a protracted period before operations can be resumed. A salient finding pertains to the prevalence of financial risks. To ensure the continuity of this process, a designated budget must be allocated and subjected to regular revisions. It is recommended that ports consider these expenses as ongoing costs and incorporate them into their operating budgets.

However, it is important to acknowledge the continuous evolution of autonomous systems, which invariably necessitates the modernization of existing infrastructure, resulting in the allocation of additional financial resources. The unpredictability of malfunctions and repair costs further complicates financial planning for ports. The inability to account for such expenses poses a substantial threat to the financial stability and sustainability of ports. The implementation of autonomous ports therefore necessitates the establishment of requirements in several areas, including those about legal,

regulatory frameworks, cyber security and labor dynamics. The potential benefits of autonomous ports include efficiency, safety and sustainability, as well as reduced operating costs and improved environmental performance. However, the emergence of autonomous ports gives rise to several challenges, including regulatory uncertainty, technical complexity and cyber security risks.

The potential advantages of autonomous ports are readily apparent, as evidenced by the findings of previous studies (Park et al., 2023). The experts who conducted the study identified cost reduction and efficiency enhancement as the primary benefits. The enhancement of operational efficiency, the implementation of advanced safety measures and the reduction of environmental impact demonstrate the potential of autonomous ports to engender a substantial transformation in the maritime sector (Park et al., 2023). In a related study, Karlı et al., (2021) utilized the Fuzzy AHP method to assess the smart port dimensions of the Filyos port, thereby demonstrating that the operational dimension of the port is significant. The most critical issues were identified as environment, energy, finance, safety and security. The integration of automation and AI-enabled systems has the potential to facilitate faster handling times, improved resource allocation and a reduction in human errors. This finding is consistent with the conclusions of Makkawan and Muangpan (2021), who posit that the development of smart port indicators can facilitate more effective performance measurement and management, thereby encouraging continuous improvement in port operations. Furthermore, autonomous ports can provide a safer working environment through enhanced security protocols and collision avoidance systems. Additionally, the shift to cleaner energy sources and optimized operations can contribute to environmental sustainability by reducing greenhouse gas emissions.

Nevertheless, the implementation of autonomous ports presents several challenges, which must be given full consideration to ensure the success of this venture. A primary concern pertains to the necessity for a substantial financial investment. Gu and et al. (2020) emphasize in their study that, despite the advantages, the initial investment is considerable, representing a notable weakness related to the transition to autonomous ports. Additionally, there is a lack of clarity regarding the allocation of responsibility and accountability, particularly in the event of accidents or malfunctions related to autonomous ships. Bokau (2024) emphasized the pivotal role of regulatory challenges in impeding the transition to autonomous ports. The author contended that existing maritime legislation may be inadequate to deal with the complexities inherent in autonomous operations, thus hindering the adoption of autonomous ports. The technical intricacies associated with control and navigation have the potential to affect the efficiency of autonomous port operations. The implementation of autonomous ports may engender a multitude of additional risks, including those about cybersecurity, the necessity for redundancies, and the need to adapt to new technologies. Elhafez (2023) hypothesizes in his study that autonomous systems may be vulnerable to hacking and other malevolent activities. In a related study, Öztemiz (2023) presents a review of the smart port concept in the context of foreign trade, with a particular focus on the port of Singapore. The author emphasizes the role of digital technologies in this context. As observed in this study, the internet infrastructure plays a critical role. This finding is consistent with the conclusion that cybersecurity risks will increase in an increasingly digitalized port environment. This finding is consistent with the conclusions of Hirata (2024), who posits that the growing automation of maritime processes may precipitate job losses within the sector. The potential risks associated with cybersecurity, labor displacement and regulatory compliance represent a significant barrier to the adoption of autonomous ports. Addressing the technical intricacies, including but not limited to, issues of liability, control theory, navigation and environmental impacts, is therefore paramount to facilitate the seamless integration of autonomous ports.

CONCLUSION

In this study, experts with a background in the maritime sector were consulted to analyze the transition of ports in the Marmara Region from conventional port management systems to autonomous port management systems. The results obtained from these analyses highlight potential expenditures for infrastructure investments and sustainability, as well as cyber-attacks and deficiencies in internet infrastructure.

The implementation of autonomous ports has the potential to cause a major paradigm shift in the maritime industry. However, this technology must be implemented with the utmost care and strategic foresight. A notable review by Zadeh (2023) on the optimization of smart energy infrastructure in smart ports to reduce the carbon footprint is particularly noteworthy. This significant technological advancement will undoubtedly have a profound impact on the future of the maritime industry. The successful implementation of autonomous ports will require the establishment of legal frameworks, the implementation of robust cyber security measures, and the upskilling of the workforce. A comprehensive approach must be adopted to maximize the potential benefits of autonomous ports while minimizing the risks, as this approach will be crucial in determining the future trajectory of the maritime sector. In conclusion, Tangstad (2023) states that the potential for lower operational costs and increased frequency of service, which will make ports more competitive on a global scale, could attract more shipping lines and cargo.

Nevertheless, the complete realization of this potential is contingent on stakeholders acknowledging and adapting to the opportunities and challenges presented by autonomous ports. The maritime industry has the potential to realize the promise of autonomous ports and to pave the way for a safer, more efficient and more sustainable maritime future through collaboration, innovation and proactive risk management. The present study diverges from preceding research in its objective to identify vulnerabilities and hazards associated with autonomous ports, as opposed to prioritizing the opportunities and advantages they present. Nevertheless, it is imperative to emphasize the significance of vulnerabilities and hazards within the context of Turkish ports' security culture and infrastructure capabilities.

Limitations of the Study:

The study is subject to two limitations. Firstly, the experts participating in the study are employed in ports located in the Marmara Region. The exclusion of experts from the Aegean, Mediterranean and Black Sea Regions from the study constitutes a limitation. Secondly, the study participants were exclusively operations managers, human resources managers and technical managers, with no representation from the finance department.

Future Research:

Subsequent studies may benefit from examining ports independently and considering the specialization of terminals according to the types of cargo handled. This would facilitate a more comprehensive examination of potential vulnerabilities and threats using a SWOT analysis tailored to the cargo types in question.

Compliance with Ethical Standards

Conflict of Interests: *The author declares that they do not have a conflict of interest with themselves and/or other third parties and institutions, or if so, how this conflict of interest arose and will be resolved, and author contribution declaration forms are added to the article process files with wet signatures.*

Ethics Committee Permission: *No ethical committee approval is required for this study. The signed consent form has been added to the article process file.*

Financial Support: *No financial support is available.*

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EXTENDED SUMMARY

Research Problem

The objective of this study is to evaluate how the advantages and disadvantages that the ports operating in the Marmara Region of Türkiye will face in the process of transitioning to an autonomous port management model are perceived by the experts working in the port sector.

Research Questions

To achieve a comprehensive understanding of the concept of autonomous ports, the following questions must be posed and answered: firstly, what is the current global situation regarding the

implementation of autonomous port systems? Secondly, what are the strengths, weaknesses, opportunities and threats that the ports operating in the Marmara Region of Türkiye will face in their transition to such systems? Finally, it is essential to ascertain how these four primary factors should be evaluated from the perspective of experts.

Literature Review

A thorough review of the extant literature, both domestic and international, reveals a mounting trend towards the implementation of autonomous port management systems within the port sector. The extant literature on the subject is diverse, with some studies employing literature research management and others utilizing Interpretive Structural Model (ISM), Fuzzy AHP, Technical-Environmental Analysis and SWOT Analysis. A thorough examination of both national and international publications within the framework of the research reveals a conspicuous absence of studies in the national literature that examine the approaches of Turkish ports to autonomous port management. While there are publications on the management of autonomous ports in the international literature, these are limited in scope and cover only general features. A seminal study in this area is that of Park et al., (2023).

The present study employed a SWOT analysis to examine the transition of Ro-Ro terminals to an autonomous port management system. The findings indicated that operating costs were reduced by 90% and that terminal operations were markedly enhanced. In addition, the employment of the CAV-loading system was found to be associated with a 12% reduction in CO2 emissions in comparison to the existing loading system.

Methodology

The present study employed the SWOT analysis method to examine the concept of autonomous ports. The study commenced with an investigation into the four primary factors confronting ports in their transition to autonomous port systems. The global utilization of autonomous ports was then examined, and preliminary information was collected. In the subsequent phase, experts with a substantial career tenure in the port sector who are currently active as managers in various departments were contacted. These experts were invited to consider the possible advantages, disadvantages, opportunities and threats in the transition of the ports operating in the Marmara Region to the autonomous port system under four main headings, and their opinions were taken within the framework of the existing classical port management. The information and findings obtained were collected and grouped under four main headings in the SWOT analysis, with the main weaknesses and threats for ports being emphasized.

Discussion

This study has conducted a comprehensive examination of the emergence of autonomous ports in the global port system and the intricate dynamics that accompany this phenomenon. The implementation of autonomous technologies and systems has the potential to enhance the operational efficiency of ports. The advantages of such ports are manifold, including improvements in efficiency, safety and sustainability, as well as reductions in operating costs and enhanced environmental performance. However, the introduction of autonomous ports is not without its challenges, including regulatory uncertainty, technical complexity and the potential for cyber security risks.

Conclusions

It is anticipated that the advent of autonomous ports will effect a transformation of the maritime industry, with improvements in operational efficiency, the introduction of more robust safety measures and a reduction in environmental impact. The integration of automation and AI-enabled systems has the potential to facilitate more expedient handling procedures, improve the optimal allocation of resources and reduce the incidence of human error. A salient concern pertains to the financial implications of implementing autonomous ports, which necessitate substantial investment. Furthermore, technical complexities about control and navigation have the potential to impact the efficacy of autonomous port operations. Furthermore, the implementation of autonomous ports has the potential to engender several challenges, including the emergence of cyber security risks, redundancies and the necessity to adapt to emerging technologies. The adoption of autonomous ports is threatened by several significant risks, including those related to cyber security, labor displacement and regulatory compliance. Addressing the technical complexities, including but not limited to, liability, control theory, navigation and environmental impacts, is imperative for the successful implementation of autonomous ports. The establishment of legal frameworks, rigorous supervision of cybersecurity measures and upskilling of the workforce are vital for the successful implementation of autonomous ports. A comprehensive approach that can minimize the risks whilst maximizing the potential benefits of autonomous ports will play a pivotal role in shaping the future of the maritime industry.