


Chapter 2

Sustainability in the Maritime Industry: Integration of Digital Twin and Autonomous Control

Arda Toygar

 <https://orcid.org/0000-0001-5548-7248>
Ordu University, Turkey

ABSTRACT

Automation in ports improves the safety and efficiency of port operations, allowing for more effective planning. Digital twin (DT) technology enables more effective use of autonomous technologies and supports the capacity for rapid assessment and instant decision-making. The integration of these two transformative technologies can create a more sustainable, efficient, and secure port ecosystem by automating port operations and enhancing them through simulations. A port's eligibility for maritime autonomous surface ships (MASS) depends on digital transformation and infrastructure obligations. The transformation of the ports and ships is expected to play an important role in port operations. This chapter addresses the potential and challenges of DT and autonomous technologies in the maritime industry and aims to provide a deeper understanding of their applications in this industry. The chapter provides valuable insights into the future efficiency, safety, and sustainability of ports and ships, two critical components in the maritime industry.

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1. INTRODUCTION

Technological developments and the growth in global trade volumes make automation and digital transformation a necessity for almost all industries (Rüßmann et al., 2015). Maritime comes to the fore as one of the industries directly affected by these technological developments, as innovations to automate processes are important in the management of large transportation infrastructures (Tijan et al., 2021). Various innovative practices are being implemented in the maritime industry to gain a competitive advantage and solve capacity problems (Lookman et al., 2023). Port operations and ship management, two key elements of the industry, are enabling the development of these implementations thanks to the innovations brought by autonomous technology. The maritime industry aims to improve operational activities and service standards with Industry 4.0 technologies. With the evolution of Industry 4.0, the terms autonomous and digitalization have become important in the maritime industry (Mızrak, 2024).

Ports are coastal facilities that provide services to ships and create logistical value. These facilities connect a country with other countries in the world and play an important role in trade activities. They are also often considered major economic hubs, providing jobs and economic growth to the communities around them. Therefore, managing ports effectively is vital to a country's economic health and prosperity. As ports seek innovative technological solutions to meet the increasing demands for freight transportation, they also strive to minimize their environmental impact (Klar et al., 2023). Accordingly, ports have adopted sustainable and innovative practices from the past to the present. They have encountered many innovations throughout their historical development process. These innovations have led to the categorization of ports into different generations. First-generation ports were only for loading and unloading operations (Jahn & Nellen, 2022); however, later generations represent the industrialization of port operations, the construction of hardware infrastructure that can be integrated into the entire supply chain, and autonomous transformation.

Increasing cargo volumes and challenging working conditions in ports create barriers to continuous and reliable operational activities. Automation is used to improve the safety and efficiency of port operations. Ports that have adopted autonomous technology can use technological innovations to improve port operations and services. Industrial automation systems minimize human involvement by automating the control of machinery and operations. Automation establishes a repeatable process and facilitates the collection, management, and control of data. This makes it possible to manage equipment and processes more effectively, standardize performance, eliminate uncertainty in response times, and minimize operational expenditures (Martín-Soberón et al., 2014). Integrating autonomous technologies with digital implementations is important to achieve complete efficiency in port operations. The

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