Managerial Issues in the Adoption of Digital Twins by Shipping Companies in Greece

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Abstract — Maritime industry is experiencing the influence of industry 4.0 solutions and investments. A commercial ship is comparable to an industrial plant and several analogies can be found between the two worlds. Digital twins represent the convergence of the engineering and the digital information technology worlds into the so-called cyber-physical systems, which promise to solve problems in the virtual world, based on the real-world data collected online, and then processed through simulation models and artificial intelligence. Although there is some research literature referring to digital twin (DT) solutions for specific problems in shipping, general lack of clarity on the level and direction of progress in this field has been observed by researchers. This paper tries to address exactly this question by collecting data using an opinion survey of managers of some maritime industry companies based in Greece – a country where a significant part of the global commercial fleet is being managed from. Drivers, enablers and impediments to the adoption of DT in shipping have been identified by an opinion survey. A first attempt to devise a generic cost-benefit framework for the adoption of DT solutions in shipping is presented as a key managerial decision-making tool for such a big investment needed for DT.

Keywords — Digital Twins, Digital Twins in Shipping, Adoption of Digital Twins, Maritime Applications of Digital Twins.

I. INTRODUCTION

The commercial maritime fleet is the most important logistics infrastructure for international commerce. Most of the global manufacturing products are transported via the sea, therefore, its operation is critical for the functioning of the global economy. Especially for Greece, shipping is the most important industry in the country. It constitutes 7% of GDP, it employs more than 200 thousand workers, while the inflows into the Greek balance of payments from maritime transport exceeded EUR 17 billion in 2021.

However, traveling overseas includes a lot of risks inherent to the nature of traveling into the sea in addition to the distance from maintenance and support land bases. Given the high business risk of the shipping industry as well as the advancements in efficiency and effectiveness pursued by global supply chains in which shipping is inextricably interwoven, technological innovation in the fields of information technology and communications, materials, environment and energy acts as a catalyst for the transformation of the shipping industry, contributing to a more effective response to long-standing challenges such as:

• the reduction of ship maintenance and operation costs,
• the achievement of greater reliability and safety of the trip,
• the optimization of fuel consumption and the reduction of carbon emissions,
• the reduction of the arrangement time of services in a transparent and controlled way,
• the optimization of the transactions of the supply chains in which ship transportation is an integral part.

Cyber-physical systems have attracted the attention of the maritime industry since shipping operations are similar to those of industrial shop floors, which transformed manufacturing into the so-called industry 4.0. “Cyber-Physical Systems (CPS) is defined as transformative technologies for managing interconnected systems between its physical assets and computational capabilities” [1] CPS are used in the maritime industry for engineering design, performance monitoring, and supply-chain management information sharing and exchange both with customers and port authorities.

Combining CPS with simulation models, artificial intelligence and augmented reality enables the creation of a digital twin (DT) to a physical object, such as a ship and its contents. DT creates a digital representation in the virtual space of the physical objects’ behavior, allowing engineers to monitor, control, enhance and evolve the real object in real-time. “The Digital Twin integrates all data (test, operation data,...), models (design drawings, engineering models, analyses, ...), and other information (requirements, orders, inspections, ...) of a physical asset generated along its life cycle that leverage business opportunities.” [2] DT is a key component of shipping 4.0 [3]–[5] and is also applicable in the maritime industry since a ship is a ‘traveling factory’ which has to comply with many regulations and with the service level agreements signed with their customers. A descriptive model for understanding Maritime 4.0 can be found in [6].

This research investigation aims at exploring the level of adoption of DTs in the maritime industry as well as managerial issues related to the adoption. To this end, the objectives of this research are:

• To find out the level of awareness of digital twins in the maritime industry in Greece
• To investigate whether components of digital twins are currently in use in the maritime industry
• To reveal the readiness level of the maritime industry in Greece to adopt such solutions
• To search for the applicability and feasibility of digital twins in the maritime industry
• To identify areas where digital twins would be of particular interest to the maritime industry.

The next section discusses DT and their associated technologies, the third one presents how the research was organized and the fourth presents the results from the interviews with the industry experts. Finally, the conclusions section makes an overall assessment of the findings and presents a generic framework for a cost-benefits analysis that could be useful a top management decision-making tool to allow decisions for DT adoption to be made.

II. ABOUT DIGITAL TWINS

“Digital twinning is an acknowledged opportunity for maritime sector improvement. [...] Three areas that will likely benefit from digital twins are fleet optimization, port optimization, end-to-end supply chain optimization, and increasing key stakeholders’ situational awareness (visibility and predictability) on the state of the transport of goods and optimization of container flows in the end-to-end supply chain” [7]

What is this new technology that is emerging as a converging point of all kinds of engineering with digital information systems?

Real-time data collection from various parts of a ship is not new to shipping. The advent of Internet of Things, intelligent simulations based on big data analysis and the use of virtual/augmented reality has set the scene for the digital transformation of shipping, under the term Maritime (M) 4.0. “Ultimately M4.0 is an integrated system of systems concept that requires the utilization of innovative technologies for the development of sustainable, secure and connected vessels. By bringing together not only the technologies and elements of it is possible to harmoniously synchronize efforts for industry improvement.” [6]

Components of DT include [8]: Physical Asset, Digital Asset, Continuous Bijective Relation, IoT, Time continuous data, machine learning, Security and Evaluation metrics / Testing. DT is seen by various researchers [9] as the natural evolution of numerical simulation models, computer-aided design, computer aided manufacturing, smart manufacturing system design and virtual/augmented reality simulation systems used in various areas of engineering such as civil, mechanical, aeronautical, space etc. Such an evolution fertilized by digital information systems (Artificial intelligence, Internet of Things etc.) has given birth to DT solutions, in which the physical world continually feeds its digital twin with data, so that the DT is a true, as real-time as possible, representation of its physical counterpart.

It is pertinent to discuss DT solutions to the challenges faced by the maritime industry, due to its crucial role in global commerce as well as the risks inherent in this industry. As put by [10] “Maritime shipping, with a significant role in global trade, confronts various accidents leading to loss of lives, properties, and the environment. Shipping 4.0 technologies are scaling up to address this problem by employing real-time data-driven technologies, including cyber-physical systems, advanced tracking and tracing, intelligent systems, and big data analytics. Despite growing attention, there is a general lack of clarity on the level and direction of progress in this field.” This paper tries to address exactly this question by collecting data using an opinion survey of managers of some maritime industry companies based in Greece – a country where a significant part of the global commercial fleet is being managed from.

III. METHOD OF RESEARCH

To collect enough evidence for assembling the answers to the objectives of this research, a questionnaire was designed to be sent out to various professionals in this sector. Target groups were mechanical / naval engineering managers and information technology managers. The questionnaire was made up of the following questions:

1. Is the maritime industry aware of digital twins? Have you seen applications of digital twins in the maritime industry?
2. Is real-time data been streamlined from ships to headquarters? For what purpose?
3. What are the limitations – if any, in data rates? How much expensive is it?
4. Do you use Internet-of-Things censors in your ships? What data are being captured?
5. Where do you store the data you are receiving from ships? (technology, tools, etc)
6. Are you using simulations to solve technical / engineering problems in the ships?
7. Do you know if augmented reality is being used in the maritime industry? If yes, in which area?
8. Do you think digital twins can be useful? In which areas? What kind of real-life problems would it be useful for?
9. Do you think your company is ready to adopt digital twin solutions? Why / why not.
10. Do you think that it is feasible for a maritime industry company to employ such solutions? Do you think that the cost is prohibitive? Would you suggest that your company invest in such a solution?

Since not everyone is familiar with the concept of DT, a short introduction of a few lines was given as a hint as well as two self-explaining figures (no 2 and no 5) specific to the maritime industry, were copied from [11]; these figures were proven to be useful in the comprehension of the issues from the respondents. Moreover, the process of building a functional DT [11] was given as a short background information, in six steps:

“Step (1): Build the virtual representation of the physical product
Step (2): Process data to facilitate design decision-making
Step (3): Simulate product behaviours in the virtual environment
Step (4): Command the physical product to perform recommended behaviours
Step (5): Establish real-time, two-way, and secure connections between physical and virtual product
Step (6): Collect all kinds of product-related data from different sources”

The amount and richness of data collected through the questionnaire was not satisfactory for an informed opinion survey research. Therefore, personal interviews were run as a second iteration for data collection. This was far more fruitful in terms of data collected and informative discussions were
held with respondents, regarding also personnel and other related managerial issues not initially included into the questionnaire. The results are qualitative, not quantitative, and they are presented below after processing the main keywords, statements and sentiments recorded during interviews.

IV. RESULTS FROM INTERVIEWS

Interviews were well held in an open discussion style, rather than on a predefined list of questions; however similar topics were asked to all maritime industry managers. The first question had to do with familiarity with smart technologies, the internet of things and finally digital twins. Smart censors are being used in most of the ships, artificial intelligence is known but not widely applied; around 40% of the managers believe that these issues will go higher in the agenda of new technologies to be adopted in the next three years (2023-2025). Higher priority issues for them include environmental issues as well as fuels, especially so, as prices of fuels are constantly increasing since the beginning of 2022. Around half of the managers have a basic knowledge about digital twins; this is dealt not as an autonomous topic but as part of the smart technologies’ context. It is interesting to find out that awareness for digital twins has emerged over the last two years and most of the managers who have a basic understanding about it, have learned about digital twins in the last 12 months. This shows a proliferation of knowledge in the digital twins’ area, mainly due to its applications in similar industries such as aeronautical and manufacturing.

Although it is considered an area to follow in the future, digital twins do not seem to be currently believed as an immediate priority. However, digital infrastructures and applications, including digital twins, are considered as part of other problems’ solutions, especially in the emissions and environmental issues, as well as in the ship performance area.

About 25% of the interviewees had such an attitude. An interesting point that arose from the discussions is that there are compliance issues in the maritime industry that require operational improvements, which could potentially benefit from smart technologies, including digital twins.

Those managers who had a good general understanding of digital twins, were asked what DT could be useful for, when applied in their ships. The main answer was to identify and solve technical problems without an onboard visit of experts. Using DT to simulate the problem and get an inside understanding while the ship continues travelling is important and necessary. Notwithstanding, around three of ten, expressed clearly that they are not in a position to clearly identify how DT would be beneficial for their company.

Unavoidably, the discussion arrived at obstacles of adopting digital twins. The cost of continually streamlining a significant amount of data from the ship ashore cannot be neglected. Satellite communications is still very expensive and, hence, not used for such issues as continuous remote health and/or performance monitoring of the ship equipment. Performance data are usually collected to a local server onboard and when ashore or close to a wireless terrestrial communication network, then data is pushed to the corporate’s central IT servers for processing and archiving.

One more obstacle is that the people who are expected to be able to use a DT solution are anxious whether they will be able to prove the cost-effectiveness of such an expensive solution, since most of the interviewees believe that their installation, deployment and operation is very costly. Moreover, they are also underlying worries whether the level of adoption of simulation models and the overall competence with simulation models are adequate enough for exploiting the benefits of a full-blown DT solution. On top, the inherent difficulty to test and/or pilot at small scale such a solution in terms of completeness and effectiveness, increases the inhibition sentiment.

Finally, business analytics applications are not very common in the maritime industry. Data collected are used for prescriptive rather than predictive type of statistical analysis, hence, the level of adoption of artificial intelligence is lagging behind the necessary one for a meaningful deployment of a DT solution.

The interviews concluded with enabler factors that may accelerate the adoption of DT. Most of the ships are using censors to collect performance data of the main machine rooms of the ship (propulsion systems) as well as for electronics ones. This is of course the first step towards any smart solution. Then, augmented reality (AR) systems used for navigation training is a good touchpoint with this technology that is an integral part of a full-blown DT solution. Managers’ understanding of AR acts as an enabler in accepting the importance of AR in high risk, high cost, low-availability areas that ships are faced with.

Currently, the discussion refers only to one-directional data flows. That from the ship to the headquarters. The feedback is currently given in human orders to the ship crew, who then perform the corresponding actions. Two-directional communication and, even more, the automatic execution of corrective and preventive actions directly from the central office is rather an immature topic for now. Completely remotely operated ships are not a priority in the future agenda; moreover, cyber security threats postpone this future vision. However, there can be found some first research results in this domain: “The cyber-enabled ship (C-ES) is either an autonomous or a remotely controlled vessel which relies on interconnected cyber-physical-systems for its operations. Such systems are not well protected against cyberattacks. […] We then apply the Secure Tropos methodology to systematically elicit the security requirements of the three most vulnerable cyber-physical systems (CPSs) onboard a C-ES, namely the automatic identification system (AIS), the electronic chart display information system, and the global maritime distress and safety system. The outcome is a set of cyber-security requirements for the C-ES ecosystem in general and these systems in particular.” [12] Even in the current unidirectional flow of communication to feed the DT operation, cyber-security threats cannot be underestimated. A systematic analysis using “two security risk assessment methods, the API STD 780 SRA and the Bow Tie Analysis methods […] that can be applied in maritime cyber-physical security applications” is presented in [13].
The issue of how DT would affect the seafarers their skills and careers was not covered in this discussion, although would be a very interesting topic. “The literature on digitalization and automation within and beyond the shipping industry has largely suggested the need for new skill sets to prepare for Industry 4.0 and for its impact on work. […] The study found that seafarers’ perceptions about their jobs remain physically oriented even in the era of digitalization and automation. The process of integrating more digitally-inclined operations of ships, might challenge traditional values of seafarers as tough and strong. Adaptation to technology will therefore require change in perceptions, in the context of the maritime workforce.” [14] The potential adoption of DT is generally accepted what it will have further implications on the ship workforce, which need to be further investigated.

According to Gartner group, managers were asked whether they agree that digital twins “can lower operating expenses and potentially capital expenses too, by extending the life of the object they represent and optimizing the performance of the asset as it runs.” [15] Around 30% of the respondents were not sure (probably because of lack of in-depth knowledge), 50% agreed and other 20% strongly agreed with the statement. Therefore, there was a strong congruence about the above statement, despite their main concern that the initial cost of investment was considered very high as well as the operating cost for the digital twins, before they could start reaping the benefits of this technology, and arrive at the truthness of the aforementioned statement. So, they agreed on the usefulness and the benefits, but the journey towards the materialization of the benefits seems to be rather long and risky.

V. CONCLUSION

Although there is some research literature referring to digital twin (DT) solutions for specific problems in shipping [16], general lack of clarity on the level and direction of progress in this field has been observed [10]. To address this issue and point out to managerial issues pertaining to the adoption of DT in the maritime industry, an opinion survey was designed and run, whose results have been summarized in Table I. This table clearly shows that there are four reasons in each of the categories: drivers, enablers, impediments and issues, making no category a clear winner. Therefore, DT adoption decisions seem to be postponed for now, although managers are keeping an eye towards the evolution of these decision-making factors.

Qualitative, mainly, results from interviews with managers in the maritime industry in companies of this sector based in Greece, show a good general awareness level about DT, however few respondents can be categorized as “well-literate” in the field. Certain enablers exist, however there are barriers to be overcome before the road is open towards the adoption of DT in regular operations, as identified above. Regarding the areas of interest for DT in the maritime industry, it seems that they don’t differ from the general norm, which is asset optimization and preventive maintenance – these have been identified as the main drivers for investing in digital twins in general. [15]

Since the initial investment is very high for the adoption a full-blown DT solution, the majority of managers agreed that had a cost-benefit equation been defined, it would be very helpful in shaping an opinion and then a decision. Although such a general equation cannot be proposed because a DT investment is very situational in terms of its cost and benefits elements, the first attempt to a cost-benefit assessment logic is tried below in terms of general categories of cost and benefits, pertinent to shipping (regarding unidirectional communication, not two way including remote control):

a. Cost side:
   - On-board
     • Censors
     • Local data collection infrastructure and local storage
     • Telecoms
     • Skilled seafarers to maintain the infrastructure
   - Ashore/ centrally
     • Data warehousing – software and hardware
     • Simulation models
     • Business analytics – Artificial intelligence solutions
     • Visualization methods
     • Virtual and/or augmented reality
     • Expert systems
     • Skilled people as problem solvers with DTs

b. Benefit side:
   - Avoidance of ship visits and travelling of experts in the ships to take measurements and identify/solve problems on-board
   - Prediction of problems
   - Continuous monitoring and reporting for prevention of difficult situations
   - Building of a body of organizational knowledge that is not lost when people move from company to company. Using DT as the organizational memory information system [17] that is useful for the learning curve of the organization
   - Solution trials before they get applied
   - Deeper expertise acquisition by the problem solvers
- (non) compliance issues in areas where DT offers better solutions that traditional approaches – depends on whether (non) compliance issues can be best served without a DT solution.

Of course, this is a very general categorization and needs further refinement, if it is going to be applied to a specific scope. This scope (e.g. propulsion systems, transport material /warehousing systems, navigation, health and safety conditions, emissions etc.) has to be first of all defined, because the ambition of building DTs of everything that constitutes a ship is a far-reaching vision. What is also obvious from the benefits listed above, is that benefits come over time; benefits are difficult to quantify in advance – as it is the case with most modern digital information systems. The ISSUE methodology can be useful here; in this approach ones starts “from quantifiable benefits directly attributable to the information system and then gradually consider more intangible and indirect effects” by using Business Process Simulation in iterative steps. [18] Devising suitable cost-benefit analysis frameworks, adjusted to vertical industries and configurable to situational scopes and organizational contexts needs further research; they may prove to be decisive managerial decision-making tools towards adoption of DT in the maritime and other industries too.

CONFLICT OF INTEREST
No conflict of interest.

REFERENCES


Dimitrios S. Stamoulis was born in Athens, Greece and holds a B.Sc. in Informatics (University of Athens), a M.Sc. in Advanced Computer Science (Queen Mary College, University of London), a Pg.D. in Business Administration (University of Leicester) and a Ph.D. in Information Systems Management (University of Athens). He has 27 years of professional experience in banking and consulting in the information systems area and more then 10 years academic experience as a tutor, teaching various courses in Information Systems Management, IT project management, e-governance, e-business, digital transformation, quality issues in IT, etc. He has published 20 journal papers, 4 book chapters and 15 conference papers in the above topics. His main research interests lay...