Internet of Things based Product-Service System in the Maritime Industrial Sector

Islam Abusohyon and Flavio Tonelli
DIME - Department of Mechanical Engineering, Energetics, Management and Transportation, Polytechnic School, University of Genoa, Italy

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Abstract: The continuous progress of technology affects all aspects of life and business, dynamically. In order to take the advantaging of technology development, business owners need to adapt themselves with the changes stemming from it. Digitalization of production and service processes is one of the directions that alignment with it will bring many privileges. Internet of Things, cyber-physical system, and artificial intelligence are the popular components of digitalization that constantly undergo evolution. Utilizing these advanced components enables business owners to transform the product-centric processes to smart control digital service-oriented ones. The main motivation of current research work is analysis a theoretical thematic of literature on IoT and CPS servitization topics to shed the light on the main areas that the researchers are focusing on since 2009 and bridge the gap that exists in the literature regarding the implementation of these technologies in the remote monitoring processes in the maritime sector. The result of the literature examination revealed five dominant areas. Through utilizing these disclosed areas, a ten-step approach block diagram for IoT-based 'smart product servitization' was designed. The proposed framework supports companies to take the first steps toward remote monitoring servitization through the implementation of IoT and CPS to produce a fully integrated smart monitor system to improve assets' health and performance and reduce costs and waiting time. Moreover, a case study of a smart injector for marine engine is analysed to propose a working framework supporting the implementation of IoT and CPS to communicate the added-value data within the smart system built on five modules: process control module, process diagnosis module, healing module, storage module, and human interaction module.

1 INTRODUCTION

The industry 4.0 revolution has brought a substantial paradigm shift in industrial practices by propelling these practices toward automation and digitalization of the industrial processes. The integration of the digital, and physical worlds along with the expanding utilization of modern technologies such as artificial intelligence, cloud computing, and Internet of Things (IoT), are the principal characteristics of fourth industrial revolution which enable organizations to achieve self-monitoring capability and consequently reduce the number of human interventions (Heiner L. et al. 2014). Therefore, the implementation of these digital technologies forces the transformation of traditional manufacturing into digital manufacturing (Tonelli et al. 2017; Kristen et al. 2018; Marco et al. 2018; Tonelli F. et al. 2019 & Damiani L. et al. 2017) and to deliver a more customized, smart and service-based offerings (Shum et al. 2008). And in order to do so, many infrastructures require a combination of these new technologies to adapt themselves with changes stemming from Industry 4.0 revolution (Damiani L. et al. 2018) such technologies originated from different disciplines. Among them, IoT and Cyber Physical System (CPS) are gaining vast attention from a wide range of industries (Li D. et al. 2018).

The "CPS," and "IoT," mechanism emanate from distinct origins, but some common features can be found in their definition. As a matter of fact, the main stimulus of both is integrating digital capabilities, containing network connectivity and computational capability, with physical devices and systems for the purpose of data collection and

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exchanging (Christopher G. et al. 2019; Sumayya M. et al. 2015; Keyur K. Sunil M. 2016). And according to the survey that was conducted by Yang L. in 2017, CPS and IoT technologies are the way toward innovated and integrated smart systems.

With the implementation of artificial intelligence and machine learning algorithms, IoT has accelerated this evolution by using sensors to extract data throughout the lifecycle of the product, in order to create value and knowledge from the huge amount of the collected data, such as the knowledge of the product performance and conditions (Marco C. et al. 2019), and this has enabled the transformation in several industries to move toward selling this data to get more revenue and higher margins instead of selling their final product (Suliman A. et al. 2018; Bianchi N. at al. 2009; Taticchi P., et al. 2009 & Enrico S. 2019), and this process of creating additional values by adding services to products to achieve financial and strategic benefits, is called servitization (Natalia K. et al., 2014). One of the ways to achieve data monetization could be by providing fee-based structures for value-added data services (Baecker J. et al., 2020).

Servitization has paved its way through manufacturing industries by proving its capabilities in being an effective strategy that provides not only financial advantage (Andrea T. and Enrico S. 2019), but competitive advantage as well, by providing competitive offerings to manufacturing companies (Natalia K. et al., 2014). In the shipping industry, servitization has helped in decreasing the cost and increasing the revenue (Pagoropoulos A. et. al., 2017).

One of the industries that are witnessing the servitization trend through the implementation of IoT, CPS and intelligent data analytics is the maritime industry, by improving the services provided to their products such as maintenance, repair and performance services (Moritz S. et al., 2016). And what characterizes the maritime sector is that systems in this sector are complex systems that generate huge amount of data continuously which needs to be analysed, used and stored in a very effective manner based on the integrated implementation of internet of things and CPS technologies (Sullivana B. et. al., 2020)

Lokukaluge P. & Brage M. in 2019 highlighted the importance of the modern internet of things in facilitating the management and the control of ship vessels through the smart aggregation and analysis of real-time data from various ships in different locations, to digitalize the shipping industry. Moreover, asset owners in the maritime sector are looking for reducing cost with smart maintenance, which is the main reason why the maritime domain is witnessing digital transformation especially in the smart remote control and automation of processes through the extraction of valuable knowledge of the large stream of data collected from sensors and actuators. Therefore, the ability to access data remotely from hard-to-reach assets and handling these huge datasets is so important in the maritime domain because it helps in achieving a cost-effective maintenance and higher performance for the assets. However, the research and interest in the maritime domain is still new while a lot of research is focusing on the manufacturing domain in the past few years (Taylor N. et al., 2020), without a clear framework for the remote monitoring through the implementation of these technologies.

The rest of the paper is structured as follows. Section 2 presents the assumptions, hypotheses, and research questions formulation; section 3 presents the case study; section 4 discusses the framework formulation and the results; and section 5 provides some conclusions.

2 FROM LITERATURE REVIEW TO ASSUMPTIONS, HYPOTHESIS, AND RESEARCH QUESTIONS FORMULATION

For an in-depth investigation of the literature in order to understand better the implementation of IoT and CPS in servitization, a group of articles were collected and analysed using Scopus database. After deciding about the articles that are related to this topic, a theoretical thematic approach was used to extract the important data and finally categorizing the final list of articles according to the important extracted data (Vaismoradi M. et al., 2013).

The first step of the literature analysis started with the search for papers' titles, abstracts, and keywords: "Internet of things" using the time frame 2008-2019. This search was done to get an idea about the size of the existing literature that is related to Internet of Things, the result shows 70.247 of articles, which reflects the importance that this topic is getting from the researchers. After that, to narrow this literature and focus it on the articles that discussed the implementation of this technology within a specific device, another search was conducted but this time with the key words "IoT" and "physical device", and this reduced the list to 12.119. Speaking specifically about the situation of the IoT in the Maritime industry, "IoT", "Physical device", and "Maritime" were used as keywords on Scopus, and this time the result shows just 75 articles showing that the implementation of "IoT" is still a new area of interest in maritime sector deserving research effort.

A more focused research refinement was done to understand the effect of implementing IoT, CPS, and operational research (OR) algorithms and servitization concept as the following:

The analysis was done, as mentioned above, within a fixed time range (2008-2019), carrying the following steps:

- Scopus searching for papers' titles, abstracts, and keywords: "cyber physical system" and "operational research techniques";
- Filtering the results and make them limited to "English" articles that were published in "Journals" only in the field of "Engineering, and Computer Science", in the window frame from 2008-2019; a list of 143 articles was the result.

By analysing the corpus data, a list of 36 articles were defined as the most related ones for this research according to a proper research questions and assumptions formulation process.

Table 1 is the result of the analysis of this list of articles identifying five areas of interest and development on which researchers focus the most.

Table 1: Main Research Priorities.

Research Area	Percentage of papers
IoT real-time data analysis	38%
Product control and management	22%
Cyber security	19%
Integrated design and manufacturing processes	11%
Human and CPS interaction in problem-solving	8%

After analysing these categories, the following five assumptions (A) were formulated:

A1: Cyber physical environment can integrate digital product design and manufacturing processes for higher quality and lower cost operations.

A2: Transforming product-centric processes to service-oriented ones can be done with the support of digital technologies.

A3: The digital transformation can be achieved by the integration and the development of IoT, CPS, with other physical devices.

A4: Operational research technologies "AI and ML" can be used to support data intelligence development and analytics into this application area.

A5: Improved field service, maintenance and decision making is possible because of more information about when and how their product is being used.

According to the first assumption **A1** and the fifth one **A5**, the approved advantages of servitization, companies in the maritime sector are moving toward the implementation of this strategy. And this has pathed the way to the formulation of the first hypothesis:

H1: There is an increasing interest of the maritime sector in servitization.

Moreover, based on the second **A2** and the third **A3** assumptions, the secure implementation of digital technologies facilitates the transformation of the traditional companies to digital service-oriented ones. Therefore, the following two hypotheses were formulated:

H2: Engines and related systems (subsystems) will benefit from the integration of IoT, CPS, and OR techniques.

H3: Cyber security issues will increase in importance.

Finally, since services, maintenance and decisions can be improved by the right use of data **A5**, the following hypothesis has been formulated:

H4: The success of servitization depends highly on data understanding.

These assumptions and hypothesis lead to the formulation of the following research questions (RQ):

High level question:

RQ1: How IoT-enhanced CPS and servitization can add value to a manufacturer or a components provider in the maritime sector?

First level questions (Product level):

RQ1.1: How to use the collected real-time data RTD from IoT sensors?

RQ1.2: What is the effect of the tardiness in aggregating IoT-data?

RQ1.3: Who are the beneficiaries of the aggregated RTD?

Second level question (Manufacturing process level):

RQ2: How to improve product manufacturing process by using operational collected data?

In order to test and validate results obtained in section 2, a 10-step approach for the development of IoT-based product design for servitization was proposed accordingly by detailing the previously identified five areas represented in Table 1 and the results of the analysis of the articles found in the literature. Figure 1 shows the 10 main blocks in this approach.

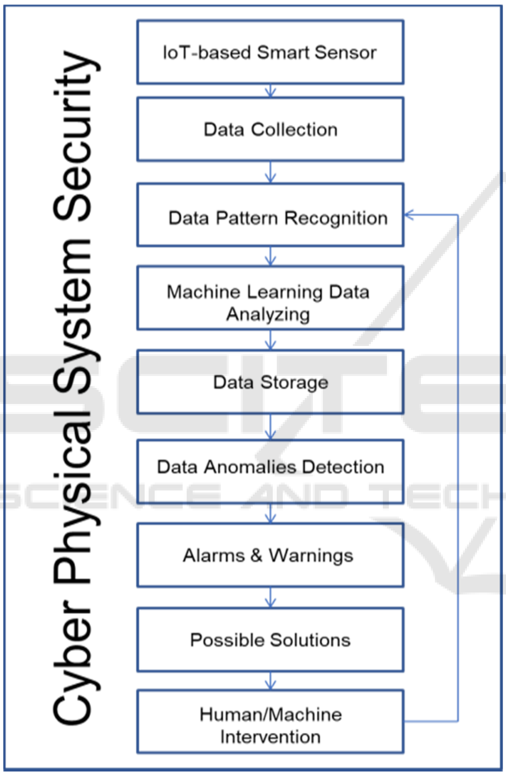

Figure 1: IoT-Based Smart Product for effective servitization block diagram.

Moreover, the framework delivered by Yoval C. & Gonen S. in 2020, was validated by implementing it in OMT-Digital Smart fuel Injection System. OMT has created the start-up company OMT Digital to quickly evolve its offer to also include services based on its products. To achieve this goal, the two companies have worked together to create an intelligent injector able to communicate its operative characteristics to a local processing unit for performing fast data analytics and providing immediate feedback to the engine control unit and to the engine room crew, as well as transmitting the processed data to a cloud-based storage for further analysis and knowledge generation (Marco C. & Marco F., 2019). As a result, a smart process control framework was elaborated.

3 THE DEVELOPED SMART SYSTEM

The aim of OMT Digital is to be able to transform traditional mechanical injectors into smart injectors to be able to share, process, and store data for further analysis to improve injectors' performance and increase its lifetime. Their smart system is made of different layers, so there is a fully digital layer where the injectors are connected in IoT system to the Hub. In this layer the digitization of the analogue signal takes place. After that comes the processing of the signal, which is done in the fog node, and here is where the algorithms run, and the reduction of data occurs -process raw data to extract value added data- and present directly to users' interface the status of the health of the system. And then the same data further reduced is sent to the cloud when the connection allows.

The IoT intelligence-related services/data provided to the user are divided into three categories (C):

- **C1:** drift compensation and product development "automation system". OMT has GUI so they can see how all the injectors "in the world" are operating and get important data to help them develop the product further. This is one of the benefits that the "injector manufacturer" can get from this automation system (i.e. getting numerous data from all the operating injectors).
- **C2:** on-board maintenance so if there is a problem in the injector; it needs to be fixed quickly. The smart system here discovers the abnormality and advises about the possible actions "on the user interface" that need to be taken in order to solve the problem. This leads to an easier and faster maintenance for the components
- **C3:** condition-based maintenance which means the ability to measure the status of the injector over time to predict failure before it occurs and calculate its remaining life to decide what maintenance needs to be done and when.

4 DISCUSSION & RESULTS

By taking into account the analysis of the literature and OMT-Digital case and pursuing improvements to the process control framework proposed by Yoval C. & Gonen S. in 2019, a smart controller framework for the fuel injection system "FIS" of OMT-Digital is presented. Figure 2 describes its main five modules and information flows in which the model operates.

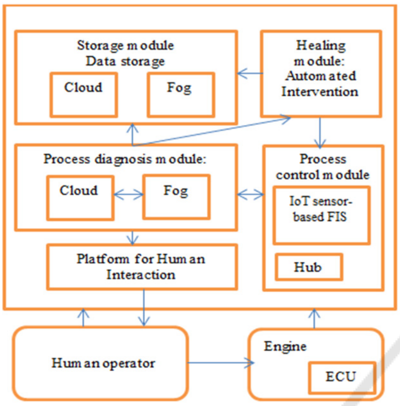

Figure 2: Smart controller framework for fuel injection systems.

4.1 Process Control Module

This module is responsible on collecting the data "mainly the temperature and the solenoid current" and sending it to the "process diagnosis" control. The injectors are connected to the system, and whenever the injector is activated by the control unit of the engine then this triggers data generation and acquisition. Moreover, there is an analogue sensor in the injector, and there is an analogue to digital convertor, and then this data is sent to the Hub and then sent via internet to this compute (fog node). So, there isn't any particular algorithm in this phase, it's just data coming into the sensor and then delivered to the fog node.

4.2 Process Diagnosis Module

The processing of the collected data is done in this module. The collected data is sent to the fog node, then the fog node will machine learning algorithms" or classical digital signal processing algorithms, in order to process the data and transform it into a more value-added data. The other level of data processing is done in the cloud.

In the ship, the real-time analysis is taking place, which means that if there is something changing significantly, then this will immediately be transferred with an alarm to people who are in charge on the ship will be informed, so they can perform immediate actions to the resulted changes.

On the other hand, the development of the algorithms to estimate the components' lifetime is done on the cloud.

4.3 Healing Module

Based on the required type of intervention, the corrective actions can either be performed automatically as part of the smart control or through manual intervention of a human expert. For example, if there is a delay in the performance of the injectors, the system can compensate for this defect automatically by itself. However, in the case of more complex faults, the intervention of human is required

4.4 Storage Module

Here is where the data get stored, and it can be stored in two ways, in the fog node for up to a month of a capacity for local analytics on the ship, and once there is internet connection, the data get automatically stored in a data lake in the cloud. It's used to give lifetime prediction and to give access to the data by different stakeholders

4.5 Human Interaction Module

This platform is used as one direction information flow to provide the user with the valuable data. The stakeholders can get access to the cloud with the graphical user interface of OMT "OMT GUI", and the health of a specific engine with some KPIs can be reviewed to the crew on the ship through alarms on the platform which reflects if there is something wrong, and the ways to solve this issue is provided to the operator through the platform as well. And this is done locally without the cloud connection

The main discussion areas in this research are the importance of internet of things technology in manufacturing comes from its ability to collect real time data and extract valuable knowledge from this huge amount of data which can be supported through the implementation of smart IoT-based servitization framework which was presented in this research together with a 10-steps approach diagram. These are highly connected to the assumptions and hypothesis that were mentioned before, so were used to answer the research questions formulated earlier in this research.

Speaking about the first hypothesis "**H1:** There is an increasing interest of the maritime sector in servitization" which is directly linked to the first and fifth assumptions "**A1:** Cyber physical environment for integrating digital product design and manufacturing processes for higher quality and lower cost operations, **A5:** Improved field service, maintenance and decision making is possible because of more information about when and how their product is being used", these were tested positive through the outcomes achieved by the company under investigation in this study after implementing the smart control fuel injection system proposed earlier. OMT is a company in the maritime sector which is achieving important benefits from implementing this IoT-based servitization framework within their operations. They start to build a good reputation in the market for having this technology "the smart control system", and seen as a technologically advanced injection system developer, and this attracts a lot of new costumers for the company "indirect revenue", as well as the financial revenue from selling the service provided by the smart monitor FIS "direct revenue". Also, having the technology of IoT-based servitization smart monitor system gives OMT the possibility to gain more projects of this kind and to be able to digitalize other products and not only the injector. These benefits also provide an answer to the higher-level question formulated earlier in this research:

RQ1: How IoT-enhanced CPS and servitization can add value to a manufacturer or a components provider in the maritime sector?

The second hypotheses "**H2:** Engines and related systems (subsystems) will benefit from the integration of IoT, CPS, and OR techniques", which was extracted from the second and third assumptions "**A2:** Transforming product-centric processes service-oriented ones through the help of digital technologies implementation, **A3:** The digital transformation can be achieved by the integration and the development of IoT, CPS, with other physical devices", also found support since the IoT-based framework that was implemented in a CPS environment to support the smart fuel injection system produced by the OMT-Digital, showed that all the data were fed to machine learning and artificial intelligence algorithms to enable the prediction of the injector lifetime depending on the actual conditions of use; this also answers the second research question:

RQ2: How to improve product manufacturing process by using operational collected data?

Regarding the third hypotheses "**H3:** Cyber security issues will increase in importance", this is tested positive since the high amount of collected and shared data needs to be processed in a secured way otherwise the risk of cyber-attacks will increase dramatically to the point where the implementation of these new technologies will affect negatively on the company. On the other side, if these real-time data were treated securely, this will expose any abnormalities that might occur. In the case study in this research, the collected real-time data "RTD" helped OMT in the detection of injector operation anomalies such as delayed start of injection, which is linked to higher fuel consumption, and their compensation by the control unit to keep the engine operating optimally. So, the RTD is used to detect the performance and the lifetime of the injector, and this data can support decision makers who are either the ship stakeholders or the engineers in the crew of the ship and guide them toward better understanding of the performance of the injectors and therefore, better maintenance. This answers the following questions:

RQ1.1: How to use the collected real-time data RTD from IoT sensors?

RQ1.3: Who are the beneficiaries of the aggregated RTD?

However, since the proposed framework in this research doesn't cover the effect of the tardiness in the detection of the real-time data, this leaves the following question without an answer:

RQ1.2: What is the effect of the tardiness in aggregating IoT-data?

Therefore, for being able to answer this question, a further development to the proposed framework can be suggested and then validated in other real-case scenarios.

Finally, understanding the value of the collected data and being able to extract knowledge out of it and transform this huge amount of data into valuable services, is the heart of servitization, and this supports the final hypotheses "**H4:** The success of servitization depends highly on data understanding" and its related assumption "**A4:** Operational research technologies "AI and ML" are used to support data intelligence development and analytics"

Moreover, the 10-steps approach diagram and the smart control framework for the case under investigation developed by this research can be considered as the first steps toward implementing IoT-based servitization concept in a CPS environment to collect and analyse data for further development and improvement in product performance and maintenance. However, the smart controller FIS framework proposed by this research differs from the one described by Yoval C. & Gonen S. in 2020, since it's considering the storage process of the collected value-added data, which is a new module that was not covered in their framework. Also, the healing module is mainly responsible on performing the automatic intervention but can't send any updates or modifications to the machine learning weights in the process control module. Moreover, the human interaction platform in the framework presented here is used just like a tool to provide information to the operator, so the operator can't send any data to the other modules within the framework. Finally, their framework assumes that the sensors practice self-awareness and maintain their own reliability, while it's not the case of the sensor developed by OMT-Digital.

5 CONCLUSION

With the evolution in the requirements of more integrated and connected world, companies are moving toward servitization and smart monitoring of their assets to satisfy their customer's needs. However, smart monitoring and servitization through the implementation of IoT and CPS technologies in the marine sector, has remained under-researched in literature.

In this research, we aimed to propose a framework and approach to support companies in remote mentoring and improving hard-to-reach assets health and performance.

This paper introduces a ten-steps approach and a framework to support the smart implementation of IoT and CPS in the manufacturing companies in order to be able to catch and communicate the added-value data within the system in real time, and this helps in servitization and the digital manufacturing. It also shows that the majority of the articles are focusing on the role of IoT real-time data in supporting decisions. And this is exactly the main idea behind the use of IoT data in service-oriented manufacturing. Detailing these five areas resulted in the formulation of a IoT-based servitization block diagram that was implemented within OMT-Digital boundaries, and one of its main features is the "storage module" since this feature was neglected by the researchers in the literature who produced similar process control frameworks. The proposed framework supports manufacturing companies who want to take the first steps toward smart monitoring through digitalization and servitization by the smart implementation of IoT and CPS in the manufacturing companies to produce a fully integrated smart control system starting from the aggregation of information to the storage of value-added data in real time. Moreover, a case study of a smart injector for marine engine is analysed to propose a working framework supporting the implementation of IoT and CPS to communicate the added-value data within the smart monitoring system built on five modules: process control module, process diagnosis module, healing module, storage module, and human interaction module.

Three important constraints limit the generalizability of the framework presented in this research. Firstly, the aggregation of data was mainly focused on the first stages of the digitalization process, because the smart system investigated in this research was not yet acquired by so many customers in the maritime sector, which made it difficult to follow the complete servitization strategy till the end of the product's lifecycle. Future work could include a longitudinal study for the complete investigation of the servitization process by the implementation of IoT and CPS. Secondly, the focus of this research is on the maritime industry, future research could include pursuing improvements to the framework and validating it in other industries.

REFERENCES

Heiner L., Peter F., Thomas F., Michael H. (2014). Industry 4.0. Business and information systems engineering.

Demartini M., Tonelli F., Orlandi I., Anguitta D. (2017). A manufacturing value modeling methodology (MVMM): A value mapping and assessment framework for sustainable manufacturing. 4th International Conference on Sustainable Design and Manufacturing.

Kristen L., Sven P., Kristin V. (2018). Drivers of digital transformation in manufacturing. Hawaii international conference on system sciences.

Marco S., Carlo A., Fabrizio D. (2018). How digital transformation is reshaping the manufacturing industry value chain: The new digital manufacturing ecosystem applied to a casy study from the food industry. Springer International Publishing AG.

Tonelli F., Galluccio F., Mattis P., Abusohyon I., Lepratti R., Demartini M. (2019). Closed-Loop Manufacturing for Aerospace Industry: An Integrated PLM-MOM Solution to Support the Wing Box Assembly Process. Advances in Production Management Systems. Towards Smart Production Management Systems pp 423-430.

Damiani L., Demartini M., Cassettari L., G., Revetria R., Tonelli F. (2017). Digitalization of manufacturing execution systems: The core technology for realizing future smart factories. Proceedings of the Summer School Francesco Turco.

Shum, Kwok L., Watanabe, Chihiro (2008). The effects of technological trajectory in product centric firms upon the transition to smart service provision. The case of smart solar photovoltaic. Journal of services research.

Damiani L., Demartini M., Guizzi G., Revetria R., Tonelli F. (2018). Augmented and virtual reality applications in industrial systems: A qualitative review towards the industry 4.0 era. IFAC-Papers OnLine p.624-630.

Li D., Eric L., Ling L. (2018). Industry 4.0: state of the art and future trend. International journal of production research.

Christopher G., Martin B., David W., Edward G. (2019). Cyber physical systems and internet of things. National Institute of Standards and Technology Special Publication

Somayya M, R. Ramaswamy, Siddharth T. (2015). Internet of Things (IoT): A Literature Review. Journal of Computer and Communications.

Keyur K. & Sunil M. (2016). A New Approach to Integrate Internet-of-Things and Software-as-a-Service Model for Logistic Systems: A Case Study. International Journal of Engineering Science and Computing.

Yang L. (2017). Cyber Physical System (CPS)-Based Industry 4.0: A Survey. Journal of Industrial Integration and Management

Marco C., Francesco C., Marco F., Marco L. (2019). Fuel Injection 4.0: The Intelligent Injector and Data Analytics by OMT Enable Performance Drift Compensation and Condition-Based Maintenance. The 29th CIMAC World Congress 2019 in Vancouver, Canada.

Suliman A., Husain Z., Abououf M., Alblooshi M., & Salah K. (2018). Monetization of IoT data using smart contracts. IET Digital Library.

Bianchi N. P., Evans S., Revetria R., Tonelli F. (2009). Influencing factors of successful transitions towards product-service systems: A simulation approach. International Journal of Mathmetics and Computers in Simulation.

Taticchi P., Tonelli f., Starnini E. (2009). A Framework for Evaluating Product-Service Systems Strategies. Proceedings of the 10th WSEAS Int. Conference on mathematics and computers in business and economics,

Natalia k., Sebastian k., Michal G. (2014). Servitization Strategies and Product-Service-Systems. IEEE 10th world congress on services.

Baecker J., Engret M., Krcmar H. (2020). Business Strategies for Data Monetization: Deriving Insights from Practice. In book: WI2020 Zentrale Tracks

Andrea T. & Enrico S. (2019). Exploring the relationship between the product-service system and profitability. Journal of management and governance.

Sullivana B., Desaib S., Solec J., Rossia M., Ramundoa L., Terzi S. (2020). Maritime 4.0 – Opportunities in Digitalization and Advanced Manufacturing for Vessel Development. Procedia Manufacturing
Volume 42, Pages 246-253

Pagoropoulos A., Kjær L., Bejbro J., Andersen1 and McAloone T. (2017). The influence of costs and benefits' analysis on service strategy formulation: Learnings from the shipping industry. Cogent Engineering..

Moritz S., Carl R., Bjornar H., Klaus-Dieter T. (2016). Utilising the Internet of Things for the Management of Through-life Engineering Services on Marine Auxiliaries. The 5th International Conference on Through-life Engineering Services.

Lokukaluge P. & Brage M. (2020). Ship performance and navigation information under high dimensional digital models. Journal of Marine Science and Technology.

Taylor N., Human C., Kruger K., Bekker A. Basson A. (2020). Comparison of Digital Twin Development in Manufacturing and Maritime Domains. In book: Service Oriented, Holonic and Multi-agent Manufacturing Systems for Industry of the Future

Vaismoradi M., Taurunen H. & Bondas T. (2013). Content analysis and thematic analysis: Implications for conducting a qualitative descriptive study. Nursing and Health Sciences, 15, 398–405

Yoval C., & Gonen S. (2020). Framework for smart process controller implementation in an industry 4.0 setting.

Marco C. & Marco F. (2019). Towards the digital engine: the OMT smart injector enables performance monitoring and condition-based maintenance. 29TH CIMAC World Congress.