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ANALYSIS OF INDUSTRY 4.0 AND THEIR IMPACT ON PORT ENVIRONMENTAL MANAGEMENT

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ABSTRACT

Industry 4.0 (I4.0) is a reality in several business segments worldwide. Technologies (I4.0) collaborate to improve production processes, in manufacturing or services. The use of these technologies in port operations for container handling can assist in environmental management and allows the service system to be sustainable. This research analyzed the use of technologies from I4.0, applied in port handling operations of containers, to verify their impact on environmental management. Some ports of great international relevance were searched for data collection regarding the use of I4.0 technologies and environmental management (port sustainability). These data were analyzed to understand the relationship between those technologies and sustainability in logistics operations (green operation). The focus of this study was to analyze some container terminal operations of five ports, to assess the use of I4.0 technologies and their impact, or not, on sustainable environmental management. The method of carrying out the research was the application of an online questionnaire to those five Ports: Los Angeles (USA), Hamburg (Germany), Rotterdam (Netherlands), Singapore (Singapore) and Busan (South Korea) exclusively for container terminals. Public materials available on the websites of each port were also used. The questionnaire was developed by reviewing the literature on the topic (Digital Business – I4.0 and Sustainability – green operations). An online survey to collect information took place between September-2019 to June-2020, which was complemented with publicly accessible material on the internet. The data collected were treated statistically for analysis of the research information applied in the ports (mean, standard deviation, significance level, Kolmogorov-Smirnov Test, critical statistical value, correspondence analysis and relative frequency). Overall information was collected from 20 container terminals. Experts (managers and supervisors) responded to the online survey.

Keywords: *Industry 4.0; Smart Port; Sustainability; Environmental Management; Port Management*

1. INTRODUCTION

The Industry 4.0 (I4.0) is the merger of some technologies and the digital technology is a boost to the infrastructure of the industries. Accordingly, the use of some technologies in port operation, like container handling, is one way that promises to embed green operation and port sustainability (Garg & Kashav, 2019; Davarzani et al., 2016; Nebot et al., 2017). Container transportation is increasing year by year and some ports around the world are using new technologies to improve their performance and reduce emission of the greenhouse gas, reducing air pollution, noise and increase the use of renewable resources (Darbra et al., 2004; Peris-Mora et al., 2005; Molavi et al. 2019; González et al., 2020; Kuo & Lin, 2020).

In recent years, much research has focused on port management sustainability and the concepts of I4.0 address tools and technologies to support sustainable operation in ports. Environmental management must be one of the main objectives of a port authority, with a focus on sustainability (Puig et al., 2017; Puig et al. 2014; Kuznetsov et. al., 2015; Walker, 2016; Zhao et al. 2019; Alamoush et al. 2020; Liu et al., 2020).

A port should not harm the environment, let alone the city and its surroundings. The environmental problems that the world has been experiencing recently are notorious and public policies must concentrate efforts to implement measures, with innovative and technological solutions in the area of transport and movement, aiming to reduce or eliminate this disorder (Yang et al., 2020).

Container terminal operations, if not well monitored, can cause damage to air, water and land use. Therefore, the ports are gradually becoming environmentally aware (Kuo and Lin, 2020). Maritime transport is essential in the global logistics chain, since most products use this means of transport to insert their products in the global market. The role played by ports is vital for the environment. Port operations have a direct integration with nature (flora and fauna), air, water, soil, etc.

This environment must be monitored, with specific, well-defined and rigorous measures that contribute to the preservation of the environment, humanity will increase its problems related to sustainability and the world will have more and more difficulties to control emissions of polluting materials on the planet Earth. Therefore, new environmental guidelines, combined with innovation and technologies, can make port operations live in harmony with the environment, adding value to global supply chain management, allowing all actors involved in the process to benefit from the system and the world to be more environmentally conserved.

The focus of this study was to analyze some container terminal operations of five ports, to assess the use of I4.0 technologies and their impact, or not, on sustainable environmental management.

The review carried out on the scientific articles did not show any work that relates to the use of I4.0 technologies in port terminals, with environmental management. Therefore, this work aims to fill this gap in the literature, evaluating some port terminals, that use technologies I4.0 and what benefits, or not, they brought to the environmental port management. Molavi, Lim and Race (2019) highlighted the importance of intelligent operations for ports that aim to obtain an international sustainability certification.

These so-called smart operations use technologies from I4.0. Therefore, the focus of this work is to analyze whether these technologies from I4.0 can collaborate or not to improve the environmental management indicators of ports. Puig et al., 2017 defined tools to identification and implement environmental indicators in Ports (TEIP) and Garay-Rondero et al., 2019 addressed the need for interconnectivity related to the virtual value chain for logistical operations.

Analyzing the main elements addressed in the scientific literature on the themes I4.0 and sustainability in port management, this work applied a field survey (online) to assess whether there is any existing adherence between the use of I4.0 technologies, by port terminals of containers, which may or may not contribute to sustainable port management.

2. LITERATURE REVIEW

2.1. Environmental Management

Environmental management (Darbra et al., 2004) becomes a competitive differential for several ports worldwide (Darbra et al., 2005) and knowing how to define and evaluate the main performance indicators is important (Peris-Mora et al., 2005; Puig et al., 2014). Well-defined environmental port public policies (Puig, et al., 2017; Walker, 2016) is an essential factor in logistics operations (Cavallo et al. 2015). The use of ports as conduits to transport products is renowned and increasingly intense (Woodburn, 2017).

Therefore, monitoring elimination or reduction of elements that damage the environment is the core of port management (Wang et al., 2017; Davarzani et al., 2016). Without very clear and objective environmental management policies, seaports are unlikely to achieve sustainability in their day-to-day operations (Hall et al. 2013).

Therefore, tools (Puig et al., 2017) that assist in decision-making, for the benefit of the environment, can reduce or eliminate factors that negatively affect the port environment (Song and Shon, 2014). The use of renewable energies (Acciaro et al. 2014; Alamoush et al. 2020) in port operations is an important element in environmental management, which contributes to sustainable processes, to the management of the supply chain committed to the indicators (Lirn et al. 2013) sustainability of air, water, noise pollution etc.

The use of renewable energy, when the vessel is moored, thus avoiding the use of auxiliary engines and fossil fuel consumption (Ammar & Seddiek, 2020; Chen et al., 2019; Dai et al., 2019), is also a relevant differential for proportional environmental management engaged and committed to the environment. Innes and Monios (2018) studied emissions from maritime transport.

They assessed the use of Cold Ironing - Onshore Power Supply - (Yang et al., 2019; Tseng & Pilcher, 2015). The use of Liquefied Natural Gas (LNG) in ports to supply ships is also an element that contributes to sustainable port operations and some ports in Europe are already implementing this system (Mjeldea et al., 2019).

The movement in the container yard, using AGV (Automated Guided Vehicle), using renewable energies, powered by batteries (Amjad et al., 2018), also characterize logistically sustainable operational processes, avoiding the use of fossil fuels. This is also applicable to other equipment used in port operations for container handling, such as the STS (Ship top Shore Crane), RTG (Rubber Tyre Gantry Crane) and MHC (Mobile Harbor Crane), which must avoid the use of fossil energy and be powered by renewable energy, such as electricity, etc. (Sadek & Elgohary, 2020; Yap & Lam, 2013).

The definition of public and private policies with well-defined environmental management objectives is important (Attardi et al., 2012; Di Vaio & Varriale, 2018). It must have measurement of indicators, external audit and engagement and commitment of all actors involved in the process (Ashrafi et al., 2019; Frantzeskaki et al., 2014; Langenus & Dooms, 2018).

The management are fundamental elements that will determine the success or failure of sustainable port operations (Casazza et al., 2019; Borriello, 2013; González Laxe et al., 2017; Kadir et al., 2020). Schipper et al. (2017) proposed a model to assess port policies, focusing on sustainability. Schrobback and Meath (2020) studied the ports and their stakeholder's corporate strategy, and the main point was how sustainability can be part of both objectives without conflicts of interests (Yang et al., 2020; Zhang et al., 2017).

The truck appointment at ports is a process that helps to minimize greenhouse gas. Santos and Hilsdorf (2019) studied the impact of the truck appointment and what process, integrated with an electronic communication system can contribute to more sustainable operations (Hartman & Clott, 2012; Daamen & Vries, 2013). This system directly affects the port, as well as its surroundings (Aregall et al., 2018) or the cities close to it, avoiding the congestion of trucks on the roads and surroundings and contributing to the environment (Hou & Geerlings, 2016; Jia et al., 2017; Kuznetsov et al., 2015; Moura & Andrade, 2018).

A port has an important role with its community, its surroundings and its hinterland for local, national and international trade (Sislian et al., 2016; Oh et al., 2018). Increasingly, the use of containers (Rødseth et al., 2020) in transportation is intensifying and port logistics processes must accompany this evolution, optimizing their logistics operations, with the use of connected equipment, with renewable energy, automating the logistics processes and integrating information in supply chain management (Santos et al., 2016).

Maritime transport must be integrated with other modes of transport using information technology to improve operational processes and contribute to the management of the environment. Adding value to everyone who is directly and indirectly involved with port operations, such as the dredging operation, support operation and logistical support (Roos & Kliemann Neto, 2017; Carpenter et al., 2018; Garg & Kashav, 2019; Jansen et al., 2018).

2.2. Industry 4.0

The so-called digital age (Pashkevich et al., 2019) is dynamically changing manufacturing and service worldwide (Yau et al., 2020; Chauhan & Singh, 2019). The use of new technologies (Mathauer & Hofmann, 2019), combined with information systems, are revolutionizing operations (Stank et al., 2019). The use of those new technologies, applied in transport operations (Queiroz & Wamba, 2019), increases competitiveness and can collaborate for a better environment (Molavi et al., 2019).

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The technologies from I4.0 and sensors (Andersson and Jonsson, 2018), are essential elements for the design of a digital environment, to assist the logistic operation processes. Integrating several actors in the supply chain management, which involves port operations, as an important conduit in this transport system (Garay-Rondero et al., 2019).

Connectivity between machines in the manufacturing segment (Brozzi et al., 2020; Liu et al. 2020; Woschank et al., 2020), has been widely reported in scientific articles (Meudt et al., 2017). However, there is still little research on smart ports, using I4.0 technologies (Botti et al., 2017), aiming to improve environmental management indicators. When you combine smart ports with environmental port management, the scientific literature scarcely addresses anything about the problem. With the lack of scientific research relating I4.0 to port environmental management, this work seeks to fill this gap, assessing whether there is a correlation between these two elements.

The transportation system uses several tools from I4.0 (Molka-Danielsen et al., 2018) to improve its performance in supply chain management (Cichosz et al., 2020). A port, as an essential link in this logistical system (González et al., 2020), is an important element in the supply chain management in the worldwide, and the use of I4.0 technologies is increasingly contributing to improve performance in handling of containers between nations (Facchini et al., 2019).

The use of I4.0 tools eliminates operational and material waste, adding value to the process (Zhao et al., 2019). The automation of operations (Nagy et al., 2018) contributes to improving operational quality, system reliability and optimizes the use of resources (Peukert et al., 2020; Sarc et al., 2019).

In so-called smart ports, the use of these tools grows too much, mainly with the use of 5G, which serves as a primordial digital platform. It boosts interconnectivity of equipment, which improves performance in the processing of data, information, operations planning, the exchange of information between ships and ports and between all logistical agents (Cichosz et al., 2020; Woschank et al., 2020).

3. RESEARCH METHODOLOGY

This section presents the proposed methodology to analyze I4.0 and the Sustainability in container handling terminals of some ports.

This research focused on the container terminal operations of some of the world-renowned ports for their importance to international business, for the application of new technologies in their operational processes and for environmental management.

The method of carrying out the research was the application of an online questionnaire to five Ports: Los Angeles (USA), Hamburg (Germany), Rotterdam (Netherlands), Singapore (Singapore) and Busan (South Korea) exclusively for container terminals. Public materials available on the websites of each port were also used. The questionnaire was developed by reviewing the literature on the topic (Digital Business – I4.0 and Sustainability – green operations).

In the online questionnaire, the Likert scale was used, varying from one (1) to five (5). Where: Value 1 - Not relevant until Value 5 - Extremely relevant. Two main factors were assessed: port sustainability and technologies (I4.0 – the ability to grasp the overall idea of I4.0), used in ports. Accordingly, Table 1 (Port Sustainability Technologies I4.0) lists the items that were searched. All items mentioned in Table 1 were gathered from the literature (papers from Scopus and Web of Science).

The literature review on the theme of environmental management, shows that the factors presented in Table 1, gathered from the literature, are essential elements in the analysis of port management indicators, which carry out their operations in a logistically sustainable manner and collaborate for a harmonious environment between ports and the environment. Measuring and controlling all key performance indicator environmental are essential to obtain green port management. These factors have been widely studied in the scientific literature by (Darbra et al., 2004; Darbra et al., 2005; Peris-Mora et al., 2005; Puig, Wooldridge & Darbra, 2014; Puig, et al., 2017).

These authors have also developed systems for evaluating port management operations in ports, focusing mainly on these elements shown in Table 1. Management instruments like PERS (Port Environmental Review System), EMAS (Eco-Management and Audit Scheme) and the International Organization for Standardization ISO 14001 also focus on these factors presented in Table 1, for analysis of environmental port management (green).

The technologies, tools, equipment, devices, shown in Table 1, are also elements that were gathered from the literature review on the theme (I4.0), which the literature addresses as essential elements for a port to be considered intelligent, using the concept, the techniques, the technologies, from I4.0.

The authors, Molavi et al. (2019), Andersson and Jonsson (2018), Garay-Rondero et al. (2019), Molka-Danielsen et al. (2018), Cichosz et al. (2020), González et al. (2020) and Nagy et al. (2018), stressed the importance of the technologies from I4.0. I4.0 can be used in transport and movement operations, which collaborate for an integrated supply chain management, with innovations in the use of renewable energy, increased productivity, better efficiency and efficiency in the process operational, reducing energy consumption, human physical effort and integrating total information with all actors in the process.

An online survey to collect information was hold between September-2019 to June-2020, which was complemented with publicly accessible material on the internet. The collected data were treated statistically for analysis of the research information applied in the ports (mean, standard deviation, significance level, Kolmogorov-Smirnov Test, critical statistical value, correspondence analysis and relative frequency). Overall information was collected from 20 container terminals. Experts (managers and supervisors) responded to the online survey.

4. ANALYSIS AND RESULTS

Table 1 presents the final analysis of the questionnaires applied at the port terminals. The darker green color represents the highest adherence between the variables analyzed in the two axes (sustainability factor x I4.0 technologies used in smart port). The result shown in Table 1 comes from the answers given by each port terminal. The information was consolidated and treated statistically, analyzing the mean, standard deviation and residue analysis.

The mean and standard deviation of the analysis of the responses of the 14 terminals were statistically treated to arrive at the final values presented in Table 1. The residue analysis was also applied to have the most real number for the analysis of the results, as they will be presented in this part of the job. The inference made throughout this work item comes from the values shown in Table 1.

The score closest to scale five (5) shows the existing adherence between the variables analyzed. For example, when using the AGV (Automated Guided Vehicle) equipment and analyzing its impact on sustainability factors, the score that approaches the value 5, has strong adherence to a system focused on improving the environmental impact and strengthening the

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environment, without causing negative damage to port operations, its surroundings and the city where the port is located. The use of this type of technology (AGV) is considered important for the environment, as it contributes to an environmentally clean operation system.

When the score is closer to one (1), it means that there is no relationship between the variables analyzed in the study. That is, the use of a technology in a port terminal has no impact on a sustainability factor. For example, when using AGV technology, this has no impact on the terminals available bunkering LNG. There is no relationship between these two variables. There is no impact whatsoever, neither negative nor positive among these elements studied.

In general, when analyzing the colors in Table 1, it is clear that there is a strong relationship between I4.0 technologies, positively affecting the factors related to the sustainability of port operations. It means that the increasing use of these technologies by the ports can considerably reduce the impact on the environment and make port operations more sustainable.

The investments required for the implementation of I4.0 technologies in port operations were not addressed in this work. This work focused on the use of these technologies and their impacts on the environment, whether they collaborate or not for clean operations, without denigrating the environment.

Table 1: Sustainability and Technologies I4.0

I4.0 - Technologies Used in Smart Port	AGV - Automated Guide Vehicle	Artificial Intelligence (AI)	Augmented Reality	Automation and Robotic Processes	Autonomous Drones	Big Data and Analytics	Cloud Computing	Cyber-Physical Systems	Digital Internet	Digital Supply Chain	GPS	Intelligent Transportation Systems	Internet 5G	IoT (Internet of Things)	MHC – Remote	Machine Learning	Mobile Computing
Factor -Sustainability																	
Air quality	4,3	4,7	2,8	3,8	3,9	4,1	3,9	4,8	3,9	3,8	3,8	4,7	3,9	3,9	4,7	4,1	3,9
Dangerous cargoes	4,5	4,8	4,7	4,1	3,8	3,1	3,8	4,7	3,9	3,9	4,6	3,8	3,9	3,9	4,6	4,4	3,8
Dredging operations	4,2	3,8	3,2	3,8	1,9	3,9	3,9	2,9	3,8	3,8	4,5	3,9	1,8	3,7	1,2	3,8	3,7
Dust	4,3	3,7	3,1	4,8	3,9	3,8	4,1	4,1	3,8	3,9	4,8	3,8	3,7	3,7	4,6	3,9	3,7
Emissions from ships	4,8	4,1	3,8	3,9	4,1	3,9	4,7	4,6	4,4	3,8	3,7	3,7	3,6	3,6	1,2	3,8	3,8
Emissions from terminal	4,7	3,2	3,9	3,8	3,8	4,1	4,5	4,7	4,6	4,4	4,1	3,6	3,7	4,4	4,6	4,5	4,6
Energy consumption	4,2	3,9	4,1	3,8	2,9	3,9	4,6	4,5	4,7	4,6	3,9	4,4	3,4	4,7	4,5	4,6	4,5
Environmental policy	4,8	4,8	3,7	3,7	3,7	4,2	3,9	4,6	4,7	4,5	3,9	4,5	3,8	4,6	4,6	4,5	4,7
Fuel in ships	3,8	3,2	2,7	1,8	2,7	2,9	1,8	2,9	2,8	2,9	2,7	2,9	1,7	1,9	1,1	1,8	1,8
Garbage/port waste	3,7	2,8	2,8	2,9	3,1	2,8	2,9	3,9	3,8	3,8	4,1	3,9	3,9	3,9	2,8	3,8	3,8
Hazardous cargo	4,2	3,9	3,9	3,9	3,9	4,2	4,1	4,1	3,8	3,7	4,1	3,8	4,1	4,1	4,6	3,8	3,8
Industrial effluents	2,7	2,1	2,8	2,9	2,8	2,8	2,9	2,8	3,2	2,8	3,8	2,7	4,1	2,8	1,2	3,9	3,9
ISO 14001	4,8	3,9	4,2	4,1	3,9	4,7	4,1	4,6	4,7	4,7	4,6	4,4	4,6	4,6	4,7	4,6	4,6
LNG bunkering available	1,4	1,8	1,8	2,8	1,3	1,7	1,7	1,8	1,7	1,7	2,9	1,7	1,8	1,7	1,1	1,9	1,1
Marine traffic accidents	4,7	4,6	3,8	3,8	3,7	3,8	4,1	4,6	3,8	3,9	4,7	4,7	4,7	4,8	4,6	4,7	4,6
Noise pollution	4,6	4,7	2,8	4,6	3,6	4,5	3,8	4,7	3,9	3,8	4,5	3,8	3,9	4,4	4,5	4,5	4,5
Odours	3,8	2,8	1,2	2,8	2,8	4,6	4,2	4,6	4,1	3,9	4,6	2,8	3,8	4,6	4,6	4,6	4,6
Onshore Power Supply	2,2	2,5	2,8	3,1	2,4	2,9	2,8	2,8	1,8	2,1	2,9	1,7	1,8	2,1	1	1,9	1,8
Port accident	4,8	4,2	4,7	3,8	3,9	3,9	3,9	4,6	3,8	3,9	4,7	4,4	4,5	4,8	4,6	4,7	4,6
Risk of oil spill	4,7	3,7	3,9	2,8	3,9	4,1	3,8	3,8	2,8	2,8	2,8	2,8	2,9	3,9	2,8	4,6	4,5
Ship waste	3,2	3,8	2,8	4,7	2,9	3,2	3,8	4,1	2,8	2,9	3,9	2,8	2,9	3,8	1,1	2,9	3,9
Solid wastes	4,8	2,8	2,7	2,9	2,8	3,9	3,7	3,9	2,9	3,2	4,1	3,9	2,8	3,9	1,8	4,1	3,9
Waste management	3,7	3,2	3,9	3,1	2,9	3,8	3,9	3,8	2,7	3,8	3,9	4,6	4,1	4,5	2,8	4,5	4,7
Water quality	4,8	4,2	4,6	4,2	4,1	4,6	4,6	4,5	3,8	3,8	4,5	4,5	4,5	4,6	3,9	4,6	4,1

I4.0 - Technologies Used in Smart Port	Multimodal Systems Intelligence	OCR	RFID	RTG – Remote	Sensors (Data Collection)	Simulation Systems	STS – Remote	System Integration – ERP	Railway Traffic Management	Traffic Management Systems	The Cloud	Vehicle Data Collection	Vessel Traffic Management System	Virtual Reality	Warehouse Management Systems	Wireless Network Devices
Factor -Sustainability																
Air quality	3,9	3,9	3,9	4,5	3,8	3,8	4,5	4,7	4,6	4,5	3,9	3,9	3,9	3,8	3,9	3,9
Dangerous cargoes	4,1	3,8	3,8	2,8	3,7	3,8	3,9	4,5	1,8	3,9	3,9	3,9	3,8	3,8	3,9	3,9
Dredging operations	1,7	1,1	1,1	1,1	3,8	3,9	1,1	3,8	1,2	4,1	2,8	3,8	3,8	2,9	1,1	3,8
Dust	3,9	3,9	3,9	1,8	3,9	3,8	4,5	3,8	4,7	3,9	4,1	4,1	3,8	3,9	3,8	4,1
Emissions from ships	2,8	1,2	1,2	1,8	3,8	3,8	1,8	3,9	1,1	4,1	2,8	2,8	3,9	1,8	1,2	2,8
Emissions from terminal	3,9	3,9	3,8	4,6	4,5	4,4	4,5	4,6	4,6	4,2	4,6	4,6	3,8	3,8	3,8	3,9
Energy consumption	4,4	3,9	3,9	4,6	4,5	4,5	4,6	4,5	2,8	3,9	4,5	4,5	3,7	3,7	3,8	3,8
Environmental policy	4,5	3,7	3,8	4,7	4,7	4,5	4,5	4,5	4,6	4,4	4,7	4,6	4,4	3,8	3,9	3,8
Fuel in ships	1,4	1,2	1,1	1,1	1,1	1,1	1,2	1,8	1,2	1,1	1,1	1,1	1,1	1,2	1,1	1,2
Garbage/port waste	3,8	2,9	1,8	1,4	3,8	3,8	1,8	3,9	1,1	2,8	3,9	3,9	2,8	2,8	2,8	3,9
Hazardous cargo	2,8	3,8	2,8	3,8	3,8	3,9	3,8	3,9	1,8	3,9	4,1	2,8	2,8	2,8	3,9	3,8
Industrial effluents	1,6	1,1	1,2	1,1	3,9	1,2	1,2	2,8	1,2	1,1	1,9	3,9	1,2	2,9	1,2	2,8
ISO 14001	3,9	3,9	3,9	4,6	4,6	4,6	4,6	4,6	4,6	4,6	4,6	4,6	4,6	3,9	3,9	4,6
LNG bunkering available	1,2	1,2	1,1	1,1	1,1	1,2	1,4	1,2	1,2	1,2	1,1	1,1	1,2	1,1	1,2	1,1
Marine traffic accidents	3,9	1,8	3,8	3,8	4,5	4,5	3,7	4,4	2,8	4,4	4,6	4,6	4,6	3,9	2,7	4,6
Noise pollution	4,1	3,9	3,7	4,5	4,5	4,6	3,8	4,7	2,8	3,9	4,7	4,4	2,8	3,9	3,8	4,5
Odours	3,7	1,7	1,7	4,7	4,7	4,5	4,7	4,6	3,9	4,1	4,6	4,5	2,8	2,8	2,7	4,5
Onshore Power Supply	1,2	1,2	1,2	1,2	1,1	1,1	1,2	1,3	1,1	1,2	1,2	1,2	1,2	1,2	1,1	2,8
Port accident	3,9	2,8	2,8	3,8	4,7	4,5	4,4	3,8	1,8	4,6	3,8	3,8	3,9	4,6	3,9	4,4
Risk of oil spill	1,8	1,1	1,1	1,2	4,6	3,9	1,9	2,9	1,1	1,1	3,9	2,8	1,4	1,7	1,2	3,9
Ship waste	1,1	1,9	1,1	1,8	3,8	3,8	1,2	2,8	1,1	2,8	2,8	2,9	3,8	2,8	1,8	3,8
Solid wastes	1,8	1,7	1,8	1,8	3,9	3,9	1,2	2,7	1,2	2,8	2,8	3,1	3,8	2,8	1,8	3,9
Waste management	3,9	1,7	2,8	1,7	3,8	3,8	2,8	3,6	1,8	2,9	4,1	2,8	3,9	2,9	1,7	3,8
Water quality	4,5	2,8	2,7	3,8	4,6	4,5	4,4	4,5	3,9	3,8	4,6	3,8	3,8	3,9	1,7	4,6

Source: The author

Currently, several tools related to I4.0 are being implemented in ports considered intelligent. Tools such as RFID, OCR, GPS, sensors, mobile devices, cloud computing, port, road, rail monitoring system, ship traffic management and truck scheduling, are some of the systems that assist port operations and environmental management (Bayhan et al., 2020).

Ports use many smart solutions for planning container-handling operations in the port yard. Virtual remote augmented reality applications in areas such as training, maintenance and management of port operations are some examples (Botti et al., 2017).

Industry 4.0 technological solutions, which improve the safety of the user and of all human-machine interfaces, are important to increase productivity. Port operations become more productive with autonomous machines, with an efficient navigation system, regardless of any meteorological climate. In some container terminals, those technologies are already part of the operations system. Real-time information from multiple sensors and smart sources is used for data analysis. These data are analyzed to extract the necessary information to run the routine operations in container terminals, thus stimulating more intelligent processes, eliminating waste of time, machine, labor along with optimizing the resources (Stank et al., 2019).

Systems with intelligent algorithms (Artificial Intelligence) can detect inappropriate vessel procedures, such as sudden speed reduction, change of direction (Yau et al., 2020). The system can alert port operators about anomalies in operations. Constant changes in speed increase fossil fuel consumption; thereby, increase emission of polluting gases into the air. Real-time digital information allows documents to be transferred between the interested parties, with cybersecurity. The use of Big Data, Analytics and Artificial Intelligence in container terminals improves the predictability and planning of operations in the supply chain and contributes to eliminate wasteful processes (Woschank et al., 2020).

Integration of real-time information within the actors in the port operations process, authorities, pilots, tugs, navigation agents, service providers aiming at better coordination of activities is a key element. In that way, the role of I4.0 technologies in port container handling operations is relevant and adds value to supply chain management. A solution based on a mobile cloud platform, using real-time traffic and transport truck positioning information aims to improve collaboration and coordination at transport terminals (Molavi et al., 2019).

The increasing use of digital platforms and block chain technology for maritime service (i.e., brokerage, customs clearance, maritime cargo insurance, commercial financing, etc.) has boosted the flow of information and reduced bureaucratic bottlenecks in transportation (Queiroz & Wamba, 2019).

The growing use of digital platforms and block chain technology for maritime service is revolutionizing operations and contributing to the use of resources intelligently. The use of I4.0 is increasingly improving the predictability and planning of supply chain events. Assured access to real-time information and documents to all actors in the supply chain, supported by cybersecurity, contribute to improving productivity and minimizing negative effects on the environment.

The Cloud Computing system, available through the internet or intranet, provides information technology resources such as networks, servers and data storage. It has been collaborating to gain control and enhance quality in port operations, contributing enormously to the environment. Cyber Physical Systems (CPS), which are embedded systems with intensive use of software, promotes connectivity between different sectors and services.

That means that computers, devices, machines, communication systems, identifiers, such as RFID (Radio-Frequency Identification), and sensors are connected. The use of sensors has led to new possibilities to collect and process data, facilitating the process of the logistics system (handling, transport and storage). Therefore, the interfaces among all the actors of an integrated logistics system are connected. Some devices can collect data like smartphones, computers, tablets, or any mobile device (Garay-Rondero et al., 2019).

The use of computer science in ports helps the electronic transmission of documents, which optimizes cargo handling. The truck scheduling system, which reduces congestion, helps to reduce pollutant gas emissions, benefits from this technology as well and saves the environment. The increase in size of container ships ends up requiring an adequate infrastructure of the ports to carry out the loading and unloading operations with containers.

The use of information technology combined with other technologies (I4.0), are essential elements in smart port operations. Those technologies, combined with new equipment, allow the ports to increase their productivity and consequently remain logistically competitive. Those technologies also contribute to the reduction of emissions of polluting gases, particulate matter, noise, etc. and this contributes to a friendly environment (Cichosz et al., 2020).

The handling of containers in the yards in a terminal, along with the use of battery-powered AGVs, as well as remote-controlled quay cranes, are highly positive in smart ports. Equipment such as Remote Ship to Shore Crane (STS) and Remote Rubber Tired Gantry Crane

(RTG) perform the container storage operation automatically. Storage is performed through software. Thus, the aim is to optimize the operation, saving energy and resources. Increasingly, the use of remote augmented reality applications, autonomous machines equipped with sensors, etc. are being implemented in port logistics operations for container transport.

The communication system between the areas that carry out container handling and storage operations in the yards of smart ports is carried out using technologies such as videos and images from the cameras of the port equipment, in addition to the exchange of electronic signals (sensors) through several devices. In addition, there is communication with the roads, to avoid congestion of trucks in the port or around the port area. There are self-service terminals for truck drivers to unload containers. That system reduces queuing time and greenhouse gas (Stank et al., 2019).

The optimization of railway logistics operations, through the use of I4.0 technologies, integrated with port logistics operations, is also a competitive advantage for smart ports and this system uses broadband internet (5G) increasing port productivity in container handling to contribute to increase productivity and eliminate unnecessary tasks in the processes (waste). The use of integrated sensors allows control of air and noise pollution. Operations management allows optimization of cargo movement, route and network, granting real-time visibility of the supply chain, stowage planning and empty container repositioning (empty repositioning). The use of digital intelligence allows computer systems programmed to use data, to learn and solve problems quickly and optimally, for example, monitoring emissions, monitoring energy consumption, etc. (Meudt et al., 2017; Puig, et al., 2017).

The liquefied natural gas (LNG) is currently a reality in some ports worldwide (Mjeldea et al., 2019). The use of renewable energies, like the one from the ocean, and wind energy are essential elements in the sustainability of port operations. Air quality is an important factor to be managed in port operations, as large scale of inappropriate gases contribute to an unsustainable environment (Acciaro et al., 2014; Puig et al., 2014; Peris-Mora et al., 2005).

Fossil fuels in machines, cranes, vehicles and boats in a port is an issue to be rethought and somehow replaced by renewable energies. Electricity consumption, including the energy used for lighting, heating or cooling areas and equipment in a port, should come from renewable energy sources like wind power energy, solar energy, wave (sea) energy and others are necessary (Zhang et al., 2017).

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The port authorities must adopt measures to contribute to reducing noise pollution. The use of AGV, E-RTG (electrification), STS remote, MHC remote, VTMS, for example. Making the electricity generated on the continent (Onshore Power Supply) replace the energy used in the ships' auxiliary engines when they are docked, is also an important factor, and some ports have already implemented such systems (Yang et al., 2019). Therefore, the use of I4.0 technologies, renewable energy etc. allows that indicator (noise) to be decreasing in some container handling terminals. The use of I4.0 technologies in the container terminals can positively affect the port environmental management in smart ports.

Figure 1 shows a form of integration between I4.0 and sustainability in container port operations. The use of new technologies and innovations can collaborate for a more sustainable logistic process and, thus, allow economic growth. Integration between I4.0 and sustainability is a way to show concern for the environment, the society, fauna and flora. Sustainable development, avoiding damage to the environment and its surroundings leads to harmonious coexistence between port and city.

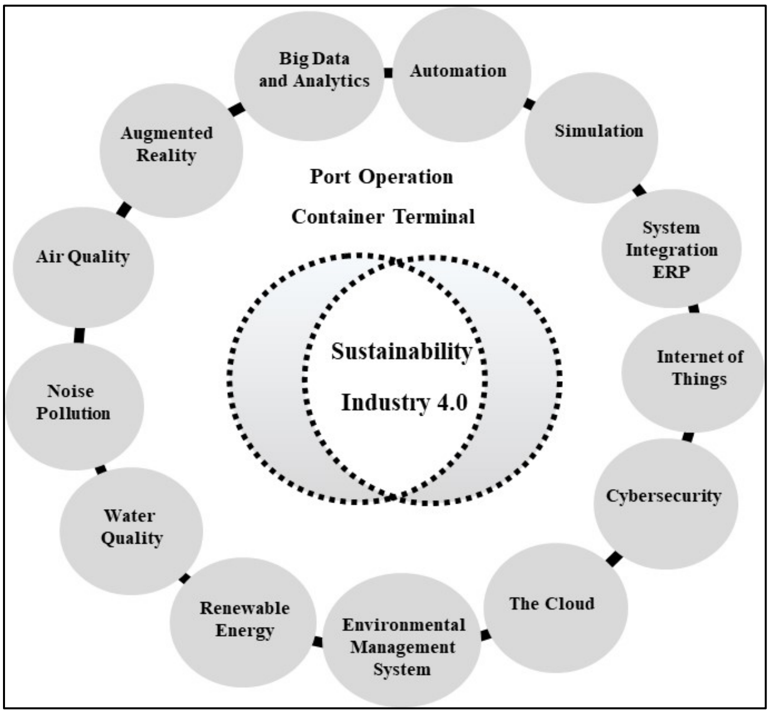

Figure 1: Integration between Technologies (I4.0) and Sustainability
Source: The author

The results obtained by the research, show that the technologies (I4.0) implanted in these port terminals, are collaborating with the management of the environment, because there was a considerable reduction in the use of fossil fuel in the logistics operations, the use of renewable energy increases considerably and this factor is a key element for green operations.

Managing arrival at ships, at terminals, planning the optimization of handling equipment and eliminating operational waste, also contributed to the reduction of harmful elements in the environment. Having real-time information on hand, integrated with all the actors involved in logistics operations, will also assist in making the most appropriate decision.

The real-time information of the operational process collaborates to monitor and evaluate the environmental performance indicators and propose quicker solutions for any abnormality in logistics operations. There are considerable gains with the use of these technologies to eliminate environmental risks and the port to live harmoniously with its surroundings and the city.

However, these technologies do not solve the environmental problem. It is necessary to focus on sustainability, disseminated to the entire port community, with very specific goals, with external audits, with the planning of continuous improvements, definition of sustainable goals, with the participation of the public agents, private companies, research centers, universities, and society.

The use of I4.0 technologies contributes to sustainable logistical operations (green operations). Those technologies help to reduce the emission of pollutants and collaborate to follow up some indicators, which are essential in the evaluation of sustainable port operations: fossil fuels, noise, air pollution, water quality, etc. Industry 4.0 collects a wide variety of information, using different devices, sensors, data processing applications, etc. that assist operational decisions, aiming to optimize operations and eliminate waste.

Therefore, it is possible to bring gains for the environment in operations of container handling in the port terminals. As I4.0 is becoming increasingly widespread, more ports around the world can collaborate with the environment, both making ongoing improvements to their operations and accepting upcoming technological advances. Although, sustainability doesn`t depend on the I4.0.

Figure 2 shows the relationship between the main technologies addressed in the Industry 4.0 theories and the main elements related to the theory addressed in the topic of port sustainability. Thus, the research proves that there is a correlation between the uses of I4.0 technologies with the increase in port sustainability indicators, improving the performance of smart ports, contributing to operations to become more environmentally sustainable.

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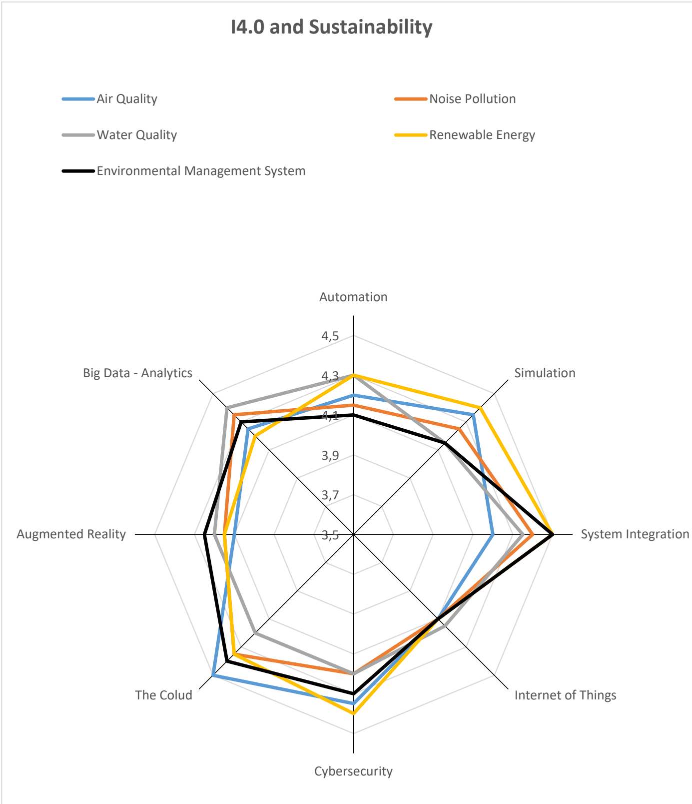

Figure 2: Cross-analysis: Industry 4.0 and Port Sustainability
Source: The author

In figure 2, the value 1 corresponds to no correlation between the analyzed variables and 5 a very strong correlation between them. Figure 2 shows that all the main elements of port environmental management analysis, such as Air Quality, Sound Pollution, Water Quality, Renewable Energy and the Environmental Management System (EMS) analyzed in this research, in container terminals, stood out positively with the use of I4.0 technologies.

These technologies intelligently optimize the use of port resources, adding value to container handling operations. It eliminates wasted resources, contributing to the use of renewable energy, planning the loading and unloading of ships efficiently and effectively. There is a digital monitoring of port operations, which helps in decision-making and helps to eliminate or minimize negative effects on the environment and its surroundings.

An environmental management system must have well-defined indicators, being constantly monitored, disseminated to all actors involved in the process of logistical operations in port terminals, and I4.0 technologies applied in port terminals allow these terminals to be on the way to obtain a certificate of sustainable logistics operations (green operations) contributing to the environment.

The survey did not address whether a port has international certification of green operations, or even if it is necessary to have implemented I4.0 technologies to obtain international certification of green operations. Analyzing whether ports have international certification of port sustainability in their operations was not the scope of this scientific research, but rather to verify the impact of I4.0 technologies on the sustainability factors of port logistics operations.

An intelligent port depends on the implementation of technologies, which involves costs. Thus, the decision to implement or not, depends on the business strategy of each port authority and its main stakeholders. However, the use of these technologies can positively collaborate in the environmental management of the port.

5. CONCLUSION

The technologies from I4.0, which are being used in the port terminals for container handling, in ports considered relevant worldwide, could contribute to a sustainable environment.

Each port has its corporate strategy. However, there is a strong concern for the environment. Increasing productivity and attracting cargo to its terminals is one of them. For this reason, investment in cutting-edge technologies that provide productivity gains can also promote better control of activities that denigrate the environment and cause damage to the air, water, the ecosystem, the atmosphere and human beings.

Most cargo handled around the world uses ports as a link in the transportation logistics chain. Each year, the use of containers for maritime transport increases considerably, and so does the size of container ships. Thus, port terminals must be agile to carry out operations, eliminating waste of time and resources, optimizing processes, integrating the actors in the logistics chain and above all, conserving the environment and not bringing environmental problems to their surroundings.

Industry 4.0 technologies can guarantee agility, flexibility, innovation, reduction of time, reliability of data and information, promoting decision making and planning. Industry 4.0 can play a pivotal role to compete for cargo. Moreover, a smart port gathers technology to help the world to have a sustainable and harmonious environmental management system.

The use of I4.0 technologies in ports allows assisting and collaborating to reduce the emission of gases, materials, noise, odor and several other products, which cause contamination in nature. In addition, the use of these technologies assists in the speed of information, in real time, which allows ports to manage environmental activities and monitor the entire logistics operations process. However, the research showed that it was essential that the port authority, as well as all stakeholders, be committed to the same purpose, objectives and goals and define a strategic plan integrating environmental management. Technologies emerged to assist human life and contribute to increased productivity, for the well-being of human beings, flora and fauna, involving the entire ecosystem (land and sea).

There are limitations in this work and one of them is the lack of analysis of all port operations in each port studied, not only in the container terminals. The focus was only on container terminals. As a future study, it would be interesting to analyze all types of port terminals, like the ones that operate with liquid, solid and general cargo bulk.

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