Journal of Business and Management Sciences, 2019, Vol. 7, No. 3, 140-146
Available online at http://pubs.sciepub.com/jbms/7/3/5
Published by Science and Education Publishing
DOI:10.12691/jbms-7-3-5

How Digitalization and IoT Can Improve the Operations of Panama Canal

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Received September 06, 2019; Revised October 22, 2019; Accepted November 05, 2019

Abstract The objective of this study was to review and investigate how data information systems are used to control operations and influence management decisions at the Panama Canal. It takes the view that the Panama Canal combines basic technology and complex systems to keep canal operations running safely and efficiently, and growing; ultimately keeping the Global economy in motion and profitable. From this perspective, it shows how ports around the world may look to the Panama Canal for solutions they can incorporate to remain relevant and competitive. This paper also discusses how the Panama Canal Authority utilizes legacy systems along with a wide variety of technology systems and equipment to collect data, and translate it into useful information that is used in planning and running day-to-day operations.

Keywords: *internet of things, digitalization, Panama Canal, Cybersecurity, Global commerce*

Cite This Article: Parsa Safa, Kelly Weeks, Mahdi Safa, Pamela Zelbst, and Pamela Zelbst, "How Digitalization and IoT Can Improve the Operations of Panama Canal." *Journal of Business and Management Sciences*, vol. 7, no. 3 (2019): 140-146. doi: 10.12691/jbms-7-3-5.

1. Introduction

World trade has always played a crucial roll in providing developments throughout the world. The use of the marine time sector plays a major roll in these freight movements. Ports, Canals, and Waterways across the world have become more and more crucial in the process and the use of IoT (internet of things) and digitalization are playing major roles in their development [1]. With the importance of the sector increasing, cybersecurity has become an issue in many ports. This article provides an analysis of the use of the IoT and Digitalization within Ports and Waterways, and more specifically the Panama Canal. But the development of technology leads to the problem of maintaining cybersecurity in such an important sector. A technologically advanced and safe port is the answer of trade and freight movement for the next decade of product flow. This article provides a case study of how the Panama canal is implementing the IoT into their operations and the cybersecurity problems they must take into account. This study takes an integrated and fresh look into the area of port digitalization and one the key industry 4. technologies IoT. The implementation of the IoT into the port operation and the cybersecurity problems for the Panama Canal will be also addressed.

Technology is advancing at a rapid rate every day. All around the world we see new innovations every day that is helping people operate their jobs in a more efficient was. Many companies and workspaces and started relying on digitalization and the IoT to make operations run smoother and more effectively. These ecosystems allow the interwoven elements of many different technologies to create one reliable system. In many hospitals, all patient information is now put on tablets and kept on the cloud. When patients get tests done, take medication and even food; everything is either manually or automatically put on the cloud. For these environments, these capabilities remove a large amount of human error and make the jobs of the doctors and nurses at the hospital much easier. Today many prisons use RFID embedded cloths and wristbands [2,3,4]. This allows prisons to use the cloud to actively track prisoners and make prison operations run smoother.

Technology, as we think of it today, was unheard of at the time of the Panama Canal's initial construction. The French attempted early construction of the canal in the 1880s, but it was completed by the United States beginning in 1904 and opened a decade later in 1914. Since then, it has boosted the global economy by connecting world trade routes and the networks used for conducting business. For over 100 years, the Panama Canal has been considered one of the Wonders of the Modern World and has long held the reputation as an engineering marvel and innovative leader in maritime logistics technology. Use of Legacy systems in place, along with the integration of the newest state-of-the-art

technologies, form a conglomerate from individual systems that monitor and control every aspect of the Canal's operations. Management relies heavily on the historical, real-time, and forecast data from these systems to make decisions that affect current operations and tolls, as well as the future growth of the Panama Canal. Over the past century, numerous changes and upgrades have been implemented, and expansions have been added that make the Panama Canal one of the world's most high tech operations [5].

Seaports Canals and Waterways around the world are starting to implement the IoT into their IT infrastructures. For the most effective and efficient system, the different aspects involved require close coordination and precision [6]. In the Hamburg seaport, the biggest seaport in Germany, the HPA is linking the seaport into a technologically based port. They are basing their actions on three pillars: infrastructure, traffic flow, and trade flow [7]. The adoption of technologies; such as Bluetooth, hotspot or WLAN, cloud, mobile devices, IoT, and Big Data; are the keys that allowed this port to persevere and become the most crucial port in Germany [8]. The IoT helped develop a system in which trade and traffic flow significantly improved and become their strong suit. The most important performance criteria in ports are measuring productivity [9].

2. Methods

This research project started with the author's trip to the Panama canal and meeting with the Chief Executive Officer Jorge L. Quijano and other executive management team members. The research team saw the infrastructure of the canal and most importantly saw the technological advancements that had been developing in the area. After these meetings, the project began with the idea of how the IoT infrastructure is being interwoven in the canal and its side effects. The team focused on the digitalization and IoT implementations and researched many articles to find and compelling census of the situation. We first looked at what IoT is and how it is used in other sectors. We moved our focus more specifically to seaports and ultimately the Panama canal. Our research shows a comprehensive look at the canal and the IoT aspects that help it run smoothly, and that can improve the technology in the future. The main limitations of this research include the few studies focused related to the Panama Canal; and availability of data and information.

3. Cybersecurity

Despite all the benefits of the interwoven technological advancements in ports, the risk of cybersecurity is rising with the technology. In 2017 there was a 300% increase in the amount of user account attacks. This poses a major threat in the ports sector considering its importance. Microsoft developed a scanning system which allows comparisons between encounter rates, patterns, and trends in different ports [10]. The results found that the Latin America area suffered from a higher rate of attacks than other places in the world which increases the concerns in Panama. As you can see in Figure 1, the risk of cyber-attacks in the Panama canal area is very major. The results of this data found that all involved in critical infrastructure need to take cybersecurity seriously and take actions to protect their sector [22].

Table 1. Probability of Cyber Attacks

Country	January 2017	February 2017	March 2017
United States	4.7%	4%	2.4%
Panama	12.1%	10.5%	10.7%

4. Technological Developments in the Panama Canal and the Use of IoT

The Panama Canal uses technology to efficiently operate 24 hours a day and to help handle the canal's traffic. The canal sophisticated operation can be advanced and facilitated by using real-time analytics, business intelligence and IoT (Internet of Things). IoT or the Industrial Internet is an evolution in internet technology and computer knowledge that targets to interface objects via the cloud [11,12]. The flow of data and information created by the interconnection of these objects can be used to enhance their tracking, organization, control, and management. Ships in the Panama Canal and flows are an actual example. The incorporation of diverse technologies and methodologies is the key challenge to benefit from this new paradigm [13].

While equipment and networks prepare physical connectivity, IoT makes possible a robust human-to-device/device-to-device communications and interactions [14]. Monitoring and data management on equipment performance, energy usage, and environmental conditions in Panama Canal assist operators and managers to regularly track various Canal systems performance in real-time. Quintiq, a subsidiary of Dassault Systems, which also has systems working at the Federal Aviation Administration (FAA), the International Space Station, and the UK's Ministry of Defense, is the company handling the integration of IoT into the canal. With the recent promotion of the IoT, the canal can now operate with a precise plan for all of its critical resources. "Improved situational awareness and data can inform better decision-making, which in turn will help mitigate operational risk," the company said in a statement. "Quintiq will also help reduce costs by optimizing the way in which the Canal plans and programs its resources." These are both benefits that the canal can use to operate with more precise planning for its critical resources. As a result, the Quintiq system will shorter vessel wait time, increase potential vessels per day, and improve reliability. "We provide a single software solution that can deal with any kind of planning and optimization challenge within a supply chain. We can solve anything from the Panama Canal, and the vessels transiting it, and production planning, all the way through to planning the rosters of FAA controllers," Quintiq's head of Latin America, Camilo Gaviria, told ZDNet.

One of the major obstacles that the system will have to adapt to will be the sudden weather changes in the area. Ports must analyze the potential impact of events on the

operations, even if they are miles away [15]. With the integration of IoT, the canals system will be automatically synced with local meteorological stations. This will enable the scheduling system to incorporate the weather when scheduling, increasing efficiency even more by reducing vessel delays.

The new system would allow precise scheduling to be viewed for the coming 48 hours. This will ensure that the right pilots are available when they're needed. "There are many sensors around the canal collecting an enormous amount of data," said Gaviria. "We want to leverage that data. We think it should be easy to incorporate information such as the waiting time at the locks and locking times -- the time it takes to fill a lock," he said. The IoT can also be used to manage lockage times. "Different locks fill at different rates and the previous system had different lockage times for different locks," Gaviria points out.

These technological advancements mean the number of vessels passing through the canal will increase. It is all part of the overall goal, which is to operate the canal as efficiently as possible.

5. Legacy Systems at the Panama Canal

Despite the fact that the Panama Canal is one of the highest tech operations around today, it continues to utilize some of the equipment and practices that were in use 100 years ago. The Panamax side of the Canal is the original side built in the early 1900s. The concrete infrastructure, the miter gates at the locks, and the mule systems all located on this side, and shown in Figure 1 and Figure 2, are all original systems that were used back then, and are still in use today. The Mira Flores and Gatun hydroelectric plants and Mount Hope water pumping station and purification plant, which were all built along with the Panama Panamax Canal, continue to operate and provide resources necessary to the Panama Canal. "In 1914, the Canal opened with an electrical system that represented the best engineering in the world. Remarkably, in 2003, after eighty-nine years of uninterrupted service, that system is still operating as well and efficiently as day one" [16]. A buoy system remains in use not only to mark the path for transiting vessels, but it also houses some of the equipment currently used to collect and transmit data regarding factors in the surrounding environment. The toll system has been the main source of income for the Canal since it opened in 1914; rates are adjusted annually to reflect changes in the global market and changes in the industry. These systems form the base of operations at the Panama Canal and provide the foundation for implementations of today's technology. Regular maintenance and repairs to these systems keep them functional and ensure their operation will continue well into the future.

Figure 1. Mitre Gate at Gatun Locks [24]

Figure 2. Electric Mules Guide Vessels Through the Locks [25]

6. Community Involvement

The Human aspect has been the most basic and important part of the technology used since the beginning and continues to be today. The Panama Canal Authority (known as Autoridad del Canal de Panama, in Panama) still involves the surrounding communities in aspects of the Canal's operations. The ACP provides training to many of the Panamanian employees who work there in an effort to retain skilled workers. The "Training and Development Program - Offers several training options for employees in all functions and levels, ranging from advanced marine training programs, leadership, managerial, technical seminars, as well as language courses. In FY2008, 97 percent of the total workforce reported an annual training average of 36 hours per employee" [17]. An employee of the Panama Canal, Edwin, informed me of how the ACP interacts with indigenous peoples of the area, including the Kuna Tribe and local fishermen, who monitor water levels in the Gatun and Miraflores Lakes. Periodically they meet with the ACP, to discuss the water levels and water availability to the canal, as well as to the surrounding communities. The Canal's hydroelectric plants also provide a portion of the surrounding communities in the canal zone with the electricity needed to survive and operate. The cooperative involving the Panama Canal and Panamanian communities is essential to the safety, survival, and continuous growth of all of these areas.

The ACP also works closely with the Panamanian Government and Academic Universities to ensure the preservation of surrounding tropical rainforests and local flora and fauna. During the initial stages of the Panama Canal's recent expansion project, the ACP brought in Geologists, Archeologists, Biologists, and many different kinds of engineers to survey and develop the best plan of action to preserve the landscape, and protect the plants and animals that thrive in the tropical rainforest. They also initiated constant reforestation and land restoration projects for the surrounding environment. The concepts of continuous community involvement and corporate responsibility involving the environment have been successful, and can be witnessed in the ongoing growth of the Canal's global footprint, and upscaling of its operations.

7. Modern Day Canal and Surrounding IT Infrastructure

Central America is considered one of the fastest-growing technological areas in the world. In addition to the expansion of the Canal, massive growth in other industries contributes to the need for high speed, reliable network. The MAYA-1 Ring and ARCOS-1 Ring fiber optic networks both include Panama, connecting the Caribbean Basin to the American Continents. The Panama Canal is used as an infrastructure link for the OXYGEN, GLOBAL CROSSING, and PANAMERICANA networks connecting the United States, Asia, the Pacific, Europe, and the Caribbean. Figure 3 provides a glimpse of submarine cable networks in the Caribbean area and shows the concentration of networks at the Panama Canal.

Companies in Panama and around the Globe rely heavily on the high-speed and reliability of these high-bandwidth telecom and data networks. The networks are essential to their success and contribute to the success of the Panama Canal as well. "Panama has the best access to multiple high-bandwidth continental fiber-optic networks in telecommunications infrastructure. The extremely low risk of natural disasters (hurricanes etc.), gives the Panama telecom sector security and reliability of service as well as a competitive advantage over other offshore jurisdictions" [18]. The Technopark, located at the old Fort Clayton US Army Base, sits just a few hundred yards from the submarine fiber optic cables crossing the Pacific side of the Panama Canal. Corporations such as Oracle, Microsoft, and Cisco have offices located in the Technopark and are just a few of the companies that recognize the benefits of being within such close proximity to the powerful networks that span the Panama Canal.

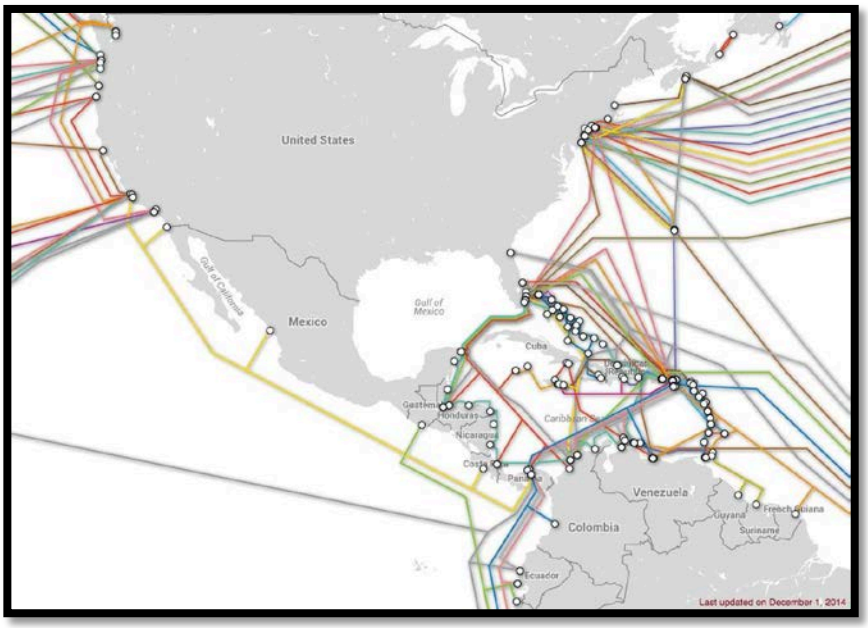

Figure 3. Fiber Optic Network Map of the Caribbean [25]

8. Technology at the Canal and How It's Used

The amount of data produced and processed at the Panama Canal each day is absolutely mind-blowing, and it will continue to grow as global commerce increases. Panama Canal employees monitor many factors including water levels and availability in the Gatun and Mira Flores Lakes, the weather, vessel tracking, and vessel scheduling and tolls. In addition, they coordinate operations for all of the Panama Canal's tugboats and dredges, the Mira Flores and Gatun hydroelectric plants, the Mount Hope water purification plant and pump station, ongoing construction and expansion projects, the Panama Canal intermodal railway, and a number of surrounding local ports. Activities such as employee and visitor interaction, canal security, and impacts made on the environment are also monitored. "As with most things these days, the software keeps everything moving smoothly, but this most impressive feat of civil engineering relies upon a hodgepodge of systems added piecemeal over the decades" [19]. Some of the original equipment and strategies used to perform these tasks in the early days of the Canal are still used today in conjunction with the newest technology available. Management at the canal must understand how to digest all of this information, use it to continue operations safely and effectively, and improve efficiency at the Panama Canal by implementing upgrades to the infrastructure and Information Systems, as they are needed.

The Panama Canal Authority implemented the AQUARIUS System by Aquatic Informatics for water data management and analysis. AQUARIUS collects, analyzes, and correlates data from numerous inputs including manual field readings, data logger uploads from equipment used at the canal such as height gauges, buoy sensors, and weather stations, and additional observation data from other global water and weather monitoring organizations. AQUARIUS also records and reports the impact operations to make on water quality and the surrounding environment. The AQUARIUS program provides real-time and historical information to end-users, who can access it through multiple platforms and portals. This information is used to help the ACP initiate appropriate responses during daily operations, assists in predicting more accurate forecasts, and create plans that minimize damaging effects to the surrounding and global environments. AQUARIUS provides the Panama Canal with a high tech solution for water management and analysis and enables responsible and effective water usage with minimal environmental impact.

Vessel tracking in real-time at the Panama Canal is pertinent to the safety of the vessels and people transiting through it. This feat uses a combination of systems executed in maritime navigation to accurately plan and follow the paths of each ship within the vicinity of the canal. Global Positioning Systems (GPS) are the main systems used in maritime travel today. Differential GPS enhances original GPS and can pinpoint vessels within inches of their actual position. The Electronic Chart Display and Information System (ECDIS) is a navigational chart system interfaced with navigational equipment such as GPS, Gyro, RADAR, ARPA, and Echo Sounder. It also incorporates and displays other information such as Tide Tables, sailing direction, weather conditions, and vessel identification. Panama Canal pilots rely on these systems, which are integrated into most common naval vessels and ships, to precisely navigate through the intricate paths of the locks and lakes. They can monitor the movements of other vessels, and calibrate their paths to prevent delays and safely get their ships from one side of the canal to the other. The control rooms at the Panama Canal, as seen in Figure 4, are able to display all of this information simultaneously and in real-time.

Figure 4. Inside the Marine Traffic Control Center [19]

Vessel management software used at the Panama Canal coordinates ship arrival times, lock and tugboat availability, and crews needed for operations. Ship schedules are based on several factors including their arrival time, the nature of their cargo, and whether they made reservations for passage ahead of time. Bigger ships require more water in the locks, which increases transit time. There are also times when locks may be undergoing maintenance and are inoperable. All of these factors must be taken into consideration when planning, and accurately choreographed for things to run smoothly. On March 16, 2017, the CEO of the Panama Canal Authority, Jorge Quijano, announced they will implement a new single integrated planning and scheduling system, developed by Dutch supply chain company Quintiq, which uses algorithms and modeling to figure out all available routes for ships and can plan weeks ahead. Ultimately, this upgrade will reduce wait time for the vessels, increase efficiency by getting more ships through the locks, and optimize costs related to using the Panama Canal.

Since 1855, the Panama Canal Railway Company (PCRC) has operated trains across the Isthmus of Panama, spanning from the Atlantic Ocean to the Pacific Ocean. In 2005, the PCRC implemented the Train Sentinel Positive Train Control, developed by Quantum Engineering Inc. Train Sentinel is a dispatching system designed to prevent collisions, enforce speed limits, and help protect railway workers and equipment by alerting crews from approaching restrictions. It will even stop the train if the crew doesn't respond appropriately. The system interacts with the locomotive's onboard computer database, which contains track information such as, sidings, turnouts, switches, interlockings, and signals. Train Sentinel also incorporates the telemetry dispatching system, which issues or removes authorizations for trains on any given track segment or route within the system; and it uses real-time GPS that is accurate within 10 yards. The Train Sentinel system displays real-time operating information, such as train speed, maximum authorized track speed, signal aspects, distance to signals, milepost locations and system-generated messages. Crews interact with the system to ensure the PCRC trains make their journeys safely from one point to another.

Security is a top priority at the Panama Canal and one of the main concerns of the Panama Canal Authority. The PCA recently contracted Indra Consulting and Technology to tackle it's latest security systems project. "The project incorporates an integrated control and security system with the latest technologies that includes building access control, vehicle control, perimeter alarms, intruder detection in buildings and video and recording control systems for the locks on the Pacific and Atlantic sides of the Canal, as well as for the associated buildings" (Indra, n.d.). Table 2 below describes the solution implemented by Indra, and the massive amount of technology and equipment installed to secure the Panama Canal [20].

Over 10,000 employees are employed at the Panama Canal along with an aquatic fleet that includes tugboats, small watercraft, and dredgers. Reliable communications are critical for successful operations and to the security of the canal. Communications technology already used by the PCA was enhanced further with the deployment of MOTOBRIDGE by Motorola Solutions. Interoperability is no longer an issue with this solution since it enables communication between different technologies and guarantees the constant and reliable flow of information. "As a result, different teams were able to communicate quickly and hear each other clearly, with optimum levels of reliability and redundancy that ensured communications in the face of different types of events" [21]. This upgrade not only promoted the usability of these devices but prolonged their useful lifespan also.

Table 2. Leading Smart Solutions for Large Infrastructures

Serial	Details
01	Over 10,000 credentials and 400 readers for access control, 350 cameras and 4,500 detectors.
02	A vehicle control system to prevent entry to the premises by unauthorized vehicles, control internal traffic within the installations and at the Canal gates, indicate authorized or unauthorized access by individuals to the gates, and prevent acts of sabotage in the most sensitive areas of the Canal.
03	The ship detection system, which can identify any floating object within the operational area of the gate chambers to avoid accidental closing of the gates if a ship or any other object is in its course, thus increasing the security of the closing operation.
04	Environmental sensor network that offers the information needed to ensure proper operation of the future installations.
06	Design and supply of a fire detection and protection system, integrated into the extinguishing system and with a mass notification system, made up of the alarm, digital signaling, telephony, PA and evacuation systems.
07	Buoy system that shows the alignment of the gates and facilitates pilot maneuvering in the canal.
08	Supply of systems for providing voice, data, video and wireless communications to the different buildings and the communication posts deployed throughout the entire infrastructure, including the complex and its interconnection with the solutions that are already operating at the current Canal installation, guaranteeing the continuity of all types of communication.

9. Reflection

Seeing the operations in person put into perspective how the Panama Canal Authority utilizes legacy systems along with a wide variety of technology systems and equipment to collect data and translate it into useful information that is used in planning and running day-to-day operations. There are systems and equipment in place for water management, to record weather activity, and to monitor and control activity along with multiple points of the canal. A collaboration of various software and hardware is used over multiple applications for scheduling and tracking vessel activity. The security of the Panama Canal is controlled through high tech systems that record, monitor, and regulate access and actions of vessels, employees, and visitors. Companies that work with the Panama Canal Authority such as, Indra, Aquatic Informatics, and Motorola are proud of these partnerships, as they should be, and information about their systems and services can be found online.

Dr. Ungo's seminar presented valuable information on how growth in global commerce prompted changes in the port and maritime industries. The Panama Canal Authority

is taking advantage of this growth to implement new services and technology and make changes and upgrades to their services that ensure they continue their reign as innovators in the maritime logistics, intermodal railway, and port industries. Mr. Quijano's recent announcement regarding implementation of the new Quintiq vessel scheduling system shared how the Panama Canal is improving and adapting to the increased traffic and larger vessels transporting a wider variety of goods, and the expected growth in global trade to continue. Conversations with current Canal employee, Edwin, and retired Canal employee, Floyd, iterated how the Panama Canal Authority embraces their commitment to involve the local community and preserve their historic legacy.

10. Conclusion

Ports and Canals around the world are preparing for this boom in demand by increasing their abilities and capacity. They may look to the Panama Canal for solutions they can incorporate to remain relevant and competitive. The ports, ships, canal, and other parties involved, work in tandem with numerous types and generations of technology and must be able to seamlessly communicate with everyone and everything involved at the same time to flawlessly perform. Integration, upgrading, and expansion appear to be the key focus of the maritime logistics and port industries presently. They should be a priority for locations looking to capture opportunities presented by the need for more and bigger facilities that can accommodate larger vessels and can handle higher volumes and types of goods. The Panama Canal combines basic technology and complex systems to keep canal operations running safely and efficiently, and growing; ultimately keeping the Global economy in motion and profitable.

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