IoT-ENABLED SUPPLY CHAIN MANAGEMENT AND LOGISTICS

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ABSTRACT

Supply Chain Management (SCM) has evolved over the years, from mechanisation in the 1920s to intelligentisation in the 2000s. Major changes in supply chain are due to challenges in the environment, such as the fragmentation of SCM activities and the introduction of the Internet of Things (IoT). The lack of visibility of assets and transportation management issues in SCM led to research being conducted to alleviate these challenges. In the South African context, the quality and competence of logistics operations, tracking and tracing of assets and management of activities are the main challenges identified in SCM, even though there are numerous companies involved in tracking assets. Effective management of supply chain activities requires the integration of technology into the SCM and logistics value chain. The supply chain value chain includes inbound logistics, outbound logistics, operations, sales, marketing, and supply services. Automating warehouse operations can help to address some of the challenges in SCM. This research paper addresses how the Smart Warehousing Management System (SWMS) and the Fleet Management System (FMS) developed aim to resolve asset tracking and tracing and improving logistics operations. Using the Internet of Things (IoT) in integrating sensors to track assets and improve warehouse operations can reduce SCM challenges. The FMS aims to resolve transportation management issues by tracking and tracing assets in logistics operations, while the SWMS automates warehouse operations, thus, improving SCM activities.

Keywords: Supply Chain Management, Logistics, Internet of Things

1. INTRODUCTION

Supply Chain Management (SCM) and logistics are some of the major functions within organisations or businesses. Effectively managing supply chain and logistics operations is, therefore, crucial for successful business operations. Logistics involve getting the right products, at a reasonable cost and time to customers (Md Zahurul Islam, et al., 2013). In recent years, there has been an increase in the use of technology in SCM and logistics. This includes the introduction of the Internet of Things (IoT) in managing supply chain and logistics operations. In addressing some of the challenges in SCM and logistics, two systems were developed, namely the Smart Warehousing Management System (SWMS) and the Fleet Management System (FMS). These systems address the transportation, warehousing, inventory, packaging, and information processing elements of SCM. The objective of this paper is to evaluate how the SWMS and the FMS, as enabled IoT systems, are aiding in improving supply management and logistics operations. IoT is defined as a network of physical objects embedded with electronics, software, sensors, and network connectivity, which aids these objects to collect and exchange data, often using the internet" (Kothari, et al., 2018). The adoption of IoT in logistics and supply chain improves visibility of assets through real-time location and tracking of assets, amongst many other benefits. In recent years, there has been challenges in logistics and SCM and this paper describes how the SWMS and the FMS address these challenges using technology.

2. EVOLUTION OF SUPPLY CHAIN AND LOGISTICS

Supply chain and logistics has evolved over the years by going through four stages: mechanization, automation, integration, and intelligence (Song, et al., 2021). In the current stage, i.e., intelligentisation, IoT, artificial intelligence and big data are key technologies, **Figure 1**.

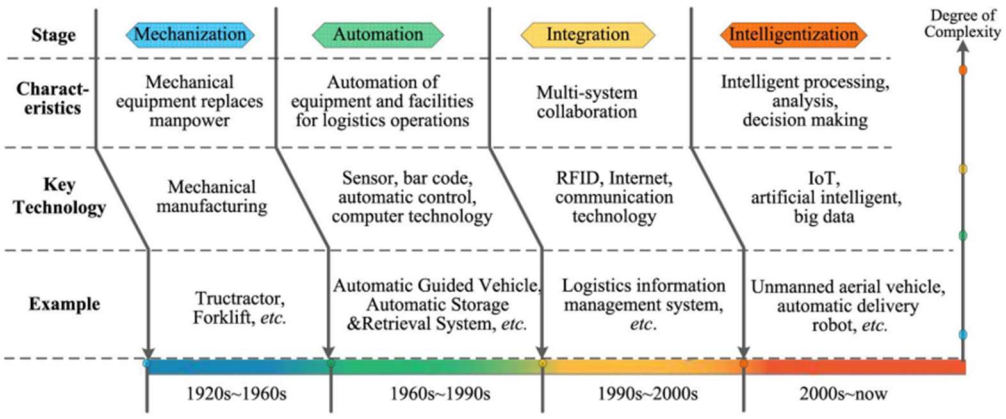

Figure 1: Evolution of Logistics [Adapted from (Song, et al., 2021)]

The adoption of IoT in the supply chain and logistics environment, and requirements from a South African government entity, led to the development of the FMS and the SWMS. Supply chain and logistics are briefly discussed in the subsequent section.

3. SMART WAREHOUSING AND ASSET TRACKING SYSTEMS AVAILABLE ON THE MARKET

The FMS and the SWMS developed are not unique systems. The differentiating factor is that the FMS was developed in South Africa for a government department that required the systems to be developed specifically for their needs. Cartrack, a leading fleet management company in South Africa has been in operation since 2004. The company provides mobility solutions for small, medium, and large fleets and an insurance analytics, security, and safety provider for both businesses and consumers (cartrack, 2020). The solution developed by Cartrack is currently deployed in the global market it serves. To reduce cyber security risks and vulnerabilities for the FMS, the government department in question required a web-based fleet management system that could be deployed in their environment only and developed specifically for them, hence the development of the FMS as opposed to Cartrack and other leading fleet management solutions available. Other fleet management companies available include Vuswa Fleet Services and EQSTRA Fleet Management (safacts.co.za, 2023). On the other hand, smart warehousing is still a new concept in South Africa. The use of sensors to automate warehouse operations has not been adopted in the South African market. Main challenges in the warehousing include data accuracy, warehouse security and power security (due to load shedding) (Barloworld Logistics, 2021). However, globally, there are numerous smart warehousing systems available such as the one used by Amazon where intelligent conveyor belts and robots are used (Supply Chain Today.com, 2022). South Africa is still lacking in the smart warehousing environment although mature in fleet management.

4. SUPPLY CHAIN MANAGEMENT AND LOGISTICS CHALLENGES

SCM and logistics are used interchangeably. However, there is a distinction between the two. Logistics is defined as the element accountable for the flow of materials from the suppliers into an organisation, through operations within the organisation and finally to customers (Waters, 2003). On the other hand, supply chain is a broader concept that includes all business activities involved with the flow and transformation of goods from raw materials to the consumer (Serdaris, et al., 2014). From the two definitions above for logistics and supply chain, logistics is thus part of SCM. The supply chain industry has experienced challenges in the past and continue to do so. Historic SCM challenges, including lack of visibility of assets, transportation management issues and the fragmentation of supply chain activities exist (Zhou, et al., 2007). In South Africa, tracking and tracing of assets and competence of logistics operations are the main challenges (Barloworld Logistics, 2021). These challenges are discussed below:

4.1 Lack of Visibility of Assets in Supply Chain

Having a view of business operations is essential in the effective management of operations, including in the supply chain context. In SCM, the ability of parts, components, or products in shipment to be tracked from manufacturer to destination is Supply Chain Visibility (SCV). SCV is essential to eliminate transaction negligence, inventory loss or misplacement and supply faults (He, et al., 2020). The South African supply chain environment is experiencing tracking and tracing challenges, making the lack of visibility of assets a distinct challenge in the environment.

4.2 Transportation Management Challenges

The rising costs of fuel, high maintenance costs and poor planning in transportation routes all contribute to transport management challenges in South Africa (Technews Publishing (Pty) Ltd, 2022). Volatile fuel prices make it difficult to plan operations and contribute to the overall costs in supply chain activities. Additionally, maintenance costs and vehicle downtime challenges, which are mainly attributed to the lack of real-time vehicle health status monitoring for fleets. These challenges all contribute to transportation management.

4.3 Fragmentation of Supply Chain Activities

Supply chain activities need to be streamlined and integrated for a seamless and efficient process. Viewing the supply chain as an integrated entity rather than a set of fragmented parts is crucial in having an efficient and intelligent process (Naude & Badenhorst-Weiss, 2011). The introduction of technology in the management of supply chain and logistics processes can aid in integrating these processes.

4.4 Tracking and Tracing of Assets

The fundamental concept of logistics i.e., the right product, in the right quantity and right quality, in the right place at the right time, for the right customer, requires companies to have tracking and tracing capabilities. Furthermore, there are other benefits that this capability can provide, including real-time location of assets and increased transparency for customers.

4.5 Competence of Logistics Operations

Process efficiency is essential to optimize logistics operations and have a positive impact on the economy. Logistics operations require all elements of logistics to be efficient. A breakdown in one of the logistics activities means that the whole logistics function is not performing at its best. Hence, transport, warehousing, inventory, packaging, and information processing all must be efficient. This challenge of having incompetent logistics operations is attributed to process optimalisation by improving all activities in SCM and logistics.

The SWMS and the FMS address these challenges by using connected components which can communicate with each other. The use of sensors for tracking and tracing, coupled with automating warehouse operations, addresses the challenges

experienced in the South African supply chain industry. A brief discussion of the SWMS and the FMS is given in the section below.

5. SMART WAREHOUSING MANAGEMENT SYSTEM (SWMS) AND THE FLEET MANAGEMENT SYSTEM (FMS) BACKGROUND

Tracking and tracing is one of the six indicators used by the World Bank to determine the Logistics Performance Index (LPI) (Ittmann, 2018) for countries. The LPI is a view on trade logistics performance across most countries in the world as seen by logistics professionals. The SWMS and the FMS focus mainly on tracking and tracing, which implies that using these systems improves logistics performance for organisations. Effective inventory management alone is not sufficient means to reduce supply chain costs and improve customer service levels, but integrating inventory management and transport management provides a means to reduce supply chain costs (Scott, et al., 2003). The two systems are thus integrated to provide a holistic view of smart logistics transportation and logistics transportation for effective SCM. During the logistics transportation process, vehicle information, cargo, driver situation, etc., are combined to improve transportation efficiency, reduce transportation costs, and reduce cargo loss (Song, et al., 2021). The SWMS and FMS are discussed below:

5.1 Smart Warehouse Management System (SWMS)

The SWMS is an IoT based inventory management system comprised of 5 key components, namely the warehouse, the server room, shipping vehicles, the operations command centre that provides an integrated common operating picture and a suite of sensors to provide situational awareness within the warehouse. The system was developed for a South African government entity and is currently being tested in one of their warehouses. The sensors integrated with the system regulate the warehouse workflows, manage inventory, and control remote access to the warehouse. **Figure 2** illustrated the SWMS system architecture.

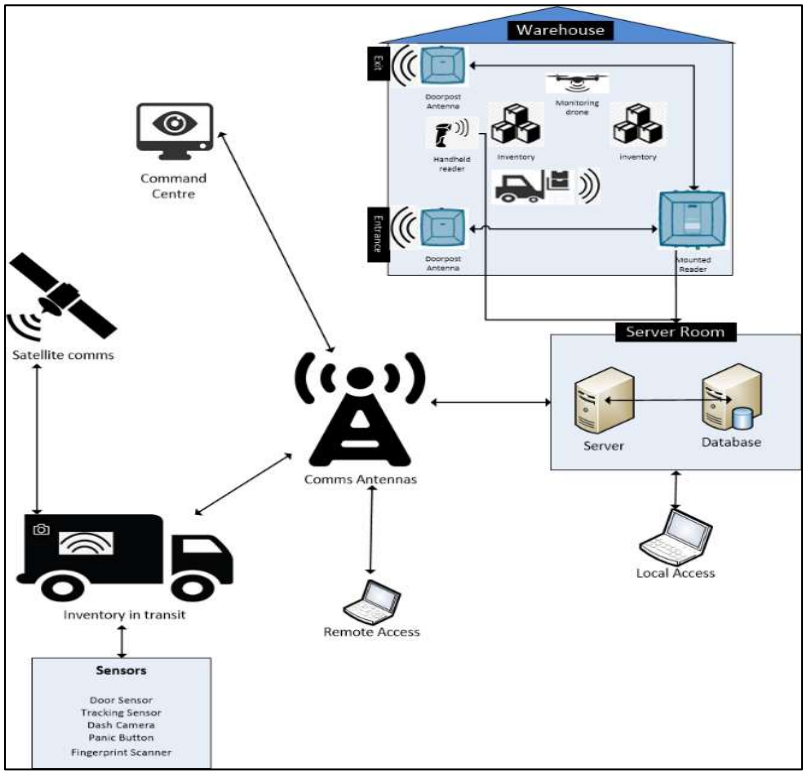

Figure 2: SWMS High Level Architecture

5.2 Fleet Management System

FMS is a decision support tool that provides situational awareness around business operations and enable effective and efficient management of operational assets. The system also provides visibility around assets and fleet through a 24-7-365, live tracking and monitoring capability. The command centre is viewed on a web application developed for situational awareness and data collected and stored within this platform is managed through a secure platform. The application is also available as a mobile application for mobile access. The FMS is currently deployed at the premises of a government entity to track and monitor their vehicles. Vehicles being tracked in the FMS are fitted with tracker units that communicate through GPS satellite and a tracker database manages all data collected. The FMS has various features, including fuel management, driver behaviour monitoring, vehicle health status monitoring, alerts recording for speed and other metrics, etc. The items in **Figure 3** are linked and exchanged data to provide a connected system.

Figure 3Figure 3 illustrates the FMS high level architecture.

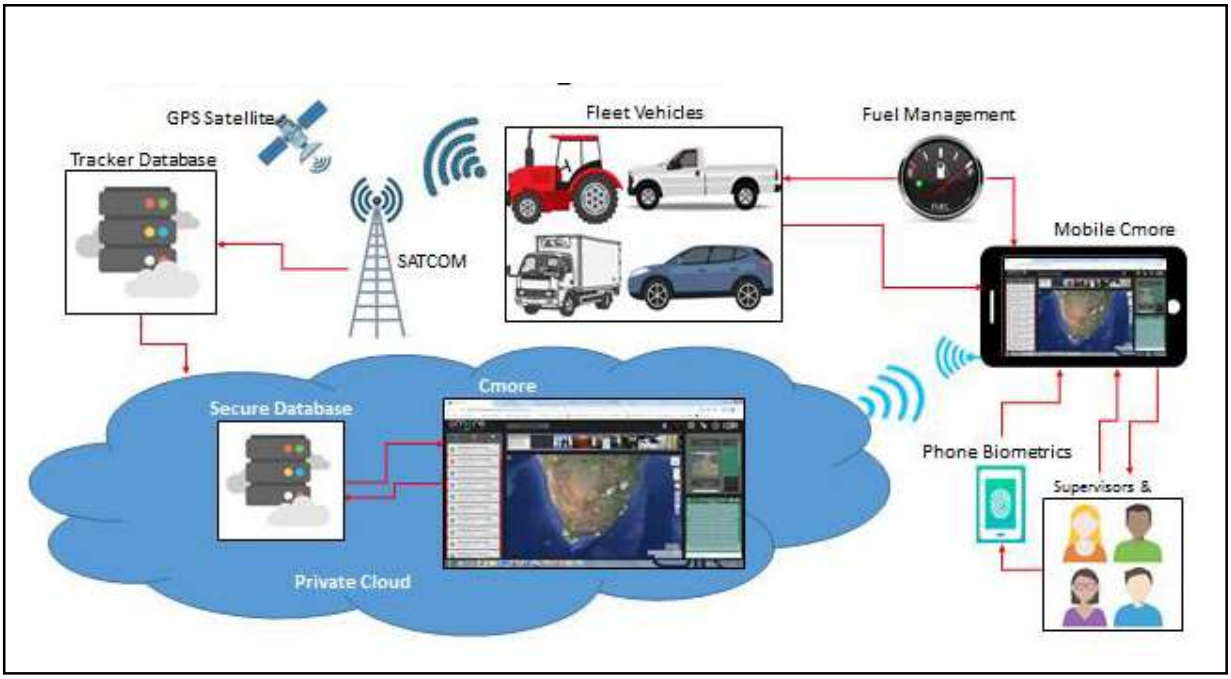

Figure 3: FMS High Level System Architecture

6. IoT IN MANAGING SUPPLY CHAIN AND LOGISTICS OPERATIONS FOR THE FMS AND THE SWMS

To connect physical things over the internet, the IoT is being adopted in the supply chain and logistics industry for optimising operations. The use of IoT can enable real-time management of supply chain processes, thereby making these processes flexible and agile to adapt to new conditions (Jia, et al., 2012). The introduction of sensors in the supply chain and logistics environment is a stride in improving these processes. The SWMS and FMS uses the following sensors: UHF tags, biometric sensors, drones, RFID readers, CAN Bus tracking units, body cameras and dashboard cameras. A brief discussion of the abovementioned sensors is provided below:

6.1 UHF Tags

Radio Frequency Identification (RFID) tags make use of radio identification to identify physical objects. The tag acts as a transponder and is attached to the object that needs to be identified. Ultra-high frequency (UHF) radio waves for the RFID tags are the preferred approach in manufacturing and distribution applications as they are inexpensive, robust, compact, and readable from a distance depending on the frequency used. Automatic tracking of items in a warehouse using RFID improves operational efficiency, productivity, and resource utilisation by eliminating the need for manual tracking. The RFID tags used in the SWMS application are passive tags, meaning they do not contain a power source but instead get their power from the radio signals generated by RFID readers. The tags attached to each item in the warehouse have a unique tag Identification (ID) which is associated with each item in the warehouse and on the database. This helps organise and optimise identification of items in the warehouse by scanning the tags to retrieve the item's information. The UHF tags can be identified from a distance reaching 10 meters. Their performance, however, can be influenced by the materials they are placed on, e.g., metal surfaces.

To uniquely identity assets, UHF tags are preferred over HF tags because they have less interference when operating at an ultra-high frequency range. Another advantage for using UHF tags is that they are small enough to be used on any item because their antennas can be reduced in size compared to those of HF tags. Each tag has a unique resonance code/tag ID which is why thousands of them can be used to identify assets without having duplicate tag IDs.

6.2 Biometrics

Access control is imperative, especially when working with sensitive equipment and high value goods. Thus, biometrics is used for access control in the warehouse. The system is made of a fingerprint sensor to take samples of the individual's fingerprint. This data is transferred to a module where the low-level embedded processing of data occurs. This module also provides the connection between the hardware and the software where access control is maintained. After the server processing, there is a user interface for enrolment of new employees to grant access within the warehouse.

6.3 Drones

Drones can be used for conducting rapid automated inventory audits within a warehouse. Manual inventory has challenges relating to the safety of workers, risk of errors, operational costs and time, thus the introduction of drones. With their ability to reach higher areas, drones can be flown manually or automatically to scan inventory data. This approach can assist in conducting scheduled cycle audits, which includes counting a certain manageable section of the inventory, with intentions to cover the entire warehouse over time. However, path planning in a smart warehouse is a challenge requiring a dynamic solution. Multiple drones utilised within scheduled deployments can be deployed to cover a large area within the warehouse taking less time. The solution is to partition the warehouse into smaller manageable sections allowing the drones to flow freely without collisions or interference.

Unlike in the SWMS where drones are used for inventory management, drones in the FMS are used to provide live feed of an incident. For example, the deployment of a drone to a specific area of interest will enable visualisation of the current situation at a specific area using the camera on the drone. The drone communicates with the system via a RESTFUL API, sending live feeds to the server.

6.4 Readers

A handheld RFID reader is used to register new assets and goods in the warehouse and used during asset management when performing asset identification and verification. A wall mounted RFID reader with multiple antennas connected as a hub, is used to assist with the monitoring of incoming and outgoing goods and the scanning of multiple assets in a smart warehouse (Dobkin, 2013). The RFID reader sends a signal at a specific frequency that will resonate with the corresponding tag/card designed at that frequency, which will send back an ID known as an EPC (Electronic Product Code) string that differentiates tags from each other.

6.5 CAN Bus Tracking Unit

A Controller Area Network (CAN) Bus tracking unit is a navigation device which is used to provide the geographical position of an object. The tracking unit accesses

information stored in vehicles and shares that information with the FMS. All vehicles tracked using the FMS are fitted with such a unit for correct tracking and tracing. The unit provides situational awareness information on the map, where users can view the current location of their assets.

6.6 Body and Dashboard Camera

Other sensors integrated with the FMS are body and dashboard sensors. Drivers are fitted with body cameras for visualisation of a live feed of what is happening around them. Body camera aids in a live view of the driver's current environment. Vehicles are also fitted with a dashboard camera, enabling the monitoring of the driver's behaviour.

This subsection explained the different sensors that are used within the SWMS and FMS. The following section focuses on how the IoT, using SWMS and FMS, addresses the supply chain and logistics challenges identified in this paper.

7. IoT TO ADDRESS CHALLENGES IN SUPPLY CHAIN AND LOGISTICS

The FMS and the SWMS address challenges experienced in supply chain management and logistics, thereby improving efficiency. Below is a discussion on how the FMS and the SWMS address challenges mentioned above:

The FMS has a route planning feature which provides fleet managers with a way to create and save common routes. These can be used to create trips where drivers are assigned to vehicles as part of trip scheduling. Proper scheduling during logistics operations aids in reducing time delays, hence this feature. The route plan feature is also enabled with functionalities such as the route distance calculator, predicted duration, reason for the trip, scheduled date and time, and estimated time of arrival. Traffic and other factors that might delay the trip are considered during the trip to optimise the trip. The FMS offers live tracking of the fleet which enables visibility of the planned route being taken. This assists in addressing the issue of poor planning in transportation management.

The FMS also provides a holistic view of all the fleet being monitored with added in-time updated information. Fleet managers can view, monitor and assess the status of vehicles which includes basic information about a vehicle, assigned driver information, speed, RPM (Revolutions per Minute), fuel level, battery level, vehicles health status (green represents good communication, while red represents faulty tracking device), last seen location, and last update (last time captured when the vehicle was able to send data to the server). This assists with real-time vehicle health status monitoring challenges for transport management.

The FMS tracks vehicles to enable fleet managers to be aware of where each vehicle is, at any given time. The live tracking of vehicles is performed 24-7. For vehicles that are transporting cargo, the FMS uses a dash camera to monitor the assets within the vehicle. Each asset has a unique RFID tag assigned to it and on the vehicle door there is an RFID reader which will read the tag when the asset enters or leaves the vehicle. When the vehicle is moving, the location of the asset is dependent on the vehicle's location, which assists with the tracking and tracing of assets.

Tracking and monitoring of assets and inventory in the warehouse and on the way to depots and depots is also enabled by the FMS. The use of both RFID and UHF tags facilitates asset identification, retrieval as well as inventory management in the warehouse. The RFID tags are attached to each inventory item in the warehouse and the items have unique tag ID, which are linked to the database. This helps with the organisation and the identification of items in the warehouse, which is done by scanning tags to retrieve item information. The UHF tags, which have longer range capacities, are used for identifying assets from up to 10 meters, which aids in covering a wide area in the warehouse.

Furthermore, the SWMS is enabled with a workflow management process for assets approval and requests, order requests, capacity triggers and repairs and maintenance. This aids in efficiency in warehouse operations by ensuring that correct processes are followed timeously. The fragmentation of supply chain and logistics operations is eliminated by the workflow process through ensuring that activities are linked and connected.

The benefits discussed above prove that the introduction of IoT in supply chain and logistics improve operational efficiency.

8. CONCLUSION

Supply chain and logistics are an integral part of a functioning economy. Therefore, the proper management of supply chain and logistics processes is crucial. The need for digitisation has pushed IoT adoption in the supply chain and logistics environment. With the development of the SWMS and the FMS, supply chain and logistics operations can achieve efficiency and perform at their best. These systems address challenges experienced in the supply chain and logistics processes, from tracking of assets, transportation management challenges, fragmentation of activities, competence of operations and lack of visibility of assets. By employing sensors in the environment, managers can track and trace assets, manage access control and view the health status of vehicles amongst the many benefits discussed. It can thus be concluded that IoT platforms are great investments in the management of activities in the supply chain and logistics industry. Further research may include investigation into how path planning for rapid automated inventory management can be implemented to guide drones in the warehouse. Also, a fully automated smart warehouse using robots to aid in improving operations could be a great research path to follow in future.

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