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Material Distribution and Transportation in a Norwegian Hospital: A Case Study

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Abstract: Automated Guided Vehicles have shown significant importance in material transportation and distribution in today's hospitals. The increasing trends of shorter hospital stays and increase of treatments and surgeries in clinics, present new challenges for the supply of goods. The rise in patients in hospitals, and consequently the increase of treatments and surgeries, cause a growth of material usage and goods movement. This study used the Control Model methodology to analyze the material and information flow within the case hospital. Information sharing and integration is still a major issue in the case hospital. The study aims to stimulate further research in material handling and distribution in hospitals.

Keywords: Automated Guided Vehicles Systems; Control Model; Hospital Logistics.

1. INTRODUCTION

Automated Guided Vehicles (AGV) have shown significant importance in material transportation and distribution in today's hospitals. An AGV system can be described as "a material handling system that uses independently operated, self-propelled vehicles guided along defined pathways" (Groover, 2016). It is applicable where different materials are moved from various loading points to various unloading points.

There have been several decisions and changes in healthcare that made the AGV system a success and a standard in material transportation in Norwegian hospitals. The current policy in healthcare for several countries is to expand larger hospitals and restructure them, and simultaneously closing smaller hospitals (Giancotti et al., 2017). The design and layout of Norwegian hospitals tend to be widespread and flat. As a result, long distances and more horizontal than vertical movements have to be overcome to distribute all goods within the hospitals. Therefore, the AGV is the appropriate solution for material handling.

Several methods apply to distribute goods within hospitals. Small objectives, e.g., blood samples, are mainly sent with pneumatic tube systems in hospitals due to timely matters. For transportation of bigger or heavier goods, AGVs have demonstrated good results in distributing goods to many different pick-and-place positions and traveling long distances within hospitals. However, since the AGVs use the same facilities and elevators as patients, visitors and healthcare staff, the high usage of AGV at these hours will affect the whole hospital logistics.

The increasing trends of shorter hospital stays and an increase of treatments and surgeries in clinics (OECD, 2014), present new challenges for the supply of goods. The rise in patients in hospitals, and consequently the increase of treatments and surgeries, cause a growth of material usage and goods movement. In a typical hospital, 25–30% of the budget is used for medical supplies and the handling of the supplies (Ozcan, 2005). A Norwegian hospital has adapted to this challenge by adding more resources to the supply and delivery of goods. Adding more resources to supply the demand for goods shows short-term positive results. However, for long-term positive results, the internal logistics has to be adapted.

Logistics-related activities have one of the highest costs, after personnel costs (Volland et al., 2017). Decisions, processes, and activities of material handling show great dependencies and should not be seen as isolated, independent procedures. Materials handling should be seen within a system context (Kulwiec, 2008). The distribution and material handling of hospital goods are closely interrelated. To reduce material-related logistics costs, academics, as well as practitioners, have recognized the potential of applying quantitative methods in hospitals. In other industries, such as manufacturing or service industries, these methods have already proven their potential.

In this study, the Control Model methodology has been used to analyze the material and information flows within a hospital. The Control Model is a method to organize and control the logistics and activities of a supply chain (Strandhagen and Skarlo, 1995), and is often used as a framework when analyzing the current situation of a supply chain. This research will end with recommendations for further improvements for the case hospital and future research within this topic.

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2. THEORETICAL BACKGROUND

In the traditional distribution model, the suppliers ship their products to distributors. At the distributor, the products are packed and shipped to the warehouse of the hospitals according to the order. The hospital warehouse stores the products until they are needed in the hospital, and then sends the products to the departments on order. Sometimes, products are delivered directly from distributors to the hospital's departments based on order. The deliveries are relatively few, which leads to low transportation and ordering costs. However, this traditional model causes large amounts of inventory in the system, causing high costs of both holding inventory and due to the high amount of material handling (Rossetti et al., 2012).

A newer model, used by Mercy hospitals, replaces the distributor with a centralized warehouse system (Rossetti et al., 2012). In this model, the amount of products stores at the hospital's warehouse can be largely reduced. The suppliers ship directly to the central warehouse. At the central warehouse, the deliveries are broken down into smaller units, which are then prepared for being used in the hospitals. The materials are sent directly from the central warehouse to the hospitals. In this model, the central warehouse takes full responsibility for material handling and inventory management.

Several hospitals using AGVs for material handling are discussed in the literature. Currently, the application of AGVs for material handling in hospitals are described (Castleberry, 1991, Ullrich, 2015), but there has been a larger focus on discrete-event simulation for AGVs in previous years. The use of discrete-event simulation has been the most appropriate method for design and validation of an AGV system in hospitals (Čerić, 1990, Ross and Cheung, 1978, Swain and John III, 1978). The simulation models and programs were used to conduct series of simulation experiments with the aim of minimizing the required vehicle fleet size and to maximize resource utilization. The transportation schedules, system queueing and transportation performances could be derived from the simulations.

A recent case study performed by Peda, Grego, and Plinta (2017) shows that the use of AGVs in hospitals relieves hospital staff, allowing them to focus on care of patients. The transportation and delivery of laundry and food are some tasks that reduce the time of healthcare workers. Implementing AGVs in the studied hospital have demonstrated great results through reduction of operating costs and increase of healthcare quality. The field of hospital-internal distribution and scheduling is less discussed in literature. A literature review in this field identified four publications concerning optimization models with the objective of minimizing work routes, workloads and costs (Volland et al., 2017). The optimization models have been evolved with both simulations and heuristic approaches, and are applied to the goods of pharmaceutics, laundry, medical supply, bed-related goods, and meals (Augusto and Xie, 2009, Banerjea-Brodeur et al., 1998, Lapierre and Ruiz, 2007, Michelon et al., 1994). The issues of routing and scheduling, and material management systems are mainly discussed in these publications. It is noted that due to different material handling equipment and delivery methods, standards and common practices of how to transport goods in hospitals hardly exist. There are several issues to take into account when designing an AGV system. Flow path layout, traffic management, number and location of pick-up and delivery points, vehicle requirements, vehicle dispatching, routing and scheduling, and positioning of idle vehicles are some of the issues (Vis, 2006). Also, battery management and AGV failures affect the performance of the transportation system by requiring that the specific AGV is taken out of operation for charging and maintenance (Vis, 2006). Implementation of an AGV system in healthcare systems also requires safety and clinical quality, productivity, user-friendliness, effective technology utilization, and information and patient management (Pedan et al., 2017).

3. RESEARCH METHOD

This research uses the Control Model as a basis for analyzing the material and information flows of the hospital supply chain. It provides a method for data collection, a visualization of the material and information flow between the actors (Strandhagen and Skarlo, 1995), analyzation of the actors, investigation of possible improvement areas, and design and implementation of the revised Control Model (Alfnes and Strandhagen, 2000). Relevant data collection involves characteristics of material flow, inbound and outbound logistics, service to market, and reliability and flexibility of the production system (Strandhagen and Skarlo, 1995). In this research, the production system entails the overall AGV system in the hospital. However, this research will not consider the design and implementation of the revised Control Model in the hospital, as more in-depth analyzations are required of the AGV system at the department level.

Several individual and group interviews have been conducted with employees from both the operating and planning departments of the hospital. The positions of the interviewed hospital employees are Technical System Administrator, Supply Planner, Operating Manager and Operating Technician. Interviews are considered to be the most important source of evidence in case studies (Yin, 2013), making it possible to reconstruct the unexperienced situation (Rubin and Rubin, 2011). The interviews were supported by a semi-structured interview guide that can provide reliable and comparable data, in addition to providing guidelines for keeping the interview within the scope (Cohen and Crabtree, 2006).

The validity of the case study is given by applying the triangulation procedure. Triangulation is used to search for convergence among many information sources (Creswell and Miller, 2000). In this research, in addition to the interviews, documents explaining the extent of the AGV system in the hospital, and observations related both to the operation of AGVs and the employees responsible for operating the AGVs have been taken into account.

Case description

The case study was carried out with a large Norwegian hospital that has a capacity of 1000 beds. The hospital treats yearly 60'000 inpatients (patients who live in the hospital as long as being given treatment) and 370'000 outpatients (patients who visit the hospital for treatment without staying overnight).

The hospital implemented and launched the AGV system in 2009. Today, the AGV system consists of 21 laser-guided AGVs, transporting approximately 50-70 tons of goods every week between 114 pick-up and delivery stations in different buildings, at different levels and departments. The AGV system is operated with a centralized structure.

Related to simulations, a transportation schedule for the AGV system has been defined. This schedule has been adapted to the demand of goods over the years. Orders are dispatched to the nearest AGV. This dispatching rule was chosen to reduce AGV idle transportation time.

The hospital has integrated a radio frequency communication system, connecting the different buildings, doors and elevators with the AGV system. The AGV can lift and move the wagons within the 4500-meter guide-path that connects all departments. The AGVs can operate continuously for approximately three hours and is then sent to be charged for one hour.

4. CONTROL MODEL

There are six main groups of goods supporting the daily operations of the hospital. The six groups consist of consumer goods, laundry, food, sterile goods, pharmaceutics, and waste. Many suppliers are connected to the hospital supply chain, shipping goods directly to the hospital or to its warehouse. At the warehouse, the products are stored and sent to the departments when needed. The hospital's warehouse packs the wagons according to the orders from the departments and places an RFID-tag on the wagon that includes information about its final destination. Trucks transport the packed wagons several times during a day to the

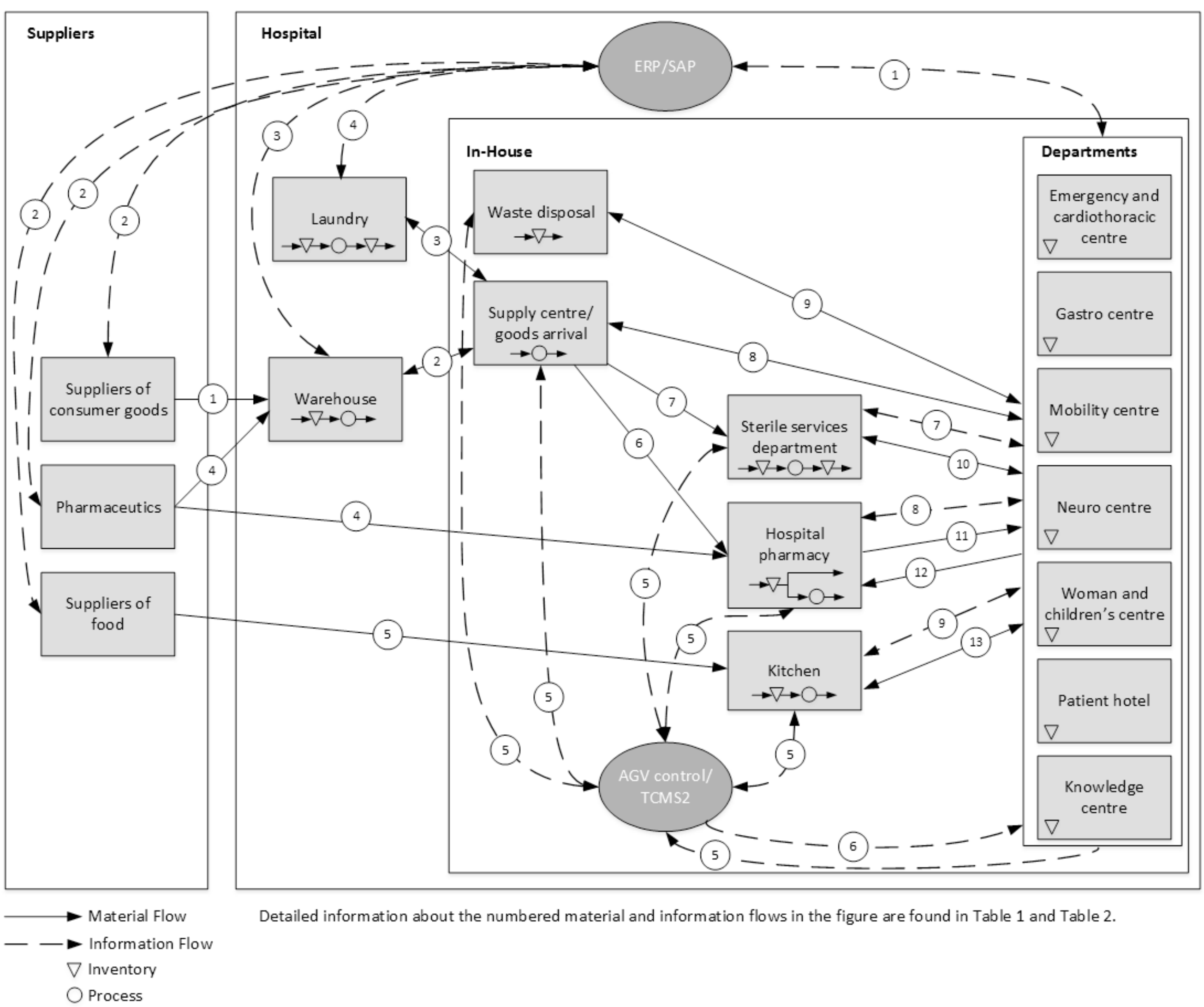

Fig. 1. Control model of the case hospital

goods arrival at the hospital, based on a schedule. When the truck returns, it takes the empty wagons back to the warehouse. On a daily basis, clean fabrics at the laundry are packed into wagons and shipped by trucks to the goods arrival at the hospital. At goods arrival, the wagons are moved to the AGV pick-up station. The RFID-tag will be read by a RFID-reader on the AGV, which sends information to the AGV system. The RFID-tag contains information about the order and delivery destination. On the return, the truck takes the dirty fabrics and wagons back to the laundry.

In general, the goods on the wagons are transported to specified delivery places at the departments. When the wagon arrives at its destination, the AGV system sends a message to the department and its person in charge. The person in charge collects the goods, and then the wagon is placed at a pick-up station or is filled with a new order of goods before being placed at a pick-up station. To initiate return transportation of a wagon by an AGV, the wagon has to be placed at a pick-up station with a RFID-tag informing the wagons final destination. The wagon is then picked up by the AGV and transported to the final destination.

There are two methods to transport the wagons containing goods within the hospital. Either an AGV picks up a wagon and delivers it to the final destination by reading the RFID-tag or an employee pulls the wagon with an electric tractor. The AGVs are operating Monday to Friday from 6.30 to 19.30. Outside of these hours, transportation of all groups of goods is performed manually by an employee.

Table 1. Material flow

#	What	How	How often
1	Consumer goods	Truck	Several times a day
2	Consumer goods on wagons	Truck	Several times a day
3	Laundry/Fabrics on wagons	Truck	Once a day
4	Pharmaceutical products and medicine	Truck	Once a day
5	Food	Truck	Once a day
6	Pharmaceutical products and medicine	Manual	Several times a day
7	Goods sterilised and equipment for sterilisation	Manual	Several times a day
8	Consumer goods and laundry	AGV or manual	Several times a day
9	Empty wagons to departments, full wagons to waste disposal	AGV or manual	Several times a day
10	Sterile goods to department, dirty goods to sterile services department	AGV or manual	Several times a day
11	Pharmaceutical products and medicine	Manual	Several times a day
12	Empty wagons	AGV or manual	Several times a day
13	Warm food to departments, empty wagons to kitchen	AGV or manual	Several times a day

Some of the goods groups have special transportation demands. Food delivered from the kitchen to the departments has to arrive warm and on time. The sterile goods have to follow a production schedule for washing and sterilization, and there are high requirements related safety and security during transportation. Waste, especially hazardous waste, has to be transported in special wagons because of the risk of contagion. Lastly, medicine is always transported manually to the departments, due to safety and security reasons. Furthermore, some medicine is produced in-house and has to be delivered within a certain, short time frame due to perishability.

The inventory levels at each department are checked daily manually by an employee by scanning the materials. Inventory levels at the warehouse are synchronized with the Enterprise resource planning (ERP) system. Low inventory levels of a certain type of goods indicate that it should be reordered. The supply department is responsible for ordering the materials from the supplier or the hospital's warehouse.

There are two types of fabrics replenished in the hospital. The first type is labeled employee. Sensors in the cupboards where the clothes and fabrics related to this fabric type are stored monitors the inventory levels. When the reorder point is reached, an order is automatically sent to the laundry. The second fabric type is related to patients or departments. Orders for this fabric type are placed directly to the laundry by the individual departments in need of fabrics.

Each department has to place orders for sterile goods the day before they are needed, to make sure the sterile goods are being delivered on time. The sterile services department follow a schedule for supplying the different departments with the ordered amount of sterile goods.

Table 2. Information flow

#	What	How	How often
1	Order	Manual scan	Several times a day
2	Order	Automatic or email	Weekly
3	Order	Automatic	Several times a day
4	Order	Automatic	Once a day
5	Wagon at Pick/ Delivery station	Automatic	Real-time
6	Message	Automatic	Real-time
7	Order	Email	Once a day
10	Order	Phone or email	Several times a day
11	Order	Email	Once a day or weekly

5. DISCUSSION

The case hospital is part of a traditional supply chain and does not have a centralized structure. There are different methods to supply the hospital departments with goods. Also, neither the material nor the information flows are standardized for ordering and delivery of goods. Not standardizing the processes and centralizing the structure will interfere with the automation process of the material flows in the hospital.

Hospital flows benefit from the technological progress of information systems and the emergence of new information technology tools, with many benefits. Some examples are RFID and ERP system. (Ageron et al., 2018). The different actors along the supply chain communicate with separate communication systems, e.g., manually by phone, email, and scan or automatically through the ERP-system. Not using a common or at least an integrated information and communication system will lead to incoherent information sharing along the supply chain. Less information sharing leads to more uncertainties in the supply chain. It will also lead to decentralized control. Performance of the whole system will be improved if each actor achieves improvements from information sharing (Yu et al., 2001). There are many inventories across the hospital supply chain. Sharing information about inventories will positively affect both position, replenishment and amount of goods in the inventories.

Information exchange might break the "silo" culture in hospitals. The case hospital has, like many other hospitals, several in-house productions and departments that often are not coordinated with each other. Food, pharmacy, and sterile goods have to be distributed with the given material handling resources. Products of both catering and pharmacy have to be consumed within a certain period. Therefore, the products are produced and delivered directly to the patients without keeping intermediate inventories. This is common practice in catering service industries, producing and delivering food to the customers directly, without intermediate inventories. However, the challenge is to find a joint schedule of production and distribution (Chen and Vairaktarakis, 2005). In such industries, the objective function for optimizing production and distribution operations have to take into account both customer service level and total distribution cost. However, at the same time, the distribution and delivery of sterile goods should not be neglected. The delivery precision of sterile goods has a major impact on the operations schedule of the operating theater. Sterilization services have been mainly discussed in literature about outsourcing the activity and the related logistical challenges (Volland et al., 2017). Outsourcing often results in longer distances, longer logistic loops, and lower instrument availability. According to van de Klundert et al. (2008), changing the logistics management principles, optimizing the composition of the nets of sterile materials and using appropriate information technology will improve material availability and reduce costs.

All the different production and delivery schedules have to be taken into account and integrated into the AGV scheduling problem, to fulfill transportation and delivery demands of the hospital. Most studies on scheduling problems of the AGV focus on the manufacturing environment and the scheduling objective of minimizing the make span (Kaoud et al., 2017). Multi-objective studies are scarcely discussed, but are significant for achieving an overall efficiency of the AGV system. There is a need to develop models for more complex AGV system (Vis, 2006), managing multiple material flows and the challenges faced in hospitals.

The challenges of the material flow in the case hospital are closely related to the hospital's environment and layout. The hospital has built and added several buildings over time. Consequently, the transportation layout has changed. The distances that the AGV has to overcome for delivery of wagons are long. In many cases, the AGV has to use elevators and hallways also used by patients, visitors and healthcare staff. These interactions affect the transportation performance of the AGV system. Obstacles in the pathway cannot be removed by an AGV. The AGV system is currently dependent on human monitoring. Errors or failures from elevators, human interactions or obstacles resulting in AGV breakdowns have to be corrected manually by an operator. These interactions and breakdowns have a strong impact on the performance of the AGV system. The AGVs operating hours are currently restricted by the operator's attendance and surveillance. Emphasizing the need to expand the knowledge of operations of AGVs in hospital environments.

6. CONCLUSSION

The study aimed to analyze the current situation of the hospital's supply chain focusing on material and information flow. Information sharing and integration is still a major issue both in the case hospitals as well as in AGV systems. Several hospitals using AGVs as a part of the material handling system should be compared to ensure that this is a common problem needing in-depth understanding.

Future research should focus on how the information of both the constraints of the hospital environment and the in-house production can be integrated into the AGV system. Furthermore, research on how internal distribution and transportation by AGVs can be moved to times where there is less activity in the hospital, to avoid the problem of sharing facilities with patients, visitors, and healthcare staff. Related to this, it should be investigated how machine learning methods can support the AGV system to operate AGVs 24 hours a day without human surveillance.

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