AUTOMATIC GUIDED VEHICLES (AGVs) FOR TRANSPORTATION OF FOOD AND MATERIALS IN HOSPITALS

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DISCLOSURE

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EXECUTIVE SUMMARY

Background

Automatic Guided Vehicles (AGVs) have been globally used in material handling for decades. The demand for mobile robots and their use in hospital had increased due to changes in demographic trends and medical cost control. For healthcare facilities, these automated systems are designed specifically for handling bulk material, pharmacy medicines, laboratories samples, central supply and transportation of food, dirty dishes, bed laundry, waste (biological, recyclable), biomedical instruments etc. Operating efficiency is gained by automating these supplies, which allows the transfer of human resources to other departments or activities.

The AGVs are electronically trolleys that automate the transport process, so the medical supplies reach from storage to “point of utilisation” requiring minimal human effort. This provides intangible long term benefits like possibility to accommodate ageing workforce, better outcomes like decreased workplace injuries, staff turn-over and medical leave rates.

The automation also offers potential benefits to healthcare facilities including efficiency improvement, patient service level increases, business activity growth adjustment, better security and comfort for staff. However, the system also challenges the healthcare facilities on several issues; investment costs compared to potential gains from operation cost reduction, a lack of flexibility in the long term, difficulty of adapting the automation system to major changes in business operations, and dependency on maintenance and informatics and programming skills.

Singapore healthcare system is at par with developed health systems and is known to employ or evaluate latest technological advances in logistics to improve efficiency. It also suffers a double whammy of tight labour market as well as ageing workforce, justifying a constant need for improvement in supply chain efficiency.2 Statistics also show that the number of hospital patients is increasing in western countries such as Denmark, which substantially increase the load of supporting logistic functions. The variety of materials and equipment that are being used in hospitals is expanding. Therefore, the AGVs maybe the appropriate solution for the handling.

Hence, this technology review was requested by Engineering Services Division of Ministry of Health, and Dietetics and Food Service Department of Hospital Tengku Ampuan Rahimah, to review the evidence related to AGVs for the above purpose.

Objective/aim

To evaluate the efficacy, safety, cost-effectiveness and organisational issues related to AGVs for transportation of food and materials in hospitals.

Results and conclusions

There was very limited evidence to suggest AGVs have the potential to reduce labour man-hour and healthcare staff workload when compared to manual process. However, the effect was found to be less when compared to Radio-frequency Identification (RFID) alone. In terms of safety, evidence suggests that AGV was able to avoid collision with static and moving objects. The cost-analysis suggests the use of AGV alone was expensive. However, combination of AGV with RFID were found to be cost saving compared to manual process. Handling of AGV system in healthcare facilities require proper training, expertise and knowledge.

Methods

Electronic databases were searched through the Ovid MEDLINE(R) In-Process & Other Non-Indexed Citations and Ovid MEDLINE(R) 1946 to Present EMBASE - 1996 to August 2019, Ovid MEDLINE(R) and Epub Ahead of Print, In-Process & Other Non-Indexed Citations and Daily 1946 to February 07, 2020, Ovid MEDLINE(R) and In-Process & Other Non-Indexed Citations 1946 to February 07, 2020, Ovid MEDLINE(R) and Epub Ahead of Print, In-Process & Other Non-Indexed Citations and Daily 2015 to February 07, 2020, Ovid MEDLINE(R) and Epub Ahead of Print, In-Process & Other Non-Indexed Citations and Daily - without Revisions 2015 to February 07, 2020, Ovid MEDLINE(R) 1946 to January Week 5 2020, Ovid MEDLINE(R) without Revisions 1996 to January Week 5 2020, Ovid MEDLINE(R) Epub Ahead of Print February 07, 2020, Ovid MEDLINE(R) Daily Update February 07, 2020, Ovid MEDLINE(R) 2015 to January Week 5 2020. Searches were also run in PubMed. Google was used to search for additional web-based materials and information. Additional articles were identified from reviewing the references of retrieved articles. Last search was conducted on 11 February 2020.

AUTOMATED GUIDED VEHICLES (AGVs) FOR TRANSPORTATION OF FOOD AND MATERIALS IN HOSPITALS

1. BACKGROUND

Automatic Guided Vehicles (AGVs) have been globally used in material handling for decades. The demand for mobile robots and their use in hospital had increased due to changes in demographic trends and medical cost control. For healthcare facilities, these automated systems are designed specifically for handling bulk material, pharmacy medicines, laboratories samples, central supply and transportation of food, dirty dishes, bed laundry, waste (biological, recyclable), biomedical instruments etc. Operating efficiency is gained by automating these supplies, which allows the transfer of human resources to other departments or activities.[1]

The AGVs are electronically trolleys that automate the transport process, so the medical supplies reach from storage to “point of utilisation” requiring minimal human effort.[2] This provides intangible long term benefits like possibility to accommodate ageing workforce, better outcomes like decreased workplace injuries, staff turn-over and medical leave rates.[3,4]

The automation also offers potential benefits to healthcare facilities including efficiency improvement, patient service level increases, business activity growth adjustment, better security and comfort for staff. However, the system also challenges the healthcare facilities on several issues; investment costs compared to potential gains from operation cost reduction, a lack of flexibility in the long term, difficulty of adapting the automation system to major changes in business operations, and dependency on maintenance and informatics and programming skills.[5]

Singapore healthcare system is at par with developed health systems and is known to employ or evaluate latest technological advances in logistics to improve efficiency. It also suffers a double whammy of tight labour market as well as ageing workforce, justifying a constant need for improvement in supply chain efficiency.[2] Statistics also show that the number of hospital patients is increasing in western countries such as Denmark, which substantially increase the load of supporting logistic functions. The variety of materials and equipment that are being used in hospitals is expanding.[6,7] Therefore, the AGVs maybe the appropriate solution for the handling.[8]

Hence, this technology review was requested by Engineering Services Division of Ministry of Health and Dietetics and Food Service Department of Hospital Tengku Ampuan Rahimah, to review the evidence related to AGVs for the above purpose.

2. OBJECTIVE / AIM

To evaluate the efficacy, safety, cost-effectiveness and organisational issues related to AGVs for transportation of food and materials in hospitals.

3. TECHNICAL FEATURES

The use of AGV monitors all major movements in the hospital and may prefer the most important jobs and tasks that can be completed first (surgical instruments transported first, then food for patients, bedding, garbage, etc.).[9] The AGV is equipped with sensors to detect obstacles that allow safe stop before hitting obstacles that might be in the way. Applications and commands are medicated through a user-friendly touch screen.[10] There are several types of AGVs used in health facilities. Each type of AGV has their own unique characteristics which is suitable for different environment.

Types of AGVs

a) Helpmate
Helpmate was one of the pioneer implementations of automated robotic hospital transportation systems.[11] It was designed for transporting small sized cargo between departments, and it is able to autonomously navigate inside the hospitals, take elevators and avoid obstacles.[12]

b) Care-o-bot
Care-o-bot was developed to provide physical support to people requiring mobility and tele-presence capabilities for remote inspection, in addition to navigation capabilities.[13]

c) I-Merc
I-Merc was introduced as a new and automated method of distributing meals in hospitals.[14]

d) TUG robot
TUG robot was commercialised by Aethon, is a robotic system consisting of a tugging vehicle and specially designed charts to which the robot can be connected to. The system can navigate autonomously by using Radio-frequency Identification (RFID) technology.[15]

e) Speciminder
Speciminder was specifically designed for distributing lab specimens throughout the health facilities. It has similar autonomous navigation capabilities to TUG, but the cargo container is directly placed on top of the robot.[16]

f) Transcar
Transcar was developed by Swisslog, which consist of a laser guided low-height vehicle that can go under wheel supported cargo carts (with loads

up to 450kg), lift them up and transport to designations that are written to the RFID tags on the carts.[17]

g) FMC Technologies
FMC Technologies was developed based on the AGV platform that was already being used in manufacturing plants. It is very similar to Transcar, but it is larger and has greater payload (680kg).[18]

h) Pathfinder
Pathfinder is a prototype of AGV for hospital logistics which is a unique combination of industrial-based components and the latest state-of-the art technology for autonomous navigation. Pathfinder was partially inspired by similar existing commercial AGVs but the project intended to develop a vehicle which would be optimised for the requirements of working in health facilities.[19]

Particular features of the hospital robots towards common industrial AGVs are summarised as follows:

- The systems have the option to be switched from automatic mode to manual mode at any time.
- The systems immediately stop the motion in the case of human or other obstacles crossing their trajectory.
- The systems warn their nearby surroundings about their presences (by music, sound, light, etc.).
- The systems are designed so that they look pleasant to human.[19]

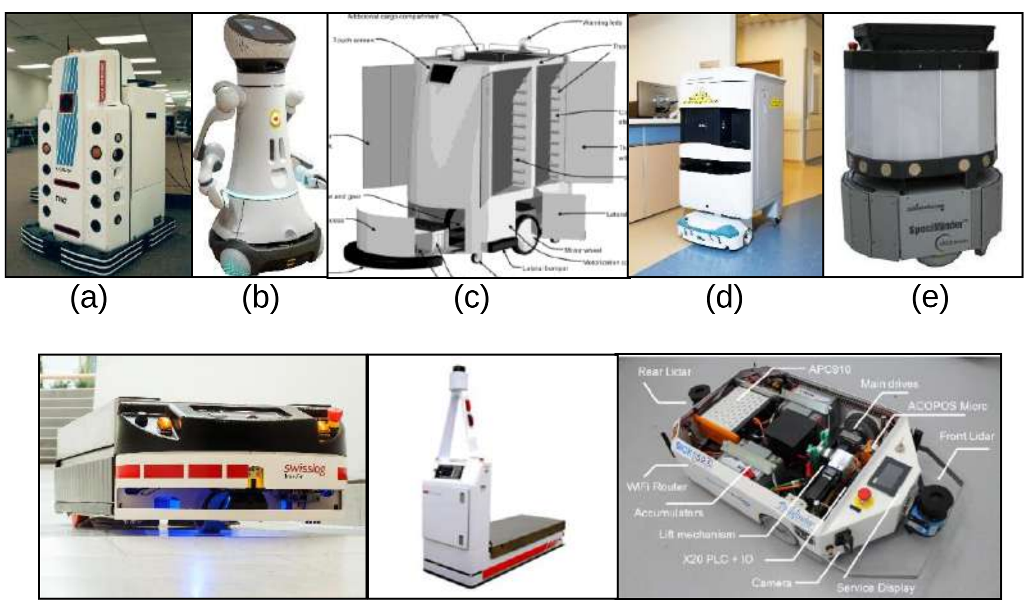

Figure 1: Types of AGVs; a) Helpmate, b) Care-o-robot, c) I-Merc, d) TUG robot, e) Speciminder, f) Transcar, g) FMC Technology and h) Pathfinder

4. METHODS

4.1. Searching

Electronic databases were searched through the Ovid interface:

- Ovid MEDLINE(R) In-Process & Other Non-Indexed Citations and Ovid MEDLINE(R) 1946 to Present EMBASE - 1996 to August 2019
- Ovid MEDLINE(R) and Epub Ahead of Print, In-Process & Other Non-Indexed Citations and Daily 1946 to February 07, 2020
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Searches were also run in PubMed. Google was used to search for additional web-based materials and information. Additional articles were identified from reviewing the references of retrieved articles. Last search was conducted on 11 February 2020.

Appendix 1 shows the detailed search strategies.

4.2. Selection

A reviewer screened the titles and abstracts against the inclusion and exclusion criteria and then evaluated the selected full text articles for final article selection.

The inclusion and exclusion criteria were:

Inclusion criteria

Population	Health facilities, hospitals
Interventions	Automated guided vehicles (AGVs)
Comparators	Manual logistic system/no comparator
Outcomes	i. Effectiveness/Efficacy: Delivery time man hour, manpower ii. Safety: Adverse events, complications iii. Organizational: Training, building restructuring iv. Economic: Cost-effectiveness, cost-analysis
Study design	Health Technology Assessment (HTA) reports, Systematic review (SR) and Meta-analyses, Randomised Controlled Trials (RCT), Non-randomised controlled trials (NRCT), cohort studies, case control studies, cross-sectional studies, case series.

Exclusion criteria

Study design	Studies conducted in animals, narrative reviews.
	Non English full text articles

Data were extracted and summarised in evidence table as in Appendix 3.

5. RESULTS AND DISCUSSION

A total of two titles were identified through the Ovid interface and PubMed, and 27 titles through Google Scholar. There were four articles included in this review; a qualitative survey study, two simulation studies and one experimental study as shown in Figure 2. The studies retrieved and included in this review were conducted in Slovakia, France and Singapore.

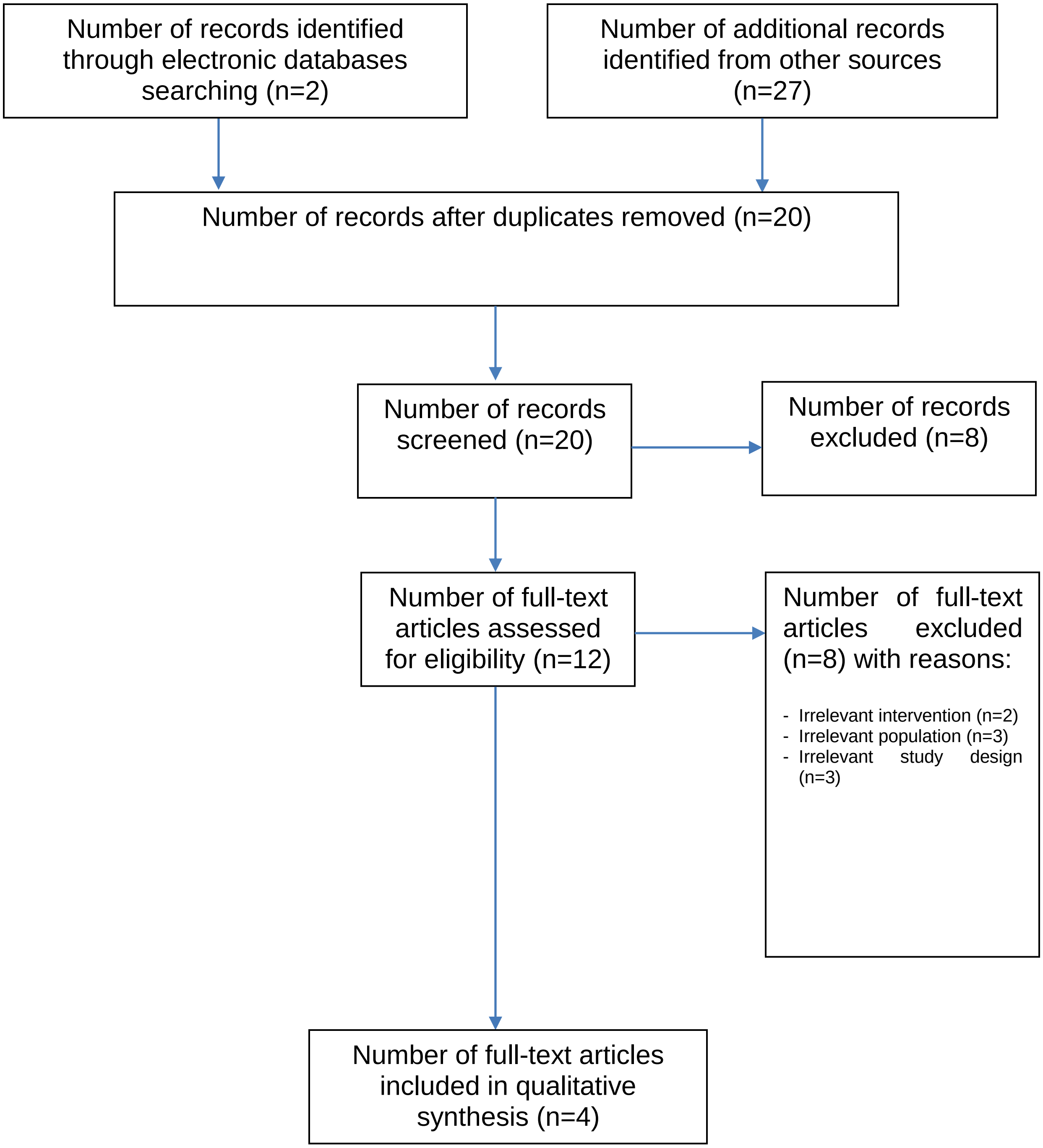

Figure 2: Flow chart of study selection

5.1. EFFICACY

Three studies reported the efficacy of automated guided vehicle, of which two simulation studies and one qualitative survey study.

Chikul et al. (2017) conducted a simulation study to simulate and compare a manual supply chain management versus a process that is technologically integrated (RFID or AGV) in a general hospital in Singapore. The aim was to simulate the supply chain models for manual and technologically integrated processes using value stream maps and deterministic modelling to compare these processes in terms of labour man hours, total costs as well as productivity.[2]

The deterministic model was created for manual and technologically integrated processes as part of operations research under the institutional quality improvement exercise. Furthermore, the inputs for the model were obtained from subject matter experts (healthcare supply chain management experts within the hospital as well as other hospitals locally, also including hospital planning team, AGV and RFID vendors) by using semi-structured interviews (SSI), on-site observations, experience from previous implementations, human resources department, hospital information system as well as published literature thereby increasing the reliability. The assumptions used in deterministic model were then compared in terms of labour man hours, costs and productivity over a period of ten years. The study was conceptualised during re-location of 355-bed general hospital to newer premises within Singapore with an increased capacity of 700 beds. Study duration was 1.5 years and data collection was performed from September 2014 to September 2015.[2]

Three hospital supply chain management models were studied; Model 1 (manual), inventory checking, picking as well as transportation was done manually and order was generated by manually keying the data into the existing hospital information system; Model 2 (automated inventory check/ RFID Model), inventory checking was automated using a RFID enabled two bins replenishment system. Two bins for each supply were placed at each service point. Staff used supplies from one bin; once empty, the RFID tag helped signal inventory supply while staff could continue to use the other bin; and Model 3 (automated delivery/ AGV Model), inventory checking, picking and replenishment at service points were manual, order was generated by manually keying in the existing hospital information system while transportation was automated using AGVs.[2]

The results showed RFID intervention required least number of man-hour per day (187), resulting in savings of 95 man hours per day (33.0%) between manual and AGV process. While using AGV alone also resulted in man-hour savings, but of a smaller magnitude as compared to RFID. The number of staff required decreased from 55 to 38 with RFID technology, a reduction of more 30% as compared to manual process (Table 1). The authors concluded that the augmentation of the manual system with a combination of RFID and

AGVs further enhanced automated delivery benefits of AGVs and added ergonomic.[2]

Table 1: Comparison of hospital supply chain process: Manual versus RFID and AGV.

System Resource Requirements	Manual	RFID	AGV
		Total service points (9,100)	
		Process	
Inventory Check	Manual	RFID enabled 2 bin replenishment system	Manual
Order Generation	With current hospital information system	New hospital information system linked to RFID	With current hospital information system
Order Picking	Manual	Manual	Manual
Order Delivery • Transport • Replenishment	 • Manual Trolley • Manual	 • Manual Trolley • Manual	 • AGV, AGV trolley (+ few Manual trolleys) • Manual
Total Man-hours required to serve all areas/service points*	282 hours	187 hours	265 hours
Number of Staff required**	55	38	53

Note. * based on value stream maps; ** based on deterministic modeling

Pedan et al. (2017) conducted a simulation study to identify the potential implementation of AGV system in the hospital in Slovakia. The AGV cart and transport methods were designed for inpatient ward of healthcare facility. This way of transport was subsequently created in a three-dimensional environment where the movement of AGV had been simulated and verified in terms of the physical layout of the building and material flows in the ward.[1]

The AGV integration was designed in three following areas; Area 1 (food transportation to the patient rooms), this process represented the provision of food transportation from the food arrival to the kitchen, then sorting the meals for patients by healthcare staff and distributing the meals by AGVs to the patient rooms. The rooms have designed areas for precise stopping and unloading food from AGVs; Area 2 (collection and transportation of used and clean laundry), healthcare facility had their external company, which carried away and washed the dirty laundry and delivered the clean one back. The facility used AGVs for the internal transport service. Transportation consisted of loading the laundry box and transporting it to the desired location (central storage). Transportation through the floors were carried by freight elevator; and Area 3 (waste transportation), waste was transported from a well-marked spaces and areas from the whole ward. The waste was collected on these places in special boxes. The AGVs took and moved the waste to the temporary storage of waste to the base floor.[1]

The visualisation of AGV was integrated in simulation software SIMIO to verify the suggested implementations of AGVs in inpatient ward. The real objects and the physical disposition of healthcare facility were imported. The AGVs in this simulation software followed the inpatient ward streams that had been mapped and analysed (e.g. the movement of medical staff and medical material). The simulation showed that AGV integration saved 345 minutes of total 1440 minutes (24.0%) for medical assistant (MA) per day (Table 2). The results also reported that MA could spend more time with patients.[1]

Table 2: Healthcare staff time reduction.

Staff	Activity	Current state (min.)	After AGV integration (min.)	Time reduction (min.)
MA	Morning toilet	150	150	0
	Blood test subscription	300	300	0
	Clean laundry delivery	75	0	75
	Breakfast delivery	60	0	60
	Lunch delivery	90	0	90
	Afternoon toilet	300	300	0
	Dinner preparation	30	30	0
	Dinner delivery	60	0	60
	Evening toilet	300	300	0
	Dirty laundry transport	60	0	60
	Total	**1440**	**1080**	**345**

Ageron et al. (2018) conducted a qualitative survey study to propose (based on the exploratory case study) an analysis grid of the new challenges and changes in terms of logistics flow that impact staff involved in managing these flows in a hospital context. The final objective of the paper was to propose guidelines to logistics healthcare managers to deploy and implement an AGV project.[5]

The study was held at Mercy Hospital in Metz (France). This hospital operated 12 units of AGVs to meet transport needs. A research protocol was established to ensure reliability in the study. This protocol consisted of creating and establishing the data-gathering instrument, namely a semi-structured interview (SSI) guide that included questions designed to provide adequate coverage for the purpose of the research. Simultaneously, a sampling strategy was formulated by defining the characteristics of the respondents. The qualitative approach was based on an interview guide. The SSI was opted rather than a structured because it offered sufficient flexibility to approach respondents differently while covering the same areas of data collection. Informal conversations with some selected medical actors (out of researchers' field of study but in other hospital and/or healthcare contexts – with a logistics manager of the Red Cross in Luxembourg, the logistics manager and director of the Nancy Hospital) identified the challenges and issues of implementing an automation project. Printed material (newspapers, professional journals) drew attention to the topicality and importance of the subject. Moreover, a preliminary hospital visit gave an insight into an automated logistics system, its operation and issues.[5]

The interview guide covered the following topics; types and characteristics of hospital flows, the limits of the previous organisation of flows, the interest of automation through AGVs, feedback from the automation of flows, the role and skills of the actors and potential improvements.[5]

The SSI was conducted among 15 respondents from both the hospital (director, project manager, current and previous logistics directors, five managers concerned and involved in the design and management of automated logistics flows, two logistics technicians who used the automated system daily, two nurses, and two pharmacists who were customers of the automated logistics system) and the AGV company (project manager, logistics manager and sales manager). The interviews lasted from 25 to 121 minutes. Data collection took place from November 2015 to April 2016. All interviews were conducted face-to-face by at least two researchers. The data collection was completed by four non-participant observation situations (the researchers visited the hospital and observed the automated logistics system in operation through the control room). Data collection also included the internal hospital documents on the automation project and its current operation and external documents.[5]

The study reported that the nurse workload was reduced. The automation system created well defined process and roles; nursing staff could focus on the care activities and improve patient management. Moreover, the replenishment of stocks became more efficient (no inventory or count taken at the ward level) and the automation system deployed a more rigid and reliable logistic system (catering, laundry, waste and pharmaceutical flows). The authors concluded that the functioning of the system was effective and met the logistics objectives identified in the project phase.[5]

5.2. SAFETY

Bačik et al. (2017) conducted an experimental study to evaluate the accuracy and effectiveness of developed features used in Pathfinder (AGV) in Košice-Šaca Hospital, Slovakia. The experiment was conducted during preliminary on-site tests in July to August 2017 in Košice-Šaca Hospital. Pathfinder was used to transport medical supplies between a logistics warehouse at the ground floor of the main building and various clinics located around the hospital facility. The data acquired from different traffic situations during the initial test operation helped in the development and comprehensive fine-tuning of the navigational features and collision avoidance functionality. The analysis showed that the robot could move along its global path and reached the goal without colliding of AGV with static and moving objects.[19]

5.3. ORGANISATIONAL

Two studies were retrieved on the organizational issues for AGV.

A qualitative survey study by Ageron et al. (2018) reported that different type of expertise was required for AGV supervision; operational logistics knowledge, and information technology and system knowledge. Three important issues also concerned the project boundary and led to the examination and arbitration of important questions: a) The hospital had to deal with was the identification and selection of physical flows to automate, which were numerous, different and complementary; e.g. catering and laundry (bed sheets and meals), pharmaceuticals and sterilised products, waste, blood and patients, b) The necessary flexibility needed to manage some flows for the flow prioritisation to support an efficient and effective logistics organisation; all streams did not require automation. Some had to be kept manual to remain flexible and adaptable, and c) The importance of these flows in the logistics organisation, in terms of hard working conditions; the regular flows that met the objective were selected first to relieve and help logistics operators in their daily activities.[5]

An experimental study by Bačik et al. (2017) reported that regardless of the robust functionality and advanced capabilities of the robot, it was still difficult to predict if such a device would be broadly accepted and utilised by hospital personnel in everyday life. A further goal of the pilot test operation was needed to explain and promote Pathfinder functionality to hospital staff, to demonstrate the basic usage and benefits of the system and to encourage hospital personnel to use the potential of the system.[19]

5.4. COST / COST-EFFECTIVENESS / COST-ANALYSIS

There was no retrievable evidence on the cost effectiveness of AGV for hospitals. Two studies were retrieved on the cost-analysis of AGV for health facilities; two simulation studies.

A stimulation study by Chikul et al. (2017) reported that the use of AGV alone (without other interventions to reduce manpower) had shown to be expensive; possibly due to high initial system installation costs and less reduction in no-value added time as compared to manual process. The Multifactor Productivity (MFP) dropped by 5.0% by using a AGV alone compared to the manual (Table 3). Moreover, the combination of RFID and AGV showed a positive Return of Investment (ROI) compared to manual process beyond three years. Meanwhile, the use of AGV alone demonstrated a positive ROI but not as much as the combination with RFID.[2]

Table 3: Comparison of total expenditure between the manual and automated processes.

System Resource Requirements	Manual	RFID	AGV
Manpower			
• Cost of required staff (Annual salary package)	16,501,600	11,401,100	15,901,600
Equipment			
• Trolleys and maintenance	71,600	49,500	319,100
• AGV system + Maintenance	0.00	0.00	1,084,100
Other requirements			
• Hospital Information system linked to RFID	0.00	198,800	0.00
• Hospital Information system linked to RFID (Maintenance)	0.00	151,700	0.00
TOTAL	16.5 M USD	11.8 M USD	17.2 M USD
	Service points (9,100)		
• Multi-factor Productivity* (MFP) [Total Daily Output/ Total Daily Input] • Total output calculated as service points, while total input calculated as total daily costs in USD	• 9,100/4,540.1 Service points per USD • = 2.0	• 9,100/3,229 Service points per USD • = 2.8	• 9,100/4,726.8 Service points per USD • = 1.9
Change in MFP as compared to Manual process	Baseline	2.8/2.0 = +40%	1.9/2.0 = -5%

Note. * OECD Manual for measuring productivity; all prices reflected in USD

To understand the effects of varying staff utilisation rates, manpower ratios as well as combination of technologies over 10 years, sensitivity analysis was conducted. Figure 3 shows the sensitivity analysis within all the three scenarios (best case, worst case and proposed case). The RFID intervention appeared to be most cost saving. The combination of RFID and AGV provided least manpower dependent alternative (Table 4).[2]

Figure 3: Comparison of cumulative 10 year costs based on assumptions (best case-worst case).

Table 4: Range (Based on Best case-Worst case scenario; all prices in USD)

Model	Total Amount (10 years)	Range* in Million USD	Manpower Requirement (Range)
Manual	$16.5 M	12.3M- 18.9M	55 (41-63)
RFID (automated inventory check)	$11.8M (-4.7M)	8.5M- 13.0M	38 (27- 42)
AGV (Automated Transport/Delivery)	$17.3M (+0.8M)	12.8M- 19.4M	53 (38- 60)
RFID+AGV	$11.9M (-4.6M)	9.2M- 13.1M	34 (25- 38)

A stimulation study by Pedan et al. (2017) also conducted a cost-analysis on AGV integration in selected healthcare facilities. The total cost estimated including the purchasing and setting AGV cart, installing and marking AGV navigation and customisation of hospital environment was €115,700. The monthly operating cost of AGV was four percent of input cost (€4,628) and the cost per day was €154.27. The hourly cost of running the AGV at around €6.43 per hour. These values were then compared to the hourly cost of MA in inpatient ward (€3.50), it showed that operating costs of AGV were almost two times higher compared to MA.[1]

5.5. LIMITATIONS

This technology review has several limitations. The selection of studies was done by one reviewer. Although there was no restriction in language during the search but only English full text articles were included in this review. No RCT retrieved.

6. CONCLUSION

There was very limited evidence to suggest AGVs have the potential to reduce labour man-hour and healthcare staff workload when compared to manual process. However, the effect was found to be less when compared to RFID alone. In terms of safety, evidence suggests that AGV was able to avoid collision with static and moving objects. The cost-analysis suggests the use of AGV alone was expensive. However, combination of AGV with RFID were found to be cost saving compared to manual process. Handling of AGV system in healthcare facilities require proper training, expertise and knowledge.

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19. Bačik J, Ďurovský F, Biroš M et al. Pathfinder: Development of automated guided vehicle for hospital logistics. IEEE. 2017;5: 26892-26900.

8. APPENDIX

8.1. Appendix 1: LITERATURE SEARCH STRATEGY

Ovid MEDLINE® In-process & other Non-Indexed citations and OvidMEDLINE® 1946 to Present EMBASE – 1996 to August 2019

1. Health facilities/
2. facilities, health.tw.
3. facility, health.tw.
4. health facilit*.tw.
5. HOSPITALS/
6. hospital*.tw.
7. hospital logistic*.tw.
8. 1 or 2 or 3 or 4 or 5 or 6 or 7
9. automated guided vehicles/
10. automated guided vehicles.tw.
11. 9 or 10
12. 8 and 11

OTHER DATABASES	
Ovid MEDLINE(R) and Epub Ahead of Print, In-Process & Other Non-Indexed Citations and Daily 1946 to February 07, 2020	Same MeSH, keywords, limits used.
Ovid MEDLINE(R) and In-Process & Other Non-Indexed Citations 1946 to February 07, 2020	
Ovid MEDLINE(R) and Epub Ahead of Print, In-Process & Other Non-Indexed Citations and Daily 2015 to February 07, 2020	
Ovid MEDLINE(R) and Epub Ahead of Print, In-Process & Other Non-Indexed Citations and Daily - without Revisions 2015 to February 07, 2020	
Ovid MEDLINE(R) 1946 to January Week 5 2020	
Ovid MEDLINE(R) without Revisions 1996 to January Week 5 2020	
Ovid MEDLINE(R) Epub Ahead of Print February 07, 2020	
Ovid MEDLINE(R) Daily Update February 07, 2020	
Ovid MEDLINE(R) 2015 to January Week 5 2020	

PubMeD

(((((Health facilities[MeSH Terms]) OR Hospitals[MeSH Terms]) OR Health Facility*[Text Word]) OR Hospital*[Text Word])) AND automated guided vehicles*[Text Word]

8.2. Appendix 2

DESIGNATION OF LEVELS OF EVIDENCE

I Evidence obtained from at least one properly designed randomised controlled trial.

II-I Evidence obtained from well-designed controlled trials without randomization.

II-2 Evidence obtained from well-designed cohort or case-control analytic studies, preferably from more than one centre or research group.

II-3 Evidence obtained from multiple time series with or without the intervention. Dramatic results in uncontrolled experiments (such as the results of the introduction of penicillin treatment in the 1940s) could also be regarded as this type of evidence.

III Opinions or respected authorities, based on clinical experience; descriptive studies and case reports; or reports of expert committees.

SOURCE: US/CANADIAN PREVENTIVE SERVICES TASK FORCE (Harris 2001)

8.3. Appendix 3: Evidence Tables

Evidence Table : Efficacy
Question : Is Automated Guided Vehicle effective in hospital?

Bibliographic citation	Study Type / Methodology	LE	Number of patients and patient characteristics	Intervention	Comparison	Length of follow up (if applicable)	Outcome measures/ Effect size	General comments
1. Chikul M, Maw HY, Soong YK. Technology in healthcare: A case study of healthcare supply chain management models in a general hospital in Singapore. Sciedu Press. 2017;6(6):63-70. SINGAPORE	Simulation study Objective: To stimulate and compare a manual hospital supply chain management model versus a process that is technologically integrated (either by Radio Frequency Identification [RFID] technology or automated guided vehicles [AGVs]), in a general hospital in Singapore. Method: Aim- to simulate the supply chain models for manual and technologically integrated processes using value stream maps and deterministic modelling to compare these processes in terms of labour man hours, total costs as well as productivity in a general hospital in Singapore. Deterministic model was created for manual and technologically integrated processes as part of operations research under the institutional quality improvement exercise. Inputs for the model were obtained from subject matter experts (healthcare supply chain management experts within the hospital as well as other		n=13 Subject matter experts in selected domain areas: Manpower=3 Medical supplies=4 RFID=3 AGV=3	RFID AGV	Manual	-	**Delivery time man hour and man power** • RFID intervention required least number of man-hour per day (187), resulting in savings of 95 man hours per day (33%) between manual and AGV process. • Using AGV alone also resulted in man-hour savings, but of a smaller magnitude as compared to RFID. • The number of staff required decreased from 55 to 38 with RFID technology, a reduction of > 30% as compared to manual process; this was particularly significant for countries like Singapore where labour was a scarce resource. Author's conclusion: Augmentation of the manual system with a combination of RFID and AGVs further enhanced automated delivery benefits of AGVs and added ergonomic.	

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Evidence Table : Efficacy
Question : Is Automated Guided Vehicle effective in hospital?

Bibliographic citation	Study Type / Methodology	LE	Number of patients and patient characteristics	Intervention	Comparison	Length of follow up (if applicable)	Outcome measures/ Effect size	General comments
	hospitals locally, also including hospital planning team, AGV and RFID vendors) by using semi-structured interviews (SSI), on-site observations, experience from previous implementations, human resources department, hospital information system as well as published literature thereby increasing the reliability. Assumptions used in deterministic model were then compared in terms of labour man hours, costs and productivity over a period of 10 years. Setting- Study was conceptualised during re-location of a 355-bed general hospital to newer premises within Singapore with an increased capacity of 700 beds. Study duration was 1.5 years and data collection was performed from September 2014 to September 2015. Interventions: **a) Model 1 (manual)-** inventory checking, picking as well as transportation was done manually and order was generated by manually keying the data into the existing hospital information system. **b) Model 2 (automated inventory check/ RFID Model)-** inventory checking was automated using a RFID enabled two bins replenishment							

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Evidence Table : Efficacy
Question : Is Automated Guided Vehicle effective in hospital?

Bibliographic citation	Study Type / Methodology	LE	Number of patients and patient characteristics	Intervention	Comparison	Length of follow up (if applicable)	Outcome measures/ Effect size	General comments
	system. Two bins for each supply were placed at each service point. Staff used supplies from one bin; once empty, the RFID tag helped signal inventory supply while staff could continue to use the other bin. **c) Model 3 (automated delivery/ AGV Model)-** inventory checking, picking and replenishment at service points were manual, order was generated by manually keying in the existing hospital information system while transportation was automated using AGVs.							

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Evidence Table : Efficacy
Question : Is Automated Guided Vehicle effective in hospital?

Bibliographic citation	Study Type / Methodology	LE	Number of patients and patient characteristics	Intervention	Comparison	Length of follow up (if applicable)	Outcome measures/ Effect size	General comments
2. Pedan M, Gregor M, Plinta D. Implementation of Automated Guided Vehicle system in healthcare facility. Procedia Engineering. 2017;192: 665-670. SLOVAKIA	Simulation study Objective: To identify the potential implementation of AGV system in the hospital. Method: AGV cart and transport methods were designed for inpatient ward of healthcare facility. This way of transport was subsequently created in a three-dimensional environment where the movement of AGV had been stimulated and verified in terms of the physical layout of the building and material flows in the ward. AGV integration was designed in three following areas: **a) Food transportation to the patient rooms:** This process represented the provision of food transportation from the food arrival to the kitchen, then sorting the meals for patients by healthcare staff and distributing the meals by AGVs to the patient rooms. The rooms have designed areas for precise stopping and unloading food from AGVs. **b) Collection and transportation of used and clean laundry:** Healthcare facility had their external company, which carried away and washed the		Selected healthcare facilities	AGV	-	-	**Delivery time man hour and man power** • AGV integration saved 345 minutes of total 1440 minutes (representing 23.96%) for medical assistant (MA) per day. • MA could spend more time with patients.	

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Evidence Table : Efficacy
Question : Is Automated Guided Vehicle effective in hospital?

Bibliographic citation	Study Type / Methodology	LE	Number of patients and patient characteristics	Intervention	Comparison	Length of follow up (if applicable)	Outcome measures/ Effect size	General comments
	dirty laundry and delivered the clean one back. The facility used AGVs for the internal transport service. Transportation consisted of loading the laundry box and transporting it to the desired location (central storage). Transportation through the floors were carried by freight elevator. **c) Waste transportation:** Waste was transported from a well-marked spaces and areas from the whole ward. The waste was collected on these places in special boxes. The AGVs took and moved the waste to the temporary storage of waste to the base floor. The visualisation of AGV integration in simulation software SIMIO: For verification of the suggested implementations of AGVs in inpatient ward. The real objects and the physical disposition of healthcare facility were imported. The AGVs in this simulation software followed the inpatient ward streams that had been mapped and analysed (e.g. the movement of medical staff and medical material).							

22

Evidence Table : Efficacy
Question : Is Automated Guided Vehicle effective in hospital?

Bibliographic citation	Study Type / Methodology	LE	Number of patients and patient characteristics	Intervention	Comparison	Length of follow up (if applicable)	Outcome measures/ Effect size	General comments
3. Ageron B, Benzidia S, Bentahar O et al. Investigating Automation and AGV in Healthcare Logistics: A Case Study Based Approach. International Journal of Logistics: Research and Applications. 2018;22(3):273-293. FRANCE	Qualitative survey study Objective: To propose (based on the exploratory case study) an analysis grid of the new challenges and changes in terms of logistics flows that impact staff involved in managing these flows in a hospital context. The final objective of the paper was to propose guidelines to logistics healthcare managers to deploy and implement an AGV project. Method: The study was held at Mercy Hospital in Metz (France). This hospital operated 12 units of AGVs to meet transport needs. A research protocol was established to ensure reliability in the study. This protocol consisted of creating and establishing the data-gathering instrument, namely a semi-structured interview guide that included questions designed to provide adequate coverage for the purpose of the research. Simultaneously, a sampling strategy was formulated by defining the characteristics of the respondents. The qualitative approach was based on an interview guide. A semi-structured interview was opted rather than a structured because it		n=15 Respondents had sufficient knowledge on the automation and were notably involved, also concerned with the automation project.	-	-	-	**Delivery time man hour and man power** • The nurse workload was reduced. • The replenishment of stocks became more efficient (no inventory or count taken at the ward level). • The automation system deployed a more rigid and reliable logistic system (catering, laundry, waste and pharmaceutical flows). • The automation system created well defined process and roles (nursing staff could focus on the care activities and improve patient management). Author's conclusion: The functioning of the system was effective and met the logistics objectives identified in the project phase.	

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Evidence Table : Efficacy
Question : Is Automated Guided Vehicle effective in hospital?

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Bibliographic citation	Study Type / Methodology	LE	Number of patients and patient characteristics	Intervention	Comparison	Length of follow up (if applicable)	Outcome measures/ Effect size	General comments
	offered sufficient flexibility to approach respondents differently while covering the same areas of data collection. Informal conversations with some selected medical actors (out of researchers' field of study but in other hospital and/or healthcare contexts – with a logistics manager of the Red Cross in Luxembourg, the logistics manager and director of the Nancy Hospital) identified the challenges and issues of implementing an automation project. Printed material (newspapers, professional journals) drew attention to the topicality and importance of the subject. Moreover, a preliminary hospital visit gave an insight into an automated logistics system, its operation and issues. The interview guide covered the following topics: a) Types and characteristics of hospital flows b) The limits of the previous organisation of flows c) The interest of automation through AGVs d) Feedback from the automation of flows e) The role and skills of the actors f) Potential improvements A semi-structured interview was conducted among 15 respondents from							

Evidence Table : Efficacy
Question : Is Automated Guided Vehicle effective in hospital?

Bibliographic citation	Study Type / Methodology	LE	Number of patients and patient characteristics	Intervention	Comparison	Length of follow up (if applicable)	Outcome measures/ Effect size	General comments
	both the hospital (director, project manager, current and previous logistics directors, five managers concerned and involved in the design and management of automated logistics flows, two logistics technicians who use the automated system daily, two nurses, and two pharmacists who are customers of the automated logistics system) and the AGV company (project manager, logistics manager and sales manager). The interviews lasted from 25 to 121 minutes. Data collection took place from November 2015 to April 2016. All interviews were conducted face-to-face by at least two researchers. The data collection was completed by four non-participant observation situations (the researchers visited the hospital and observed the automated logistics system in operation through the control room). Data collection also included the internal hospital documents on the automation project and its current operation and external documents.							

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Evidence Table : Safety
Question : Is Automated Guided Vehicle safe in hospital?

Bibliographic citation	Study Type / Methodology	LE	Number of patients and patient characteristics	Intervention	Comparison	Length of follow up (if applicable)	Outcome measures/ Effect size	General comments
1. Bačik J, Ďurovský F, Biroš M et al. Pathfinder: Development of Automated Guided Vehicle for Hospital Logistics. IEEE. 2017;5: 26892-26900 SLOVAKIA	Experimental study Objective: To evaluate the accuracy and effectiveness of developed features used in Pathfinder (AGV) in Košice-Šaca Hospital. Method: The experiment was conducted during preliminary on-site tests in July to August 2017 in Košice-Šaca Hospital. Pathfinder was used to transport medical supplies between a logistics warehouse at the ground floor of the main building and various clinics located around the hospital facility. The data acquired from different traffic situations during the initial test operation helped in the development and comprehensive fine-tuning of the navigational features and collision avoidance functionality. A dynamic map switching approached was applied in order to guarantee consistency between the currently loaded map and the real floor environment.		n=1 (hospital)	-	-	-	• It was confirmed that the robot could move along its global path, and reached the goal without colliding with static and moving objects.	

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Evidence Table : Organisational
Question : How Automated Guided Vehicle contributed to the development of interpersonal and technical skill of hospital staff?

Bibliographic citation	Study Type / Methodology	LE	Number of patients and patient characteristics	Intervention	Comparison	Length of follow up (if applicable)	Outcome measures/ Effect size	General comments
1. Ageron B, Benzidia S, Bentahar O et al. Investigating Automation and AGV in Healthcare Logistics: A Case Study Based Approach. International Journal of Logistics: Research and Applications. 2018:22(3);273-293. FRANCE	Qualitative survey study Objective: To propose (based on the exploratory case study) an analysis grid of the new challenges and changes in terms of logistics flows that impact staff involved in managing these flows in a hospital context. The final objective of the paper was to propose guidelines to logistics healthcare managers to deploy and implement an AGV project. Method: The study was held at Mercy Hospital in Metz (France). This hospital operated 12 units of AGVs to meet transport needs. A research protocol was established to ensure reliability in the study. This protocol consisted of creating and establishing the data-gathering instrument, namely a semi-structured interview guide that included questions designed to provide adequate coverage for the purpose of the research. Simultaneously, a sampling strategy was formulated by defining the characteristics of the respondents. The qualitative approach was based on an interview guide. A semi-structured interview was opted rather than a structured because it		n=15 Respondents had sufficient knowledge on the automation and were notably involved, also concerned with the automation project.	-	-	-	• Different type of expertise was required for AGV supervision; operational logistics knowledge, and information technology and systems knowledge. • Three important issue also concerned the project boundary and led to the examination and arbitration of important questions: a) **The hospital had to deal with was the identification and selection of physical flows to automate, which were numerous, different and complementary;** catering and laundry (bed sheets and meals), pharmaceuticals and sterilised products, waste, blood and patients. b) **The necessary flexibility needed to manage some flows for the flow prioritisation to support an efficient and effective logistics organisation;** All streams did not require automation. Some had to be kept manual to remain flexible and adaptable. c) **The importance of these flows in the logistics organisation, in terms of hard working conditions;** the regular flows that	

Evidence Table : Organisational
Question : How Automated Guided Vehicle contributed to the development of interpersonal and technical skill of hospital staff?

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Bibliographic citation	Study Type / Methodology	LE	Number of patients and patient characteristics	Intervention	Comparison	Length of follow up (if applicable)	Outcome measures/ Effect size	General comments
	offered sufficient flexibility to approach respondents differently while covering the same areas of data collection. Informal conversations with some selected medical actors (out of researchers' field of study but in other hospital and/or healthcare contexts – with a logistics manager of the Red Cross in Luxembourg, the logistics manager and director of the Nancy Hospital) identified the challenges and issues of implementing an automation project. Printed material (newspapers, professional journals) drew attention to the topicality and importance of the subject. Moreover, a preliminary hospital visit gave an insight into an automated logistics system, its operation and issues. The interview guide covered the following topics: g) Types and characteristics of hospital flows h) The limits of the previous organisation of flows i) The interest of automation through AGVs j) Feedback from the automation of flows k) The role and skills of the actors l) Potential improvements A semi-structured interview was conducted among 15 respondents from						met the objective were selected first to relieve and help logistics operators in their daily activities.	

Evidence Table : Organisational
Question : How Automated Guided Vehicle contributed to the development of interpersonal and technical skill of hospital staff?

Bibliographic citation	Study Type / Methodology	LE	Number of patients and patient characteristics	Intervention	Comparison	Length of follow up (if applicable)	Outcome measures/ Effect size	General comments
	both the hospital (director, project manager, current and previous logistics directors, five managers concerned and involved in the design and management of automated logistics flows, two logistics technicians who use the automated system daily, two nurses, and two pharmacists who are customers of the automated logistics system) and the AGV company (project manager, logistics manager and sales manager). The interviews lasted from 25 to 121 minutes. Data collection took place from November 2015 to April 2016. All interviews were conducted face-to-face by at least two researchers. The data collection was completed by four non-participant observation situations (the researchers visited the hospital and observed the automated logistics system in operation through the control room). Data collection also included the internal hospital documents on the automation project and its current operation and external documents.							

29

Evidence Table : Organisational
Question : How Automated Guided Vehicle contributed to the development of interpersonal and technical skill of hospital staff?

Bibliographic citation	Study Type / Methodology	LE	Number of patients and patient characteristics	Intervention	Comparison	Length of follow up (if applicable)	Outcome measures/ Effect size	General comments
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Evidence Table : Cost analysis/ Cost Evaluation/ Cost Effectiveness
Question : Is Automated Guided Vehicle cost-effective in hospital?

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Bibliographic citation	Study Type / Methodology	LE	Number of patients and patient characteristics	Intervention	Comparison	Length of follow up (if applicable)	Outcome measures/ Effect size	General comments
1. Chikul M, Maw HY, Soong YK. Technology in healthcare: A case study of healthcare supply chain management models in a general hospital in Singapore. Sciedu Press. 2017;6(6):63-70. SINGAPORE	Simulation study Objective: To stimulate and compare a manual hospital supply chain management model versus a process that is technologically integrated (either by Radio Frequency Identification [RFID] technology or automated guided vehicles [AGVs]), in a general hospital in Singapore. Method: Aim- to simulate the supply chain models for manual and technologically integrated processes using value stream maps and deterministic modelling to compare these processes in terms of labour man hours, total costs as well as productivity in a general hospital in Singapore. Deterministic model was created for manual and technologically integrated processes as part of operations research under the institutional quality improvement exercise. Inputs for the model were obtained from subject matter experts (healthcare supply chain management experts within the hospital as well as other hospitals locally, also including hospital planning team, AGV and RFID vendors)		n=13 Subject matter experts in selected domain areas: Manpower=3 Medical supplies=4 RFID=3 AGV=3	RFID AGV	Manual	-	• The use of AGV alone (without other interventions to reduce manpower) had shown to be expensive; possibly due to high initial system installation costs and less reduction in no-value added time as compared to manual process. • Multifactor Productivity (MFP) dropped by 5% by using a AGV alone compared to the manual. • Sensitivity analysis showed that: ○ The combination of RFID and AGV provided least manpower dependent alternative; an important consideration for economies like Singapore with a tight labour market. ○ The use of AGV alone provided less manpower dependent (53; range 38-60) compared to the manual (55; range 41-63). • The combination of RFID and AGV showed a positive Return of Investment (ROI) compared to manual process beyond three years. • The use of AGV alone showed a positive ROI but not as much as the combination with RFID.	

Evidence Table : Organisational
Question : How Automated Guided Vehicle contributed to the development of interpersonal and technical skill of hospital staff?

32

Bibliographic citation	Study Type / Methodology	LE	Number of patients and patient characteristics	Intervention	Comparison	Length of follow up (if applicable)	Outcome measures/ Effect size	General comments
	by using semi-structured interviews (SSI), on-site observations, experience from previous implementations, human resources department, hospital information system as well as published literature thereby increasing the reliability. Assumptions used in deterministic model were then compared in terms of labour man hours, costs and productivity over a period of 10 years. Setting- Study was conceptualised during re-location of a 355-bed general hospital to newer premises within Singapore with an increased capacity of 700 beds. Study duration was 1.5 years and data collection was performed from September 2014 to September 2015. Interventions: **a) Model 1 (manual)-** inventory checking, picking as well as transportation was done manually and order was generated by manually keying the data into the existing hospital information system. **b) Model 2 (automated inventory check/ RFID Model)-** inventory checking was automated using a RFID enabled two bins replenishment system. Two bins for each supply were placed at each service point. Staff used							

Evidence Table : Organisational
Question : How Automated Guided Vehicle contributed to the development of interpersonal and technical skill of hospital staff?

Bibliographic citation	Study Type / Methodology	LE	Number of patients and patient characteristics	Intervention	Comparison	Length of follow up (if applicable)	Outcome measures/ Effect size	General comments
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Evidence Table : Cost analysis/ Cost Evaluation/ Cost Effectiveness
Question : Is Automated Guided Vehicle cost-effective in hospital?

Bibliographic citation	Study Type / Methodology	LE	Number of patients and patient characteristics	Intervention	Comparison	Length of follow up (if applicable)	Outcome measures/ Effect size	General comments
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Evidence Table : Cost analysis/ Cost Evaluation/ Cost Effectiveness
Question : Is Automated Guided Vehicle cost-effective in hospital?

Bibliographic citation	Study Type / Methodology	LE	Number of patients and patient characteristics	Intervention	Comparison	Length of follow up (if applicable)	Outcome measures/ Effect size	General comments
	dirty laundry and delivered the clean one back. The facility used AGVs for the internal transport service. Transportation consisted of loading the laundry box and transporting it to the desired location (central storage). Transportation through the floors were carried by freight elevator. **c) Waste transportation:** Waste was transported from a well-marked spaces and areas from the whole ward. The waste was collected on these places in special boxes. The AGVs took and moved the waste to the temporary storage of waste to the base floor. The visualisation of AGV integration in simulation software SIMIO: For verification of the suggested implementations of AGVs in inpatient ward. The real objects and the physical disposition of healthcare facility were imported. The AGVs in this simulation software followed the inpatient ward streams that had been mapped and analysed (e.g. the movement of medical staff and medical material).							

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