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AUTOMATED GUIDED VEHICLE (AGV) SYSTEM IN HEALTHCARE FACILITY

Shaikh Aamer Maheboob
Dept. Mechanical Engineering, ICEM Pune, India
aamersk5@gmail.com, Mob. +919881210037
Prof. M.G. Landge
Dept. Mechanical Engineering, ICEM Pune, India
Mob. +918554874224

Abstract—The article deals with the use of automated guided vehicle (AGV) system in the hospital. This paper provides the requirements and technical specifications of AGV cart designed for healthcare facility. The second part describes the application and benefits of AGV implementation in selected health care facility gained from computer simulation that is used as a verification tool. And use for hospital healthcare workplace, Building Design Consideration, Navigation System, Vehicles and Operational Benefits etc. This part also contains the economic evaluation of this implementation and summary of further investments related to this technology.

I. INTRODUCTION

Automated Guided Vehicle (AGV) technology is not a new technology. Fifty years ago, when AGVs were first used they were called driverless systems. Through the years, advances in electronics have led to advances in guided vehicles. Nowadays, the technology of AGV is widely used in industrial environment to perform variety of task that involves automation. Technological developments have given AGVs more flexibility and capability in performing its tasks. These AGVs is widely used for its advantage which is the ability to move from one place to another without proper supervision by human or operators. Most of AGV's using electric power and moved by the use of electric motor. The electric motor is connected to combination of suitable and appropriate gears, which then further connected to the wheel of the AGVs. Through this mechanism, the AGV will be able to move or navigate with help of appropriate control system in order for the AGV to move correctly along path as required. In these days, the demand for mobile robots and their use in hospitals has 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. Automated systems are working 24 hours a day, 7 days a week.

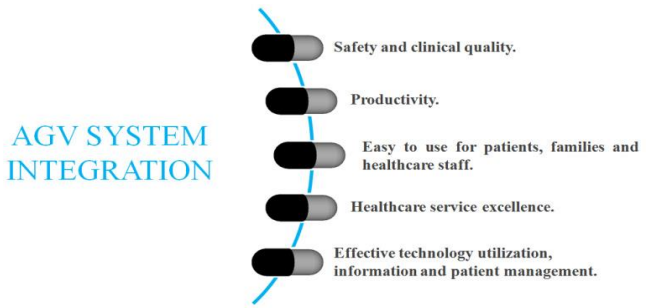

Fig. 1 AGV System Integration

Automated solution can streamline traffic flow of material in the hospital, control costs, reduce workload. Hospital operating installation have to fulfill some important of these Requirements. These requirements and the use of modern logistics systems significantly affects the operation of the entire facility and its economy, improves the quality of patient care and increases their safety.

II. LITERATURE REVIEW

Automated Guided Vehicles (AGV's) have been an established materials-handling solution in hospitals since the 1980's, internationally.R.A.Health P/L are exclusively partnered with EK Automation of Germany to widen their use across Australia. EK are continually installing AGV solutions in hospitals throughout Europe.

AGV guidance technology can be separated into two groups: fixed and free route guidance methods. Fixed route methods rely on a laid-out path that the AGV will sense and follow. Such examples include magnetic and optical tape. Free route methods store coordinates which the AGV uses to identify its current location. Such examples include GPS and vision guidance. Fixed route methods, such as magnetic tape, are not flexible as any changes would require re-taping which has a high maintenance cost, although the material cost is low. [2]. Healthcare delivery and services are undergoing dramatic changes due to the decreasing state supports, obligatory cost control, growing market competition, and transition to electronic health records (EHR) [5,17]. AGV's* operate in areas shared with pedestrians or, even more effectively, in dedicated service lifts & pathways. A fleet of such vehicles can provide a hospital with 24-hour shift operation, in poor lighting, yet with increased safety and less material damage, while also reducing costs. Controlled centrally, the software allows the AGV system in a hospital to redirect and distribute the burden of incoming orders on-the-fly – achieving a coordinated interplay of fleet movement that maximizes efficiency while providing instant reporting back through the system to trace performance, stock levels and interface with building management systems. Standard hospital AGV models are customizable with various navigation, interfacing and load handling technologies to meet the individual needs and environments of each hospital. RA Health P/L is establishing the use of AGV delivery systems in Australia's hospitals with several projects in various stages of consultation, design and installation.

III. AGVS FOR HOSPITAL

a) AGVS in Healthcare Workplace.
b) Oprational Benefits
c) Navigation System.
d) Vehicles.
e) Building Design Consideration.

a) AGVS in Healthcare Workplace- Hospital use a wide variety of carts and container to move products around the site. These include roll cages, waste carts, food carts, Linen Trolleys and many other types. In order to integrate an AGV system into the operational Hospital environment, not only must the technical challenges of introducing an AGV system be addressed, but also the interface between AGV and Manual operations Must be integrated into a viable process. Hospital AGV carries the cart or cage by driving underneath it and then raising the deck of the vehicle so that the casters of the container are clear of the ground, enabling the payload to be easily transported. This method of carrying containers is safe, secure, and can easily be validated as a "safe system" under LOLER, since both container and AGV are designed to be compatible. However, it imposes a requirement that the cages, carts and containers must be constructed so that they can engage with the AGV. Quire pace Sales Specialists have worked with many of the UK's suppliers of carts and containers to develop designs that provide a similar function to an "ordinary" container, and yet have the appropriate dimensions and clearances to engage with an AGV. The containers are usually fitted with an RFID transponder that uniquely identifies them, and this, together with the task-matching system used by the AGV installation enables each cart to be allocated to the correct route and destination.

Fig. 2 AGV Healthcare Facility

The compact "drive-under" style of AGV is the preferred solution for UK Hospitals due to its small size and maneuverability in restricted spaces.

B) operational benefits- Productivity Is the starting point for any Return on Investment calculation for an Automated Guided Vehicle System; a direct comparison between transportation costs using other methods and the AGV system. This is based on a time/distance/frequency comparison and compares AGVs to the manual resources required to achieve the same service. AGVs can be available for operation 24/7/365. The latest battery technologies only require opportunity charging in short time periods, and hence an AGV system can be designed to be on-call every hour of every day to answer the transportation demand. This means that distributions can be scheduled for off-peak periods, without requiring extensive external resources. AGVs operate to a timed schedule. Whilst the system is primarily "on-demand", it is a prerequisite that the various logistic flows are scheduled within defined time windows. With accurate scheduling of payload deliveries, it becomes easier to ensure that complementary resources are targeted to the same period. Reliable scheduling equals better use of all resources. Even with the most careful manual operators, impact damage to doors, walls, lifts and other structures is inevitable with a manual transport system. Using Automated Guided Vehicles this damage is completely eliminated; AGVs are programmed never to collide with other objects, and indeed the safety systems ensure that these events cannot occur. Without any necessity for "creative accounting", an Automated Guided Vehicle system in a Hospital environment should conservatively be able to show ROI < 5 years. Quire pace technical sales team will be pleased to assist in assessing how an installation can improve the efficiency of your Hospital.

Fig. 3 Amortization

c) Navigation System-What is "Contour Navigation" In the past Automated Guided Vehicles required physical infrastructure from which to obtain positioning information and hence navigate their way through the building. These systems used embedded wires, tapes, magnets and reflectors. "Contour Navigation" uses nothing but the building itself from which to navigate. Whilst moving, the AGV continuously scans the environment using infra-red scanning lasers at each end of the vehicle to obtain distance and directional information. By comparing the scan data with an in-built map of the environment, the software is able to calculate the vehicle's position.

The development and production team responsible for the Quire pace STEERON vehicle have delivered hundreds of vehicles to hospitals Worldwide, and have many years' experience with Contour Navigation systems.

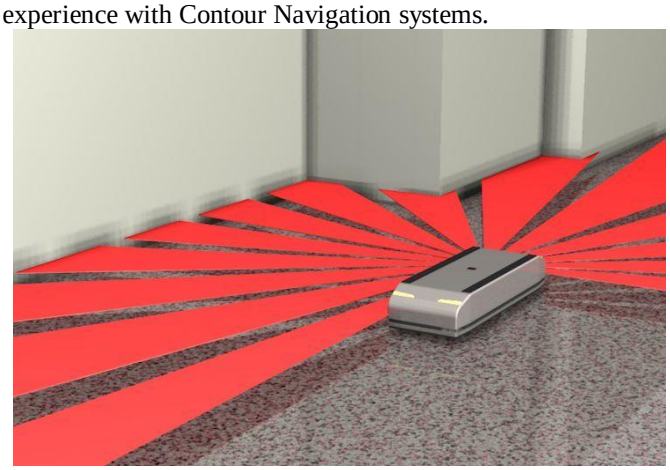

Fig. 4 Navigation System

All the lessons and experience gained in the past have been applied to the new software in order to deliver a solution that is capable of navigating an AGV in a "real world" hospital environment, where some clutter is inevitable. With two scanners continuously scanning the full 360 degree environment, dynamic adjustments within the mapping system make allowance for the inevitable changes and deviations experienced in a live hospital environment, ensuring a reliable and consistent transportation service.

D) Vehicles- The new STEERON vehicle is a development of previous AGV designs. It has a unique "Tractor & Trailer" chassis design which combines the stability of a "tricycle" configuration with the true bi-directional maneuverability of a 4-wheel design. Using small but extremely powerful motors, and the latest compact electronic systems, space has been

made within the chassis for very large battery capacity giving extended range. For example, the latest LiFePo4 battery technology can deliver 120Ah @ 48V – a massive 5.8kWh of storage. LiFePo4 batteries provide the best compromise between safety, (since they are immune from thermal runaway) and the ability to deliver high discharge rates for traction applications combined with fast opportunity charging. The STEERON AGV has 360-degree scanners for safety and contour navigation. Communication for navigation and routing is over WIFI. Manual interface with the vehicle is carried out using tablet or smartphone avoiding the requirement for additional vehicle-mounted screens, while additional up and down looking sensors further protect the vehicles operation and audio and visual signals announce the vehicle's presence to users and public. With compact dimensions, high maximum speed of >4.0 m/s, a payload capacity of up to 900kg and ability to handle slopes of up to 7% even when fully loaded to maximum capacity, STEERON delivers the performance required.

Fig. 5 AGV Used for Patient

E) Building Design Consideration- Doors, Lifts, Access Control Systems, Fire Alarm Systems, Buffer Conveyors, Cart Washers, are all examples of external systems with which the AGV installation might have to integrate with, the backbone of an AGV installation is an Ethernet Network. Some devices have direct data connections, e.g. a Lift Controller may be connected using OPC. Alternatively, local PLC controllers interface the data with digital I/O contacts to send/receive status information to external devices. For example, Door Contacts are usually interfaced in this manner. Fundamental to the performance of an AGV system is the capacity of the transport routes. This will be determined in part by the capacity and throughput of any lifts with which the AGVs interact, and the width of the corridors and streets which the AGVs may traverse. Minimum dimensions and clearances for "Driverless Trucks" are specified in BS-EN 1525:1998 which may influence the building design. Within a hospital it is important at an early stage in the design process to determine how deliveries and returns are to managed within the receiving departments. Questions that might be asked are e.g. "Do we need segregation between "clean" and "dirty" payloads?", and "are we going to deliver directly to the point-of-use, or to a central delivery hub?". Having a clear understanding of the workflow between automated guided vehicles and manual process is of paramount importance. Quire pace's specialists can help guide you through these decisions It is inevitable in a Hospital situation that Fire Protocols and "Cause & Effect" policies are extensive. An AGV system operating in a Hospital becomes part of these policies and the reaction of the AGV system to a fire situation must be determined. Escape Routes, Emergency Lifts, Fire Door actuations are all considerations connected with a Hospital AGV system. Contact Quire pace's specialists to discuss the implications and solutions in detail.

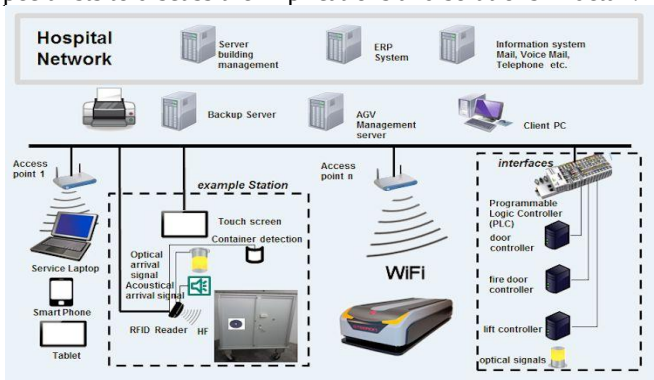

Fig. 6 Overall Hospital Network

IV. 3D Design of AGV Model for Healthcare Facility-

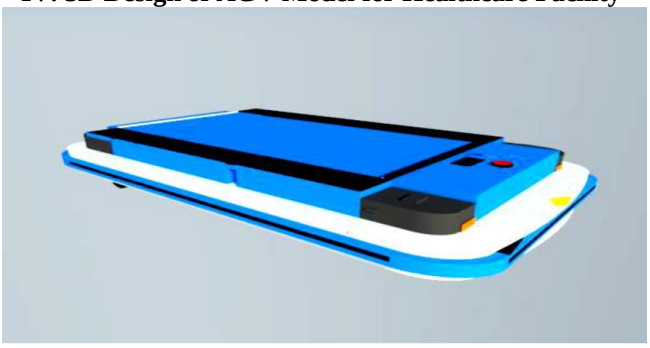

Fig. 7 3D Design of AGV model

The use of automated transport system (AGV) relieves hospital staff and allows them to spend most of their time on direct patient care. This increases safety in the hospital by minimizing potential injury to the staff when pushing heavy carts. The system monitors all major movements in the hospital and may prefer the most important jobs and tasks that can be completed first (e.g. surgical instruments transported first, then food for patients, bedding, eventually garbage, etc.) [3]. AGV is equipped with sensors to detect obstacles that allow safe stop before hitting obstacles that might be in the way. The system and its vehicles is reliable, safe, efficient and cost-effective [4]. Applications and commands are mediated through a user-friendly touch screen. The system is fully integrated for automatic control of doors, elevators, trolley washers, garbage dump truck, etc. This designed 3D model of vehicle, see Fig. 2., has technical specifications specified in Table 1, and we will use it in the simulation model, which verifies its potential implementation in the hospital.

The transport principle will be carried out in such a way that the medical supplies will be transported by special transport boxes that AGV cart undercuts and then lifts up. Fig. 3. describes the principle of object transportation using designed AGV cart. Fig. 3. also shows the key dimensions of the

vehicle and transported objects which are necessary to be observed when transporting boxes.

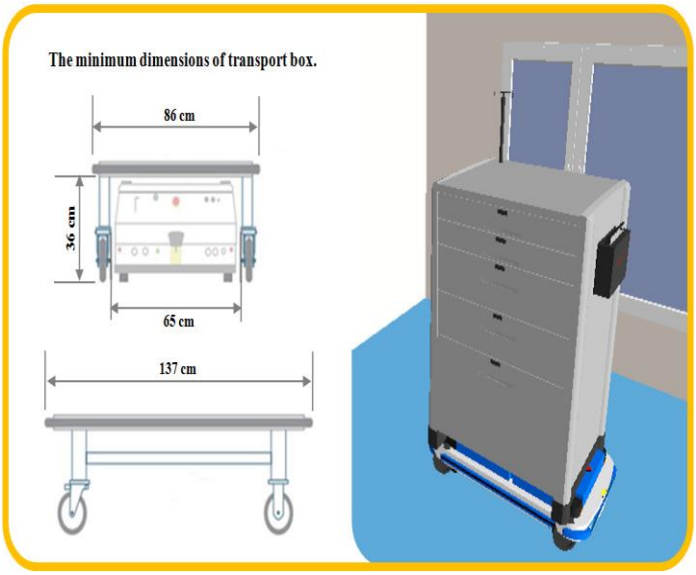

Fig. 8 Transportation Box

Table No. 1 Parameter of AGV

Technical Parameter	Values
Dimensions	130 x 68 x 36 cm
Speed (Max.)	4 m/s
Load Carrying Capacity	900 kg
Battery capacity	200 MAh

V. AGV implementation in a ward of healthcare facility-

In selected healthcare facility we designed AGV integration in the following areas

Food transportation to the patient rooms- This process represents the provision of food transportation from the food arrival, which provides the external company, to the food transportation provided by AGV's to the kitchen, then sorting the meals for patients by healthcare staff and distributing the meals by AGV's to the patient rooms. The rooms have designed areas for precise stopping and unloading food from AGV's.

Collection and transportation of used and clean laundry- Healthcare facility has their external company, which carries away and washes the dirty laundry and delivers the clean one back. The facility can use AGV's for the internal transport service. Transportation would consist of loading the laundry box and transporting it to the desired location (central storage). Transportation through the floors will be carried by freight elevator.

Waste transportation. Waste will be transported from a well-marked spaces and areas from the whole ward. The waste will be collected on these places in special boxes. The AGV's will then take and move the waste.

The visualization of AGV integration in simulation software SIMIO

We used simulation software for verification of our suggested implementations of AGV's in inpatient ward. For this purpose, we used software Simio in which we have imported the real objects and the physical disposition of healthcare facility. Fig. 4. shows the transportation process of food in the ward in digital environment [5,6]. AGV's in this simulation software follows the inpatient ward streams that we have mapped and analyzed (i.e. the movement of medical staff and medical material). Transport between the floors will be carried by freight elevator, see Fig. 4a. AGV's
will then transport the food to a designated location in patient rooms.

Simulation as a decision-making tool-

Simulation in healthcare can be considered as an effective tool, technique or method. Healthcare personnel especially decision makers - directors and managers - need reliable operational tool that supports them in decision-making process. Such techniques and tools help them in reductions of costs, waiting time of patients, future predictions of patient's arrivals and provide them with visualization that enables them to prepare staff and all resources that are necessary for provision of high-quality healthcare service to the patients at the right time [9]. These tools should also facilitate the decision-making evidence and informative environment. Simulation models, especially those with transparent structure to their core variables that can be easily understood and trusted by people with decision-making competence, are a useful tool to support decision-making, communication, discussion, ideas, policies, scenario
analysis, from which they can gain knowledge and from which they can learn. That was also our case, since we needed to create a simulation model of a real healthcare facility that will help the management to decide whether to
implement the AGV system or not. After many interviews with the hospital leaders we have created several models' variants. Whereas the creation and process of a simulation study is very extensive, in the next chapter, we bring and summarize the most important outcomes and results that were the key ones for healthcare managers.

The benefits from AGV integration gained from simulation runs-

AGV integration we were able to save 345 minutes of total 1440 minutes (representing 23.96 %) for medical assistant (MA) per day, this can result in the transfer or movement of medical assistants to activities and tasks that our legislation allows them, so they can spend more time with patients. Furthermore, we were able to relieve the cleaning and transporting services of heavy and dangerous waste by AGV system integration. Among other things, the AGV can be also used for transportation of medicines and medical supplies with low requirements on safety or hygiene. This integration will bring benefits associated with the reduction of damage, unreasonable and incorrect shipments, and physically heavy transport. Another advantage is that the vehicle can operate 24 hours a day while meeting the requirements of charge.

Healthcare Staff-Time Reduction-

Table No. 2 Healthcare Staff-Time Reduction

Activity
Morning Toilet
Blood Test Subscription
Clean Laundry Delivery
Breakfast Delivery
Launch Delivery
Afternoon Toilet
Dinner Delivery
Dinner Preparation
Evening Toilet
Dirty Laundry Transport

Economic Evaluation- This is a rough calculation of operating costs, it gives an approximate idea to the managers of healthcare facilities whether it is good to think about the implementation of this technology.

Table No. 3 Temporary Cost Estimation

cost	price	Used
Purchasing and setting AGV	40,37,009.16	
Installing and marking AGV navigation	58,302.04	Floor marking
Customization of hospital environment	54,05,829.89	Door, Elevator and AGV interface
Total	**9,501,141.09**	

IV. CONCLUSION

This way of transport we subsequently created in a 3D environment where we have simulated and verified the movement of AGV in terms of the physical layout of the building and material flows in the ward. The world's top hospitals, have already adopted this technology and therefore they are reducing operating costs and increasing the quality of their healthcare services, which lead them to rapid cost recovery. However, from our view, Slovakia and its healthcare facilities are not ready to integrate this technology now. The healthcare system is in a position in which he could not benefit from the advantages of AGV systems in a way that the world does. AGV is also a technology, which potential is high but its specific application must be analyzed through several methods of industrial engineering (e.g. simulation). Since many healthcare facilities are deterred particularly by high acquisition costs of this technology. the purpose of the new, modern technology is mainly to help healthcare professionals to work more efficiently and improve the quality of healthcare services. our healthcare facilities want to respond to technology-driven environment of care and be prepared for the future development.

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