Comparison of Hospital Logistics Systems

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Abstract

This paper thoroughly describes the logistics system used in the healthcare system. A detailed overview of the some of the widely used logistic system and methodologies throughout the world is presented and compared them to find the most feasible one and the problems and difficulties emerged in those systems are discussed as well. They were compared in different topics and valid reasoning over their need is given.

Introduction

Health care systems around the world are currently being challenged by growing numbers of elderly people, chronically ill patients and increasing costs of treatment. These factors place significant demands in terms of treatment needs as well as patient expectations, which intensifies the need for healthcare systems to work more efficiently, therefore hospitals have to find out a way to increase efficiency and productivity to treat more patients without increasing costs. The optimization and automation of logistics processes is one of the ways in which the efficiency of resource used in the hospital environment can be improved.

The availability of the high quality health care at reasonable cost for all the needed people is a major hurdle which has to be tackled for health care systems all over the world. The given figures below compare the total expenditure of the several countries on health care sector, in the form of the gross domestic product (GDP) in a different annual year at the span of 12 years.

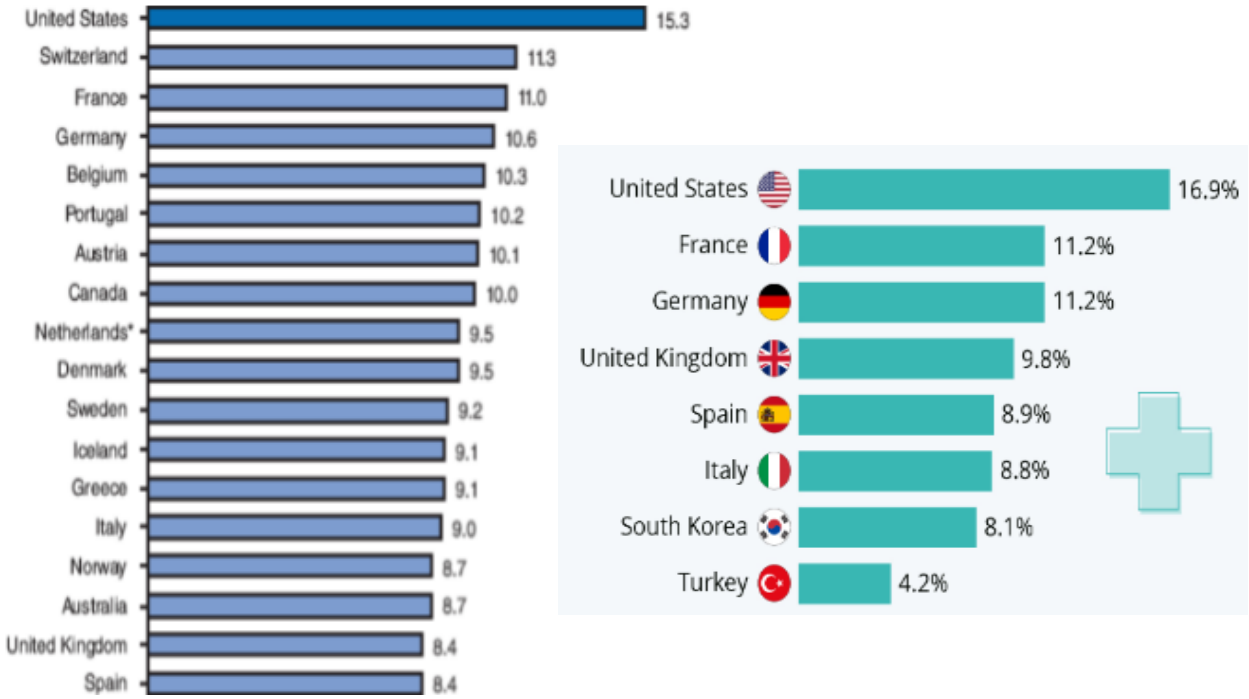

Figure 1: Yearly expenditure of different countries on health care facilities from their total GDP. (A) data of 2006 (B) Data of 2018

In the present time, the rate of spending in health care system has been rising sharply as shown in the chart above. It is mostly because of the expensive health care system, facilities and discovery of the new technologies. The feasible ways to reduce the cost in the health care sector involves having a more effective and efficient resource management likes of health professionals, examination rooms and operating theaters, various kinds of operational machines, medical supplies, surgical instruments etc.

At present, the autonomous logistic system has been an integral part of any of the hospital. To respond the growing demand of sophisticated devices in the care of elderly people, for medicine and blood transportation, immediate health reach and faster service, many researchers have been working on the development of the AGV (Automatic Guided Vehicles), autonomous UAVs, Fast transfer pneumatic tube system and so on. Many products have been already developed and many are on the testing phase. The main concern of their research would be,

1. increasing the robustness
2. improving user interface,
3. improving tracking system
4. developing multi-functional cargo transportation
5. improving electronic system
6. improving sensor mechanism and overall response system
7. lowering manufacturing costs. [1]
8. easing the user manual
9. improving the weight capacity
10. making more precise
11. making more user friendly

we always have to face lots of challenges while designing or inventing something new. The main challenges in designing autonomous logistics system for hospital, are:

1. Safety,
2. Obstacles detection,
3. mapping of the environment,
4. Path planning,
5. Navigation
6. Organization of the logistics,
7. automatic usage of doors and elevators,
8. Wireless communication,
9. Safety
10. Quick transportation
11. Requirement fulfillment
12. Stable transportation

One of the main and usually underestimated services that hospital has is the logistics. Then wain purpose of the hospital logistics system is to organize and maintain a smooth material flow in the hospital. Many different types of materials are importantly needed in a hospital, which results in the complex transportation systems and intricate flow of materials.

Generally, health care resources are not that easily available so the challenge lies in fulfilling their availability with their needs. This right goods and services should be delivered to the patient maintaining right place, right time, a right price, right quality and right quantity which are also known as the ‘five rights’ of logistics. Hospital logistic systems are typically associated with purchasing, carrying, delivering, storing, transporting, and disposing. A research carried out by Beaulieu et al. [1] As mentioned in Quebec (Canada), the activities that involve or related to logistics make over 40 percent of the total hospital’s spending. Which include mobile robotic platforms, pneumatic tube systems, UAVs and even sophisticated conveyors have already been utilized in order to boost the automation of hospital logistics.

Despite their importance, the role of logistics and OM is often overlooked by hospitals and other health care facilities.

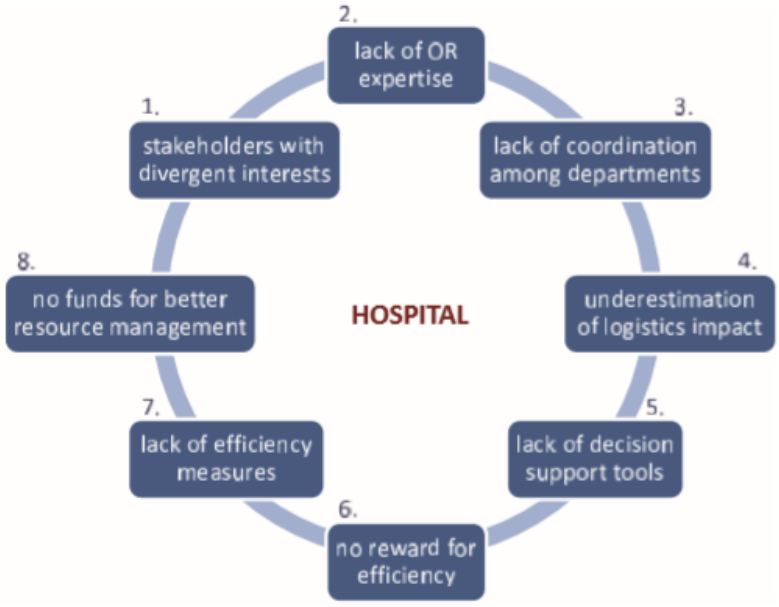

Figure:1 Challenges faced by the operational research in hospital sector

The chart above shows the key factors. Together, they carry out real challenges to operations researchers

The number of patients are increasing because of the increasing specialization of doctors within the hospital and an aging population. The research that carried out in the Netherlands show that approximately 65% of the patients visiting a hospital are multidisciplinary. Consequently, certain special arrangements have emerged for these patients. For instance, some hospitals have special centers in which different specialisms work together on backbone problems. But, the specialisms related to these centers are based on the specialist's perceptions. It also can be said that, they may have a certain sensory knowledge about what specialisms should form a center, which eventually could be also supported by some of the quantitative information (e.g., frequencies of visits), but knowledge expressed in models or rules is missing.

Looking at a broader context, logistics are also concerned with patient flows, planning, coordinating and controlling the resources involved are mainly done by Operations Management(OM). Like in the industrial settings, OM and Logistics are very much related to each-other in hospital. If we decided to do the transportation manually, we usually have to face the limitation of the human work power, perseverance and speed, in that case, upgrading into robotic system comes handy. The robotic system can do the same amount of task a lot quicker and in a feasible way. When there are only human transporters the weight limit, routs and volumes should be planned and considered thoroughly but in the other hand, the robotic transportation system is more flexible. Routes can be optimized, and more frequent deliveries can be planned for both day and night shifts. By the use of tracking system, the speed of the transportation can be improved as well as it would be able to detect the obstacles and the computerized pathways can be used. Staff can save lots of times, which can be allocated to more patient related tasks so the quality of the service provided to the patient can be improved.

The widely used types of hospital logistic systems these days are:

1. Automatic Guided Vehicle (AGV)
2. Unmanned Ariel Vehicle (UAV) transporting system
3. Pneumatic tube system (PTS)

1. AGVs

The use of robotic systems has increased enormously in recent decades. A main driver of this development is their increased processing power and the continuously falling costs of robot labor. The demand for hospital workers is expected to rise sharply in the near future due to aging population. Studies show that, currently, nursing staff spend a large proportion of their working hours executing transportation and patient guidance tasks—accounting for up to 46% of hospital expenses.

There are various prototypes and locally developed products that are successfully implemented and used in hospitals and many are under development too. It is obvious that the use of autonomous logistic delivering system improves its efficiency. Special analysis done by M. D. Rossetti, A. Kumar et.al [2] showed that, if we install 6 robot units in hospital, it reduces the annual cost by approximately 56% and improves turn-around time performance by 33%. Implementing such a system brings several advantages such as:

1. It is cost efficient.

2. Robots never get sick, do not need holidays and work also in weekends.

3. Robots are predictable and do not make human mistakes.

4. An autonomous system can work 24 hours 7 days per week.

5. Hospital personnel can focus on patients.

6. Transportation tasks could be scheduled and done in the night shifts.

There are a lot of items that can be transported within hospital by the use of robotic system:patients, medicines, food, documents, medical devices and waste products as well. Ozkil et al. [15] made a thorough study on things that are transported within the hospitals every day and the manpower that needed for the task. The other tasks include, transportation of the carts which contains linens, laundry and meals.

Evans in [3] presented the system technologies embodied in HelpMate. It is not a self-servicing robot as cargo should be put by humans and destination should be defined by the operators as well. When it finds out the destination point, it defines the path itself. When there will be obstacles on its way, either it goes around the obstacles or waits until the obstacles go away. This mainly carries unscheduled meal trays, lab and pharmacy supplies and patient records. It has sophisticated laser scanners for obstacles detection. But it has drawbacks including manual conformation of product delivery, specific carrying capacity and it is of large size.

Figure 2: HelpMate at operation by one of the hospital officials

Another AGV developed by Swisslog[4] is highly used in hospital transportation System. It is mainly used for the carts transportation. It goes under the carts, lifts them and delivers them in the required destination. But it has to be scheduled and instruct by the humans. It can't just lift any cargos as they have to be high and wide enough for The robot to carry. It can also only carry specific types of cargo only as it can't carry simple items like medicines, foods and documents.

There is a proposed type of AGV by F. Sandt et al. [5] which is an advanced version of the AGV. It uses florescent lamps on the ceiling of the corridors as the natural landmarks to localize the robot's positioning and orientation. It uses single camera to capture the images of the lamps and has holonomic ability to move in the any direction without changing the orientation. It has touch screen interface but it also has manual placement of the items and selection of the destination.

AGV for global pandemic like COVID-19

In this global scale of Pandemic COVID-19 a new design of the AGV was helping hospital officials to disinfect the large area of the Hospital with the minimal risk of virus contamination. Robots were used in Wuhan (where the virus was seen at first) that could efficiently disinfect hospitals using UV light that could slow coronavirus infections.

Figure 3: New disinfectant robot being pulled for the use at the hospital in Wuhan

Hospitals are the virus pit during this pandemic and it is at the top for the places to avoid. Even though it is not recommended to travel to the hospitals during the pandemic, the patients and health care workers really don't have any choice. To keep the hospital safe and stop the spread of the coronavirus this robotic disinfection technology is essential. It can disinfect the rooms and pathways to the hospital and minimizes the risk of virus infection to very low.

It takes only around 10 and 15 minutes to disinfect a normal room, with the robot spending 1 or 2 minutes in five or six different positions around the room to maximize the number of surfaces that it disinfects. The robot's UV array emits 20 joules per square meter per second (at 1meter distance) of 254-nanometer light, which will utterly wreck 99.99 percent of germs in just a few minutes without the robot having to do anything more complicated than just sit there. This process is better than a human cleaning because the robot follows the same path each time, and its autonomy means that human staff can be freed up to do more interesting tasks, like interacting with patients.

The new sophisticated automated hospital logistic transportation system has to fulfill following requirements:

1. *Adaptation to the existing system*: The transportation system remains the same in the global level. In certain types of transportations, logistic systems are used to fulfil existing transporting tasks. Routines remain as they are.

2. *Partial reconfiguration of the system*: Certain tasks are identified, and robots for these tasks are designed for optimal performance. Transportation routines are optimized based on the capabilities of robots.

3. *Restructuring the system*: In order to facilitate system wide optimization, a central stock system is implemented. Various types of materials can be stored in the central stock. The good thing about this system is that it is possible to combine different types of materials at the central stock and send them together; so that number of dispatches is minimized. Various types of robots are introduced accordingly, and routes are optimized for 24-hour operation.

Robot localization is based on ultrasonic sensors and structured light vision in the earlier models and laser scanners in the more recent ones. Ultrasound is still widely used as an additional safety sensor. The researchers also describe a hospital logistics system based on laser triangulation using wall mounted reflectors. To enable autonomous mobile robot operation, the robot's position must be tracked in real time. Indoor environments are particularly challenging for wireless systems because of the inherent severe multipath propagation and high accuracy requirements.

2. UAVs

Unmanned aerial vehicles (UAVs) are being used more and more in today's modern society and it will keep increasing. Their low payload capacity and ability to beat the congested road networks enables them to provide fast delivery services for urgent high-value cargo. The focus of UAV transportation system is to minimize the total cost of implementation likes of battery, vehicle, and hub establishment costs. Many research and study results demonstrate that UAV-based delivery provides significant reductions in operational costs compared with the baseline.

There is a role for health professionals in loading or unloading a UAVs, confirming schedules, securing a loading, landing

There is a role for health professionals in loading or unloading a UAVs, confirming schedules, securing a loading, landing, documenting deliveries; launching the UAV; or instructing the UAV about its next location. All of these procedures would require training and time, so the number of deliveries is important to take in consideration as well.

The cost of manufacturing and use of UAV is quite expensive so it is limited in developing countries. Only light weight deliveries are being carried by the UAVs as the heavy weight carries are super expensive and still under development. But the technology is constantly improving and the flight duration and range are elongating.The cost of UAV operation is directly related with distance and payload, and the value of UAV delivery to health provision has yet to be established.

First of all, the cost of producing the devices is high and their maintenance differ substantially. The management team has to find a feasible and efficient way of maintenance and operation. They have to build a manpower for their operation and technical team for their maintenance and the changes that are needed to carry out. Second of all, they have to find a proper way of operation in the extreme weather conditions because even though UAVs operate in the sky and they don't have to face traffic congestions and bad road condition, the bad and extreme weather impact them.

Figure 4: UAV delivering the first aid in a remote area

The logistic transportation of the system will not be the same after the introduction of UAVs. But, If UAVs are implemented to an existing supply chain field, all the current aspect of what is stocked, transported, and received at multiple locations will have to change to account for method of transport (UAV or other). They have to adapt to the advanced tracking system in the air. The route of the UAVs would be totally different that form the vehicles so the new sets of system have to be developed.

UAVs are widely being seen as an alternative to traditional road vehicles. The integration of UAVs can help reduce operational costs as they are less labor intensive [6]. Moreover, they require significantly less take-off and landing space than helicopters, which are occasionally used for urgent delivery [7]. Battery-powered UAVs also present a reduction in carbon emissions when compared with petrol or diesel-based road transport [8,9]. Most of all, UAVs is alternation to road networks, which are vulnerable to infrastructure damage and traffic congestion.

UAVs are most suitable to provide on-demand fast and reliable inter-urban hospital delivery because of the short distances between hospitals and urgency in delivery. Wen et al. proposed a vehicle routing model that considers blood temperature variation based on the quantity of blood transported and length of each trip [10]. Escribano Macias et al. incorporated energy management and recharge to a location-routing algorithm for drone-based relief distribution [11]
They are increasingly explored as a solution to transport challenges for medical goods, including emergency blood supplies, vaccines, medicines, diagnostic samples, and even organs, particularly for “last mile” delivery.

Since 2016, Zipline has operating drones to work for the Government of Rwanda, delivering up to 3 liters of blood within 30 minutes to health facilities that request it on demand [12]. It has been an essential part of Rwandan Healthcare system. It is arguably the first medical drone used in the world in the working phase. It is much more efficient for the country like Rwanda where blood delivery can be hard because of the inadequate transportation facility.

Figure 5: Zipline Drones being used for medical delivery in Rwanda

Matternet, is another company which has developed medical drones. It has conducted hundreds of test flights in Switzerland, routinely transports laboratory specimens within a North Carolina health system [13]. Alphabet’s Wing is another company which will soon be delivering over-the-counter medications, via UAV in Canberra, Australia, after a year and a half of test deliveries [14]. However, none of these drones are being able to work on the large scale and people are still hesitant about using autonomous system over human delivery system.

UAVs outperform road-based transport modes compared to energy and traveling costs. The inclusion of vehicle maintenance and labor costs should further increase cost savings as UAV networks require fewer personnel for that task. Moreover, if a carbon emission charge is imposed by the government, additional financial savings would emerge from using battery-powered UAVs. Hub location and payload capacity emerge as the most significant

factors conditioning overall system cost between UAV platforms, provided the UAV range is sufficient to travel to each hub and hospital. Payload capacity is highly dependent on expected demand.

A strategic plan to upgrade the efficiency of hospital operations has yet to be proposed. To address this gap, an optimized model is presented that can be used to design a UAV delivery network for hospital deliveries. In doing so, the model minimizes drone travelling time, battery consumption levels, vehicle investment, and infrastructure costs. The trajectories designed between hospitals confirm to the latest air traffic management regulations.

3. Pneumatic Tube System(PTS)

Pneumatic tube system (PTS) is an indoor logistic system in which cylindrical containers are pushed or pulled through a distributed network of tubes by fans. It can be used for rapid transportation of small valuable objects in hospitals where the safety and speed in a local environment is vey important. It is used for rapid transportation assisting the existing intra-logistics of a facility. It is an especial logistics transportation system and this system uses pneumatics as a power source, which is controlled by computer based CAN-bus system. With the help of the design of reasonable structure, CAN protocol and control arithmetic, this system could implement the task to carry goods between systems or within system correctly [15]. So, PTS plays an important role in modern hospital delivery system.

The use of a pneumatic tube delivery system for transporting small items likes of blood samples, fluids, liquid drugs e.tc from the emergency department to the laboratory can significantly reduce the turnaround times of results without a reduction in sample quality [16]. The PTS has been reported to be a rapid and reliable method of transporting small materials such as specimens and medications between hospital departments, thereby eliminating the need for human couriers. By PTS installed in a hospital, blood samples, drugs, injection vials, disposables, X-ray films, reports etc can be safely and speedily moved from one station to another one, and the attending staff shall have no more time to wait for other staff to run from place to place to perform errands and carry supplies. Therefore, this delivery technology has been developed rapidly and been used in hospital in the advanced countries in the world.

PTS is an innovative means of transporting services in modern hospitals. It is driven within tube system by fans. With the help of Mechanical Electronics Technology and Computer Control Technology, the PTS connects the Nurse Station, Operating Room, Medicine Distributing Center and Sample-Test Section etc. within hospital. PTS for transportation of blood specimens may present with advantages for hospital organization as it provides faster tube transfer from medical wards to routine labs. These characteristics are expected to result in faster sample processing and decreased turnaround time, therefore benefiting the patient particularly in emergency units.

Figure.6: Structure of pneumatic hospital tube delivery system

The typical PTS includes blower, blower transfer, throttle, station, 3-way diverter, transfer center and blood platform. And these devices will be installed in a hospital building and its relational rooms, which are connected by tubes. This typical pneumatic hospital tube delivery should contain one blower unit, several 3-way diverters and many stations. The blower unit constituted by blower, blower transfer and throttle can produce variable thrust or suction. The role of diverter is to create the possibility of extending tube network in many directions, so that the

carriers can reach all the destinations of the system. The station is the custom end for sending and receiving carriers. There is practically no limit on the number of stations that can be connected or the distance that it may need to cover, if the blower is powerful enough. Usually, one system is connected to other systems by direct linkage between diverters or through transfer center. And the open link ends in the system are used for adding new stations and tubes.

The blowers and transfer units are controlled and monitored by a central processor that has stored the required transaction data. The computer directs carriers to their destination via the shortest, most direct route available. The carriers are constructed of a translucent plastic with a 37.5-cm inside length and have a nominal load capacity of 1.25 kg. Molded foam-rubber inserts prevent movement of collection tubes within the carrier The carrier can be inserted into the system in either direction but cannot be inserted unless the two sections are securely latched.

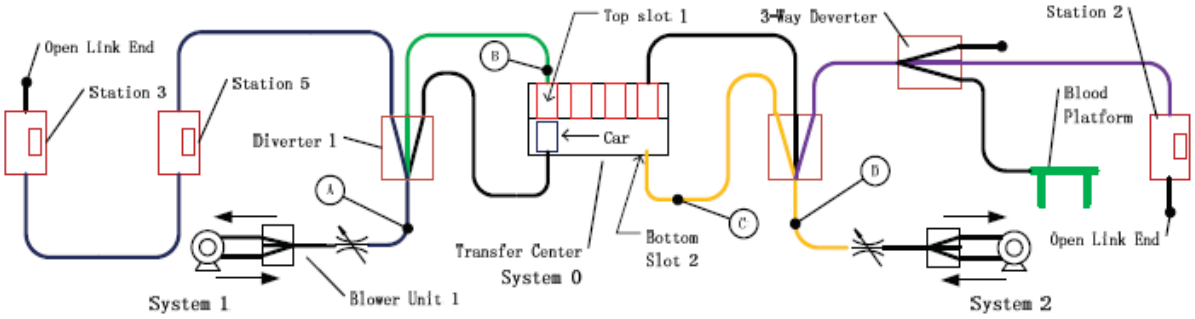

Figure.7: Topological structure of a typical pneumatic hospital tube delivery system

Since PTS is a centralized control system, the complexity of the software becomes the main challenge for the designers. The software has to control the carriers' transport process automatically and correctly, detect and handle the system exception, record the system status for further error diagnosis and information statistics, response to the maintainer's operation. In order to meet these requirements, three kernel modules are developed in the back-end including Scheduler, Monitor and Error Handler. Monitor's responsibility is to watch and record the system status. When an exception is occurred in the system, Monitor selects Error Handler to do some system recovery including sweeping the tubes and resetting the system. Otherwise, Monitor chooses Scheduler to serve requests. We develop a non-preempt priority-based algorithm for requests' scheduling. After the series of experiments carried out, researchers found that, no breakage, spillage, or leakage occurred in any of the tests. So the PTS is a very good way to transfer small hospital logistics from one place to another.

Comparison between the Hospital logistic systems

The three of the logistic systems are thoroughly described above. They have some very good advantages and some shortcomings too. They are different in nature and their service process is different as well. Every new technology can be beneficial in some sort but better among them has to be find out from the comparison.

Characteristics	**Automatic guided vehicle (AGV)**	**Unmanned aerial vehicle (UAV)**	**Pneumatic Tube System (PTS)**
Application	Very good for inter hospital transportation and overall delivery	Very effective for distant delivery and faster remote response	Fastest way to response in inter-hospital delivery requirement where service needs to be immediate

Ease of use	Most of them are manually instructed but delivery and path planning can be autonomous	Manually instructed and chosen destination but delivery can be autonomous	Most of it is manual but the process of delivery is computerized
Cost of implementation	Robotic system is costly at first but it can be cost saving in the end	They are usually small in size and not so costly compared to AGV and PTS	Very costly to design and operate the system, but very effective
Overall accuracy	Very accurate as it has many sensors and obstacles detection techniques	Accurate, as it is manual instructed and destination can be followed by the coordinates	Accurate most of the time but it works form the power of pneumatic and the system is very complex. there are still many researches going on to make it more accurate
Remote use	It is mainly used in closed area and inter-hospital use so not so useful for long distance and remote delivery	It is meant for remote delivery	It is same like AGV, only for inter-hospital use
Nature of cargo	Can be from small items up to very large boxes and things	Usually small items likes of blood samples and first-aid kits	Miniature items likes of blood samples, vile samples, reports e.t.c
Service duration	Turnaround time is slow compared to others because it has to take care of the surrounding and avoid obstacles while moving	Turnaround time depends on the location of delivery and the payload. Usually the location is in remote area so slow	Turnaround time is very fast as it uses pneumatics to operate and no obstacles in-between
Human assistance	Many of them need but some totally autonomous AGV are also out there	For loading and unloading always needed	Same as UAV, needed for loading and unloading
Problems	Has to work in crowded places with lots of people so the preciseness is still the question	Can be affected by the weather conditions likes of rain, wind, snow lightning and so on	A simple problem in the tube or leakage can hamper the whole system

Post processing requirement	Autonomous delivery and self-return to the station	Most of them need human assistance to receive and manage the cargo but return to the station can be autonomous	Need human assistance for both loading and receiving of the cargo
Futuristic	A very futuristic concept where cargo would be handled totally by the robots without human assistance	After increasing the range and payload capacity, it could be the best remote delivery system	Very supportive for the fast delivery of the cargo but to be totally autonomous, still very hard

Discussion and Conclusion

As the healthcare system is being more and more advanced and the number of patients visiting hospitals to take healthcare service is increasing as well, the hospital cargo is increasing in a rapid volume as well and their proper management is very important. As everything being modern and sophisticated, the cargo delivery service also needs to be modern and sophisticated. So the machinery cargo delivery system is imminent. As the comparison above, three cargo delivery platform have their own way of operating system and they are very different in nature but all of them are equally important.

AGVs are very helpful for inside hospital transportation and heavy cargo delivery which usually don't have any time limit. They can be autonomous, so many of them can pick up the cargo, design their own path, deliver and come back to station for next task. It is very helpful for hospitals where the flow of cargo is very heavy and continuous precious transportation is needed. It can also be used to transfer the disabled people from one place to another place with much consideration.

UAVs are very effective for remote transportation of the cargo where other means of transportation seem very hard to use. It can be used for immediate response at the remote places where patients need quick help. It is way quicker than the human delivery of the cargo. it doesn't have to face the problem likes of road congestion or, flood or road blockage but external environment conditions likes of rain, wind and snow can be problematic.

PTS is very useful for inter-hospital delivery where the immediate cargo delivery is mandatory. Some of the items likes of blood or some other fluids have to be delivered in an immediate notice and human errands to the blood bank or their location is time consuming, in that case PTS is the best solution and it can save many lives which are in critical condition. Still the concept is fairly new and it is very complex to implement and operate, but it is being used more and more.

We can't state which one is more important and which is less important as all of them are equally important and we can't just have one and avoid others. In the future of healthcare all of these platform are very important and other means of platform will also be slowly discovered.

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