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Review on Automated Storage and Retrieval System for Warehouse

Alex Low Kai Jie[1], Sim Kok Swee[1*], Lew Kai Liang[1]

[1]Faculty of Engineering and Technology, Multimedia University, Malaysia

**corresponding author: (kssim@mmu.edu.my; ORCiD: 0000-0003-2976-8825)*

Abstract - The swift expansion of e-commerce and supply chain operations has significantly enhanced the efficiency of warehouse management systems, establishing them as vital components in augmenting organizations' competitiveness. This paper delves into warehouse sorting systems to enhance the sorting process, reduce error rates, and simplify internal warehouse procedures. It aims to develop a scalable, adaptable, and efficient warehouse sorting system that can maximize sorting efficiency while effectively responding to changing market demands through the use of advanced automation technologies. The study provides an in-depth review of the literature that has explored the Automated Storage and Retrieval System (ASRS) within the context of warehouse operations. It offers a comprehensive introduction to the operational systems of warehouses, detailing each type of ASRS along with the technologies that can improve the efficiency and accuracy of these systems. Moreover, the paper thoroughly investigates and classifies the ASRS design decision problem and compares multiple types of ASRS. The analysis aims to delineate the distinctions among various ASRS configurations, assessing their scalability, adaptability, and their impact on operational efficacy in warehouse environments Through this comparative review, the paper emphasizes the potential enhancements in sorting processes that modern ASRS can provide, ensuring that warehouse operations can rapidly adapt to market changes and demands. The goal is to highlight best practices and technological innovations that can lead to more responsive and efficient warehouse management systems. This exploration contributes to a better understanding of how cutting-edge automation and adaptable system designs can significantly influence the efficiency of warehouse sorting processes.

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Keywords— Warehouse Automation, ASRS Review, Smart Warehouse, Material handling systems, Automated Storage and Retrieval System

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1. INTRODUCTION

As industries around the world have continued to become increasingly advanced in technology in recent years, the Automated Storage and Retrieval System (ASRS) has become more important in the realm of warehouse management and logistics [1]. By comparing traditional manual methods, an automated storage and retrieval system employs robotics and software to automate the storage and retrieval of goods or materials. One of the most popular material

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handling systems, ASRS, is utilized extensively in automated production settings and distribution centres. ASRS is characterized as a mechanized storage system that conducts the depositing and retrieval of goods under the precise control of operators, exhibiting high accuracy and swift movement. The system's performance is largely contingent on the storage configuration and the method of materials handling employed.

Fundamentally, computer control is the primary controller method used by ASRS to perform out-collecting and placing tasks on specific storage locations. There are many different types and layouts of the ASRS system in the world such as vertical carousel, horizontal carousel, vertical lift modules (VLM), vertical buffer modules (VBM), crane-based mini-load ASRS and so on [2]. The mechanism moves to the designated place to pick up the commodities and then transfer them to the operator. This is the basic operation concept of ASRS. Depending on the kind and command supplied to the system, many deposing and retrieving tasks can be completed at the same time. ASRS enhances efficiency by minimizing the need for manual labour, optimizing storage space, and reducing errors in inventory management. The entire process is managed and monitored through a central control system, ensuring accurate and rapid storage and retrieval of goods.

2. LITERATURE REVIEW

2.1 Background of warehouse

According to a study by Robert Reman [3], a facility that is placed strategically and intended to serve beneficiaries as quickly as feasible is referred to as a "warehouse". Receiving, storing, and preparing items for distribution to recipients are the functions of a warehouse. Logistics-related features of a warehouse include the fact that storage does not change the value or condition of a product in any way. Warehouses are normally used by importers, wholesalers, manufacturers, exporters and transport businesses. It is normally structured as a large building and normally located on the outskirts of towns and cities [4].

In the early days of the time, the warehouse was invented because people required a place to store the goods or products during the trading process. The demand for warehouses usually means that there is a large amount of goods that need to be stored in domestic storage rooms [5]. During the time of the industrial revolution, the warehouse had become more specialised for doing business and more features were developed in the warehouse. Modern technology, supply chain standardization, and modifications to procedures mean that warehouses serve more purposes than just housing retail spaces. A growing number of warehouses were constructed in the 18th and 19th centuries. For transportation convenience, they are typically found close to railroads and port areas. Figure 1 shows an example photo of a warehouse in the 18th and 19th centuries.

Figure 1. Example Photo of a Warehouse in the 18th and 19th Centuries [5]

In today's environment, loading docks are typically utilized in warehouses to facilitate the loading and unloading of cargo from vehicles. A portion of the warehouses is built such that cargo may be loaded and unloaded straight from airports, railroads, and seaports. Forklifts, conveyor belts, and cranes are some of the mechanisms utilized in the warehouse to move items. Usually, these items are organized on pallet racks or heavy-duty racks, which are essentially multilevel.

A fully customized functional warehouse is needed to enable businesses to stockpile goods. As a place to store goods, the warehouse needs to be safe, convenient, and as wide as possible, depending on the owner’s resources. Before technology became common in industry, the operation of a warehouse relied on human force, such as using a pulley system for mechanical lifting.

The warehouse is just a big building with a row of shelves inside in the early back. However, most warehouses are fully automated and require a few operators only nowadays. This type of warehouse has a specific name called “Smart Warehouse”. Smart Warehouses revolutionize traditional storage spaces with advanced automation. Unlike basic warehouses, these employ interconnected technologies for heightened productivity and efficiency. Automated order processing, stock confirmation, and robotic order fulfilment are seamlessly coordinated through a sensor network. This innovation reduces manual labour, minimizes errors, and allows human workers to concentrate on optimizing overall efficiency. The Smart Warehouse marks a significant leap toward a more streamlined and technologically advanced era in logistics [6]. Pallets and goods are lifted and placed on the automated conveyor for transporting, ASRS which functions automatically placing and retrieving loads will be coordinated by computer logistic software and programmable controllers to carry out this action. These systems are usually operated in an environment which is cold or hazardous to human force is nearly impossible [7]. But with the ASRS, the problems can be resolved. In figure 2, it shows the warehouse in supply chain.

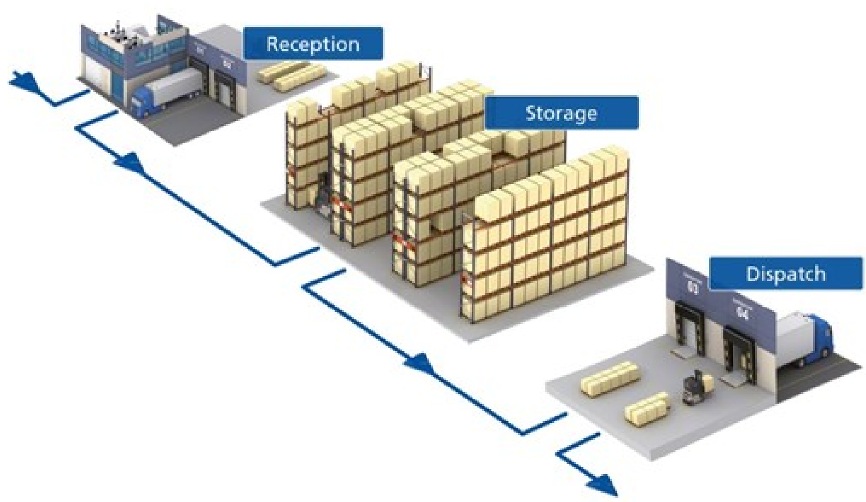

Figure 2. Warehouse in Supply Chain [7]

2.1.1 Material Handling in the warehouse

Since the programming layout controls the complete flow of materials or items between the production system's operations, material handling is regarded as one of the most essential designs in most systems.

Warehouses, bustling with activity and potential hazards, require the right material handling equipment to ensure safety and productivity. The material handling equipment is used to navigate the challenges of handling and transporting such as lifting heavy loads. There are several types of material-handling equipment which are often used in a warehouse [8].

•Pallet Jacks

The pallet jack or name as pallet truck is a device that has twin forks. They can slide under pallets to allow easy lifting and moving pallets. A pallet jack is a type of basic forklift that can make humans easily transport heavy stacks as shown in Figure 3.

Figure 3. Pallet Jack [8]

•Order Picker Forklift

Order Picker Forklift is a powered industrial truck. It is designed to aid in picking and transporting materials needed for orders. These forklifts lift operators to the inventory level, enhancing efficiency and safety. Figure 4 shows the order picker forklift

Figure 4. Order Picker Forklift [8]

•Automated Guided Vehicles

Automated Guided Vehicles (AGVs) are more effective than traditional manual methods for material handling in several ways, including increased speed, precision, and safety. They can work continuously, which allows the warehouse to process more goods and spend less on manpower. They may also be programmed to go along predetermined pathways, which can lower the possibility of crashes and other accidents. Figure 5 shows the automated guided vehicles.

Figure 5. Automated Guided Vehicles (AGVs) [8]

2.1.2 Order Picking

Order picking is characterized as the approach toward grouping and booking client orders, transferring out stock, releasing requests to the floor, and gathering and shipping out the packed goods. Order picking is the most noteworthy need activity in warehouses and distribution centres for efficiency improvement [9].

There are 2 main reasons for this concern. Firstly, this procedure is one of the most exorbitant actions in the supply chain system. It was found that around 55% of all expenses are related to order picking. Secondly, with the initiation of the new operating system and the requirement of customers' needs, smaller orders are requested to be delivered more frequently based on the customer's needs. This will eventually cause more stock streaming units (SKU) to stream into the order-picking system, which makes the procedure progressively harder to handle. Besides that, quality control which is charged by the workers in the warehouse and distribution centers is regulated more strictly to ensure that the damage to the goods is minimized, fulfillment times are reduced and improved in picking accuracy [9]. In this case, capitalisation of service level to resource limitations such as capital, and device system is the general goal for the order picking system [10].

With the ease of technology nowadays, more and more companies are equipped with advanced materials handling systems. A few principles are carried out by the company to ensure that the systems work at their top performance without delaying any orders which will affect the later process. Pareto’s law (also known as 80/20 rules) is one of the most common techniques used in many companies, businesses and manufacturing sites. The principal states that 80% of the effect comes from 20% of causes. For industrial sites, it is evident that most of the inventory is attributed to a small number of SKUs. This concept also can be used in other features such as demand and space utilization.

The next principle which is commonly seen in the industry is to combine and eliminate order picking jobs. Order picking involves a few activities such as travelling, documenting, reaching, sorting, searching, extracting and counting. These activities are included in the order picker time. To reduce the total pickup time, the elimination and combining of a few tasks together will enhance the order-picking activities. Table 1 shows the method to reduce and eliminate unnecessary movement in the task.

Table 1. Method on Elimination of Unnecessary Movement [11]

Work element	**Elimination method**	**Equipment needed**
Travelling	Bring the pick location to a picker	ASRS system
Documenting	Automated information flow	Computer / Light aided order picking and automated identification system
Storing	Assign one picker per order and one order per tour	
Extracting	Automated dispensing	Robotic order picker

Another principle which is commonly seen is that placing the goods has high demands on storage location where the machine is easy to access. Pareto's law can be seen in this principle such that the picking times are greatly reduced which will eventually increase the total productivity of the task. The path of the picking system must be calculated, and sufficient space must be provided to avoid congestion during tasks transporting. Besides arranging popular items in an accessible location, the correlation between several goods also needs to be taken into consideration. Normally, various goods are always requested together by customers. By assigning correlation items together, it will greatly reduce travel time [12].

2.2. Storage Racking System

Since storage racking systems can facilitate faster warehouse operations, they are frequently seen in warehouses and distribution centres. Warehouse managers can optimize storage space and improve warehouse organization for picking process efficiency by implementing an appropriate racking system. The arrangement of the warehouse has a big impact on storage racking. Aisle width, docking position, shipment areas, and warehouse components are some examples of factors that may often impact storage racking alternatives [13].

Pallet racks commonly are referred to as materials handling systems or storage racking systems. They come in a variety of forms. Larger racking systems are made up of shelves arranged at various levels coupled with metal, wooden, skids, or plastic pallets. Decking bases come in a variety of widths and dimensions to support the materials and commodities arranged on the storage racks. When placing an item into storage racking, which is often several meters high, forklifts are needed. In warehouses, a few different kinds of storage racking systems are employed. The most popular type of storage racking system used in most warehouses is selective racks. This system works well in warehouses with conventional systems, deep-reach systems, and narrow aisle racking. A narrow lift truck is operated between the sides of the selective racks which functions to place and retrieve products on the racks [14]. In figure 6, it shows the selective racks.

Figure 6. Selective Racks [13]

Push-back racking systems are also frequently used in distribution centres and warehouses as shown in Figure 7. It is typically utilized for large storage, holding two to five pallets. The old pallet is pushed behind as fresh products are put onto it, leaving the front unoccupied. The rear pallet will push back toward the front of the system after it is emptied. Push-back racking systems often have sliding carts and inclined rails, and they make use of the last in, first out (LIFO) method [15].

Figure 7. Push-back Racking System [15]

High-density merchandise can be stored in drive-in and drive-through racks. Typically, steel-type materials are used in the construction of this rack's framework to support the weighty goods. This mechanism is specifically designed to allow the forklift to enter its berth. Drive-in racks and drive-through racks vary in that the former can access both sides of the bay, while the latter has just one entry and exit at the bay. Drive-through systems employ the first-in, first-out (FIFO) procedure, whereas drive-in racks use the LIFO approach, which is often utilized for non-perishable goods or products with low turnover [16]. In Figure 8, it shows the drive-in and drive-through racks.

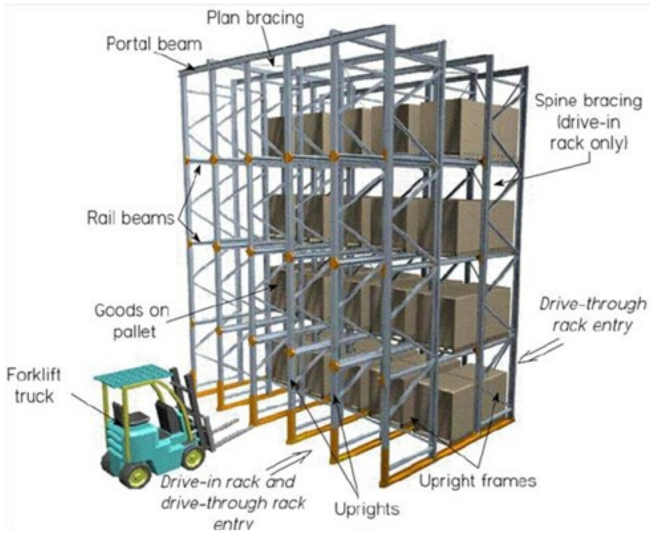

Figure 8. Drive-in and Drive-through Racks [16]

Flow rack, often referred to as gravity rack, is typically utilized for high-density storage. This kind of storage racking system uses the FIFO method. The top of the rack is loaded with items, which are retrieved at the end of the rack. When loading and unloading are done, the rotation of the objects happens automatically. The gravity rollers that move in tandem with the rack load are utilized by flow racks. To direct and control the movement of the object, the system additionally has brakes and speed controls. The primary benefit of flow rack systems is that they do not require an electrical source to function because gravity is their primary force [17]. Figure 9 shows a stack of flow rack.

Figure 9. Flow Rack [17]

2.3 Automated Storage and Retrieval System

An automated storage and retrieval system is a collection of devices that work together to handle duties such as handling, storing, and retrieving objects at a specified automation level that must be completed promptly, precisely, and accurately. According to an article written by Amalie Nordeide [18], ASRS represents a transformative approach to warehouse management. A completely automated system for product storage and retrieval is provided by ASRS. Assisting with initial supplies, semi-finished items, and final products, the ASRS functions are in both production and distribution environments. The main components include aisles, racks, cranes, input/output points, and picking stations. Cranes, often automated storage and retrieval machines, play a crucial role in allocating and retrieving goods, while input/output points facilitate the movement of goods into and out of the system. Figure 10 shows the warehouse with ASRS.

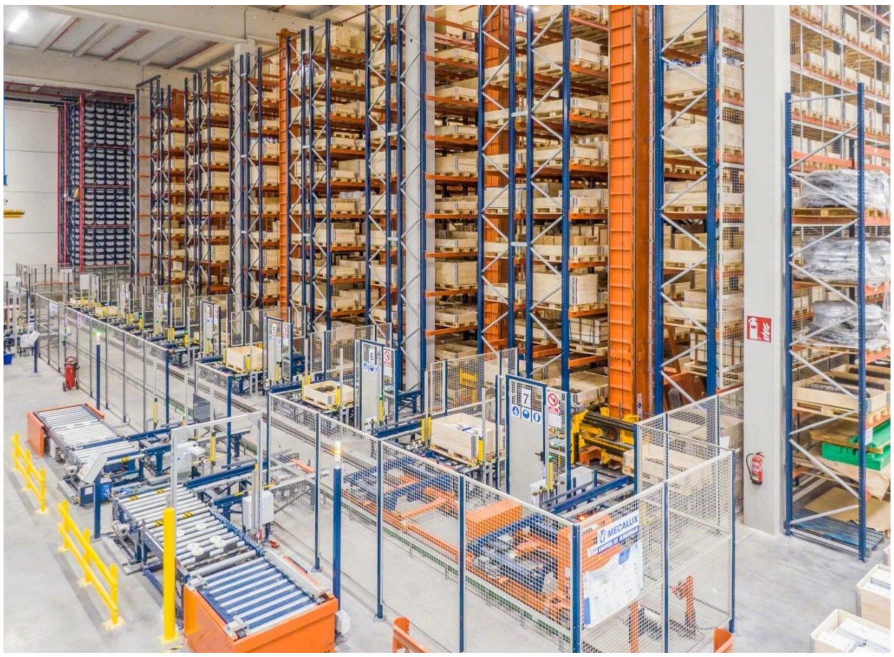

Figure 10. Example Photo of Warehouse with ASRS [18]

According to an article by Roodbergen [19], the growing need for ASRS is evidence that the process now in place is very beneficial to the warehousing industry. Using ASRS has two main advantages: it increases storage capacity and enhances operator performance. This is a result of the ASRS mechanism's ability to reach high places due to operator-controlled control systems. To complete tasks like picking and packing supplies, operators will just need to establish a connection with the ASRS controller [20]. The ASRS system will be able to trace every piece of merchandise that is placed on the rack, including its position, source, and duration it has been there. To optimize storage capacity and reduce floor space, multilayer racks are integrated into the production site. In addition, it eventually lowers the overall cost of labour and operations by reducing the number of workers in the production area. It has also been discovered that employing ASRS will increase inventory security and decrease product damage [19].

2.4 Type of Automated Storage and Retrieval System

The ASRS comes in many types and categories. There are two main types of ASRS. The first main type of ASRS is called a unit-load ASRS crane [21]. A unit load system is usually used in carrying heavy goods or materials whose weights are between 1000-5500 pounds. This kind of system performance enables the handling of pallets and complete or partial packages. [22]. Unit-load ASRS typically consists of narrow aisle racking that may be extended to heights of over 100 feet. When necessary, pallets and other items can be placed and retrieved using the crane that is attached to these racks [23].

A unit load system is usually used in carrying heavy goods or materials. This technique is typically used in warehouses or distribution centres where pallet-level storage is scarce and retrieval times are crucial. Fixed-aisle and movable aisle cranes are the two main types of unit-loads ASRS. The primary distinction between the two is the movable aisle crane's inability to be fixed to a certain aisle. This makes it possible for the mechanism to operate at many aisles [24]. Figure 11 shows the unit-load ASRS

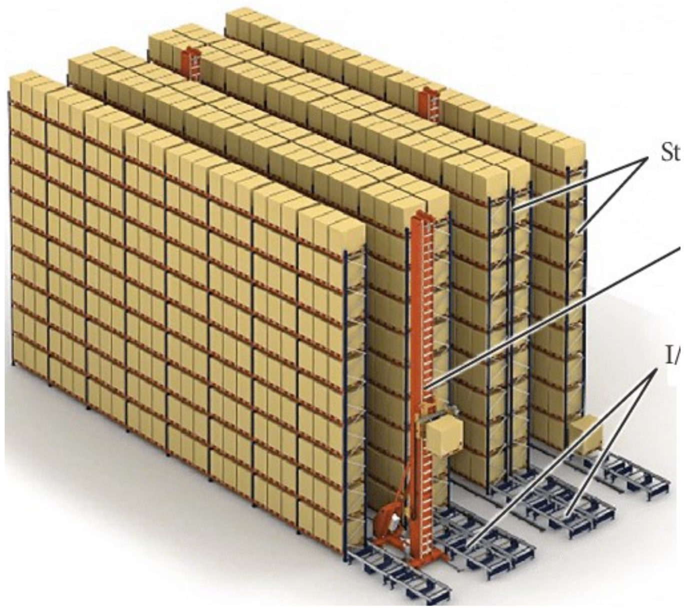

Figure 11. Unit-load ASRS [22]

According to an article written by Gopal [25], an automated vertical lift module that is board-controlled is called a Vertical Lift Module (VLM). An inserter and extractor are located in the middle of a VLM, which is housed in an enclosed structure with a row of trays on either side. This system is a system of goods-to-person machinery. The inserter or extractor will detect the location of the tray requested by the operator, retrieve it, and send it to the operator to complete the order. Once the task is completed, the VLM will return to its initial position while waiting for the next order. Trays in this system may be either fixed or dynamic [26]. In Figure 12, it shows vertical lift module.

Figure 12. Vertical Lift Module (VLM) [26]

The next type of system is called Mini-load ASRS. Based on the study by Rie Gaku [27], In comparison to unit-load systems, this system typically handles lower loads (weights of about 80 pounds). Mini-load ASRS handles totes, trays, and cartons in addition to complete pallets and commodities. This method is typically referred to as a "tote-stacking" or "case-handling" system. This system is appropriate for operations that need to store a very large number of Stock Keeping Units (SKU). To efficiently buffer and release the products and products to the picking station, the mini-load ASRS system is also utilised. The system works similarly to a carton-flow system in that it will automatically replenish the pick spot. Figure 13 shows mini-load ASRS.

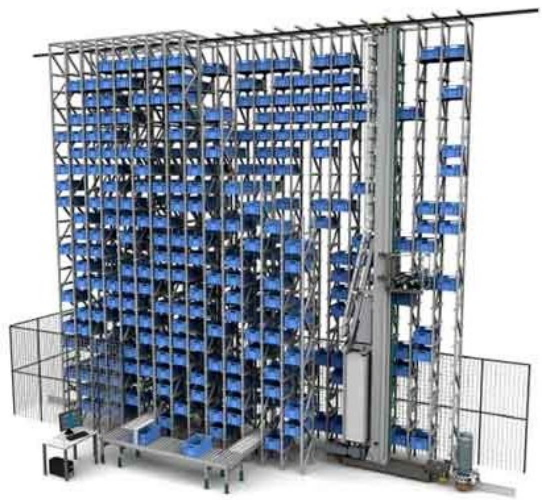

Figure 13. Mini-load ASRS [27]

Shuttle-based ASRS systems are also common and can be seen in warehouse systems. This system delivers inventory and goods via a shuttle that moves on a track between a racking structure. The system can be powered by a capacitor or battery. Operators control the shuttle to move to the requested location and retrieve the carton or tote that contains the required items. After that, it will be placed onto the conveyor or directly transferred to the workstation [28]. Figure 14 shows the shuttle-based ASRS system.

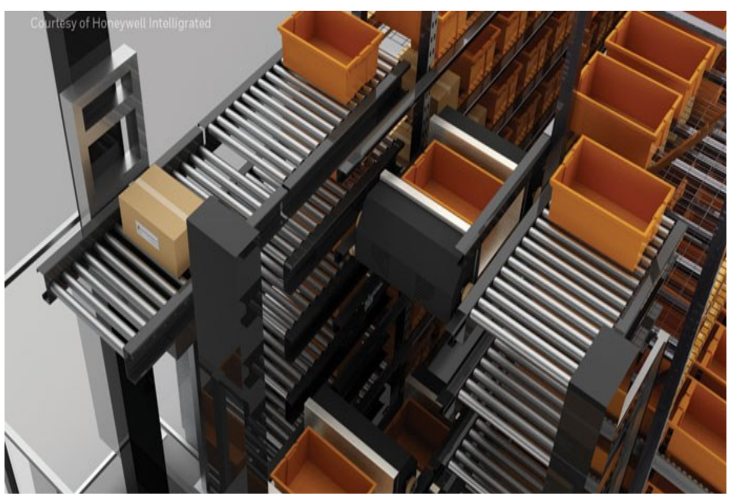

Figure 14. Shuttle-based ASRS [28]

3. ASRS DESIGN CONSIDER

ASRS is categorized based on rack and crane configurations and the type of handling. Besides that, there are 5 main classes of problems that are categorized under the ASRS design decision problems. The class of problems included system configuration, storage assignment, batching, sequencing and dwell-point problems [29] as shown in Table 2.

Table 2. Classification of ASRS design decision problem [30]

Class of Problem	Decision to made
System Configuration	• Number of pathways • Length of pathway • Height of the storage rack • Number and location of I/O point • Number of cranes per pathway • Number of orders pickers per pathway
Storage Assignment	• Number of storage classes • Assignment method • Position of the storage classes
Batching	• Type (static or dynamic) • Size (capacity/timebase) • Selection rule for assignment of orders
Sequencing	• Sequencing restrictions • Type of operation (single/dual) • Scheduling approach (block / dynamic) • Sequencing method
Dwell-point	• Type (static/dynamic) • Location of idle crane will be placed

An ASRS efficient design is a complex issue that includes several crucial decision-making components for the system's functionality. A thorough characterization of the important design choices needed to create an ASRS [31] is shown in Table 2.

The system configuration is the framework used in the ASRS. Determining the total capacity and footprint of the system requires making decisions on the number and length of paths as well as the height of the storage racks. The accessibility and throughput of the system are directly impacted by the quantity and position of input/output (I/O) points. The number of order pickers and cranes per pathway both play a crucial role in determining the retrieval and storage rates, which in turn affect the system's responsiveness. The storage assignment involves decisions related to the internal organization of goods within the ASRS. The number of storage classes, their assignment method, and their positioning determine the effectiveness of the ASRS to accommodate varying item sizes and demand patterns. This stratification aids in optimizing retrieval times and storage density [32]. Batching decisions, whether static or dynamic, play a pivotal role in order consolidation efficiency. Static batching tends to be predetermined and can be more straightforward to implement, while dynamic batching is responsive to real-time order flow but requires more complex algorithms to manage effectively.

In the field of sequencing, order fulfilment becomes more important. For order cycle time to be as short as possible, batch size or capacity, order assignment guidelines, and sequencing constraints are all essential. The response of ASRS to incoming orders is contingent upon the type of operation (dual or single) and scheduling approach (block or dynamic). The sequencing technique which establishes the retrieval order of objects has a direct impact on the efficiency of the system. To maximize response time for the subsequent retrieval or storage task the dwell-point consideration also includes figuring out where to put an idle crane. The cranes' average travel time can be greatly impacted by the choice of either a static or dynamic dwell-point strategy.

A storage system's long-term scalability and flexibility are determined by the complex trade-off between these options and its immediate operational efficacy. In-depth analyses of each of these factors' effects and interdependencies will be provided in this paper as it explores deeper into each one.

4. COMPARISON

ASRS is essential for accurate and effective inventory management. ASRS is developed and assembled from several configurations to meet specific storage requirements, performance, criteria and operational characteristics according to the class readings. Table 3 provides an analytical comparison of three types of ASRS: Multi Drawer Cabinets, Mini

Load, and ASRS Vertical Carousel Storage. When comparing three ASRS types, the values of systems performance, life span, and cost, as well as floor space utilization, are included. This side-by-side comparison illustrated the relative merits of each system and the critical elements that will determine which ASRS is the best solution for a diverse set of logistical needs.

The floor space is one of the most critical factors to consider when designing a warehouse. It must be product operational efficiency and cost-efficient space. When operating the floor space, the overhead can be minimized, and the object can be stored. This is one of the most critical factors for operational product management and operational planning. Storage space is an essential aspect of the effective management of various profiles. Floor space also helps to ensure that items are stored and recovered on time by reducing the lead time overall, which in turn increases productivity.

The performances of ASRS are based on speed, accuracy, and throughput. Fast storage and retrieval operations are made possible by high-performance systems, which also shorten cycle times and increase order fulfilment rates. These improvements boost customer satisfaction and boost a company's ability to compete in the market. Automated operation systems reduce labour costs with minimal human intervention and increase system reliability to improve warehouse performance. Efficient systems increase system uptime with powerful automation functions and intuitive workstations.

Table 3. Comparison between multiple types of ASRS [34]

	Multi drawer cabinet	**Mini load ASRS**	**Vertical carousel storage**
Floor space	Fixed and less space needed	More space is needed for both the racking structure and the ASRS crane	Space used is lesser compared to mini-load ASRS due to that the mechanism is designed vertically
Storage size	Any size depends on the cabinet used	Usually stored small components	Usually stored small size of components in large quantities
Performance	No extra performance	It is possible to configure the system to do several tasks simultaneously.	The device may be configured to do several tasks simultaneously.
Operation	The operator manually goes and finds the required samples	The machine transfer unit will travel horizontally and vertically	The machine delivers the required sample by rotating the storage carousel vertically via a rotating belt system
Reliability	Low reliability	Generally high reliability with tracing ability and high accuracy	Generally high reliability with high automation speed and greater storage
Cost	Low cost	High cost	High cost
Life span	Usually long, depending on the materials used	For the machine to last as long as possible, maintenance must be done sometimes.	Maintenance is carried out once in a period to maintain its lifespan

Reliability is essential to ensure continuous warehouse operations. An ASRS is trusted to maintain service level agreements with customers to minimize downtime and reduce the possibility of inventory errors. A robust system design requires regular maintenance and efficient fault detection procedures to maintain high reliability. Cost considerations encompass both upfront capital expenditure and long-term operational costs. Even though the initial investment is important it is also important to consider ongoing operating costs like labour, energy use and maintenance. Cost-effective ASRS solutions strike a balance between upfront investment and long-term cost savings.

The lifespan is the durability of the ASRS. The high durability of ASRS can reduce costs. Factors such as equipment, maintenance and technology development affect the life of an ASRS system. The comparative analysis in Table 3 delineates the functional disparities among Multi Drawer Cabinet, Mini Load ASRS, and Vertical Carousel Storage systems across a variety of parameters crucial to warehouse design and functionality [33].

5. TECHNOLOGY CAN BE IMPLEMENTED

In the field of warehouse management, the incorporation of state-of-the-art technology has evolved to be a critical component that allows us to stay ahead. The ASRS has evolved to be the modern solution to efficient inventory management. However, integrating new technology and implementing it into existing systems is also essential to enhance the capabilities of ASRS [35]. Some of the technologies that can be implemented into the ASRS system include:

5.1 Artificial Intelligence

Artificial Intelligence (AI) can be implemented in ASRS Offices and various businesses and may greatly enhance warehouse operations. AIs can dynamically change courses to achieve the best possible utilization of available space and minimize travel time. With information such as stock levels and order patterns presented to them in real-time, they can cover all elements of the system, including traffic congestion or network connection failures, to ensure operations run smoothly. The first one is dynamic path optimization. AI algorithms can analyze inventory levels, order trends and traffic data in ASRS in real-time. Artificial intelligence can optimize storage and retrieval routes to make the most of available space and reduce autonomous vehicle travel time [36]. Second, predictive maintenance is another key aspect of AI integration in ASRS. By utilizing machine learning algorithms, the system can analyze historical performance data to identify patterns that indicate potential equipment failures [37]. This proactive approach predicts maintenance needs, reduces downtime and improves the overall reliability of your ASRS equipment. The result is a more resilient and cost-effective warehouse management system [38]. An essential component of AI is adaptive learning which turns ASRS into a system that is always improving and optimizing. By learning from past data and adjusting its processes over time machine learning algorithms allow the ASRS to adjust to shifting patterns in warehouse operations. To maintain continuous efficiency gains this adaptability makes sure that the ASRS is responsive to change demands and operational dynamics [39]. Accurate demand forecasting is one of the key benefits of combining ASRS with artificial intelligence. Artificial intelligence (AI) analyzes market trends and other developments and accurately predicts demand using historical sales data [40]. ASRS improves inventory levels by ensuring that there is no excess inventory, and that inventory is always available when needed. A more cost-effective and customer-focused inventory management strategy is important. The integration of artificial intelligence with supply chain networks, ERP systems, and warehouse management systems increases the flow of information, ensures coordination and efficient operation of the entire integrated supply chain, and provides overall visibility and consistency in inventory management. improve [41]. AI helps ASRS with its intelligent selection and sorting procedures. In response to rising service demands, artificial intelligence systems dynamically adjust processes and instantly assess methods. Orders from customers may therefore be handled swiftly and effectively, improving order fulfillment's overall effectiveness. In conclusion, there are many advantages of integrating AI into ASRS, including increased responsiveness, efficiency, and error resilience for the automated storage and retrieval system.

5.2 Radio-Frequency Identification

The operations of security can be improved by the installation of an ASRS-equipped Radio-Frequency Identification (RFID) system that can function automatically. Now those ID tags can be attached to any object, dish or compartment. With these tags transmitted via radio frequency, which is the self-identifying nature of the transmission, consumers can engage in trendy and unique styles. ASRS and RFID are a breakthrough because the mixture of these two technologies is characterized by some important advantages [42]. RFID makes inventory tracking and identification easier [42]. All tags embedded with RFID and unique identification enable much faster precision in retrieving all the items within the ASRS. It provides an additional scanning solution that lowers the probability of error during barcode processing or manual scanning which increases the counters' precision. Second, RFID helps with instant visibility. Through associated collectors, RFID technology will collect and turn over the data input on everything that comes in the ASRS immediately, which will be updated and consequently help in location and inventory levels. Warehouse managers are now able to manage their decisions with this real-time openness which gives them data at the click of a button. For instance, it conserves inventory levels and product status [43]. Thirdly, RFID can accelerate the process of ASRS. ASRS with RFID technology can be operated more automatically, which becomes a faster way to recognize things and bring them closer by eliminating the manual scan and line-of-sight operations. This fact makes the warehousing system the one that is more worried/ responsive and resourceful. [44]. RFID enhances the traceability and accountability of the processes [45]. Tracking operations at a very minute level allow for each item to retain logs of their specific locations within the associated ASRS. It is this assurance that products have not been counterfeited that gives quality control and compliance with the regulations for some teeth, and which makes it possible to react to a product recall. As a result, accurate, real-time visibility and simplified identification made possible by RFID integration into ASRS transform the effectiveness of warehouse operations and, in the process, optimize inventory management and retrieval procedures.

5.3 Internet of Things

With the growing ability of the ASRS robots to improve their efficiency creation and warehousing management using the perspective of IoT technology. IoT devices, sensors and connected devices are certainly the most important factors in that these devices can offer real data from which the system can make its decisions. [46]. Real-time tracking and monitoring are one significant enhancement. The robotic arms are equipped with Internet of Things (IoT) sensors; With ASRS conveyor belts and warehouses, you can constantly monitor the location and condition of your warehouse. This real-time visibility allows warehouse managers to continuously monitor inventory levels; able to identify disruptions quickly respond to change in demand; and adapt to and react to actions that can do more. IoT uses data from embedded sensors in equipment to gather and analyze it to enable predictive maintenance in ASRS. These sensors can track the functionality and condition of equipment, looking for irregularities or wear indicators. The system can schedule preventative maintenance, reducing downtime and increasing equipment lifespan, by forecasting maintenance needs based on this data [47]. IoT additionally makes it possible to screen the garage environment`s condition. Sensitive gadgets may be saved in perfect situations via means of the use of real-time temperature, humidity, and different environmental thing monitoring. For businesses like pharmaceuticals or perishable goods, which have strict storage regulations, this capability is especially important [48]. Using IoT, resource utilization can be improved by monitoring the usage and movement of vehicles and equipment in ASRS. By analyzing this information, warehouse managers can improve resource allocation, ensuring vehicles are used efficiently and all machines are operating at optimal levels [19]. In the safety industry, IoT can assist enhance incident tracking and detection. Motion sensors may be included in safety cameras to stumble on unauthorized use or safety breaches. This protection method enables preserving the place of work and securing and defending personnel and property. Integration with other systems is another strength of IoT in ASRS. IoT devices facilitate smooth data exchange by establishing connections with other components of the supply chain and the warehouse management system. This interconnectedness enhances coordination, leading to improve synchronization of operations and better overall supply chain visibility [49].

5.4 Multi-color code

The implementation of a Multi-Color Code with a High Data Capacity system can significantly enhance ASRS by introducing a visually intuitive and information-rich method for inventory management. This innovative approach utilizes colour-coded labels or markers with embedded data capacity, providing a visual identifier that can convey diverse information about each item or storage location [50]. A key gain is the progressed ease of detection [51]. In ASRS, different colours can suggest different classes or object attributes. The identification process between the automation and the human operator is made simpler by this visible code. Lower the likelihood of errors and make the locating process easier. It provides a larger data capacity within each only a few bits sequence which allows more details to be encoded. Category, expiration date, batch number and the relevant information might be provided in this product info. However, by doing so, it is equipped with a label variation technique which is not rigid. With this in mind, the calculation concerns the number of inventory and their complexity. Additionally, the Multi-Color Code system encourages systematic and uniform storage procedures. By assigning specific colours to designate categories or storage zones, the ASRS can enforce a structured approach to inventory management, making it easier to locate, organize, and manage items within the storage facility [51]. This system streamlines identification, enhances data capacity, supports dynamic information conveyance, reduces errors, integrates seamlessly with automation, and promotes standardized storage practices, collectively contributing to a more efficient and responsive automated storage and retrieval system [53].

5.5 Data Acquisition System

ASRS and integrated data acquisition systems (DAS) include an organized approach to improve operational and organizational efficiency. DAS covers a wide range of topics, including process optimization, inventory control, and security assurance. Subsequently, it becomes imperative to carefully select and install the right sensors, such as proximity sensors, load cells, RFID readers, and barcode scanners. These sensors are positioned thoughtfully at key points within the ASRS to rapidly gather information for necessary functions such as object detection, weight measurement, and position determination [54]. This statistic is transmitted through stressed and WIFI methods to a crucial management system, which permits thorough processing, evaluation, and storage in an expandable database. Operators can acquire essential insights into music's overall performance and make smart selections via means of using statistics evaluation tools, algorithms, and visualization techniques [55]. The alarms and notifications can guarantee that abnormalities or system failures are responded to quickly. The DAS's insights-driven continuous monitoring and optimization help to raise the ASRS's overall productivity and efficiency.

5.6 Voice Control

ASRS systems can benefit from the integration of voice control technology, which can improve operator interaction and decrease reliance on input by allowing the operator to command the system with greater productivity. This streamlined approach fosters communication between operators and the system resulted in an improved efficiency for quicker retrieval and storage of goods. Combining voice control with ASRS provides a way to improve device performance and availability. The green use of voice management requires the application of technologies such as natural language processing (NLP) and language proficiency to understand instructions. System mastering is necessary to improve accuracy in various speech patterns and languages. Its operation depends on seamless integration with the ASRS control software and hardware infrastructure, which makes the introduction of interfaces and protocols crucial to allow verbal communication between the ASRS and the voice management device. It is crucial to customize voice commands to fit the features and capabilities of each ASRS. The quantity management technique usually encompasses tasks, like storage, warehousing, product control, device tracking and protection procedures. Clear and impartial verbal comments and steerage are important to help customers at some stage in the experience [57]. Additionally, reliability and security are important when using voice control in an ASRS environment. To prevent errors or accidents caused by wrong instructions or system failure, the system must have failures - safety and protection. To further restrict access to sensitive activities and data, access control and user authentication functions are available [57]. Once implemented, voice control could substantially improve the effectiveness of ASRS operations by decreasing the need for manual input devices, expediting user engagements, and avoiding downtime related to conventional user interfaces [58]. Tasks may be completed swiftly and hands-free by users, facilitating more efficient workflows and higher productivity. Voice-activated ASRS systems promote inclusivity and diversity in the workplace by making the workplace more accessible to people with disabilities or limited mobility. The integration of voice control technologies holds significant potential for enhancing ASRS performance and user experience across diverse commercial and industrial settings. [58].

5.7 Blockchain

Blockchain technology is a distributed digital ledger technology that ensures transparency, traceability, and security. The blockchain enhances various aspects of the supply chain processes. Blockchain provides a transparent and immutable record of transactions, enabling all parties involved in the supply chain to access real-time information about products, transactions, and processes. This transparency enhances trust among stakeholders and allows for better traceability of products from their origin to the end consumer [60, 61, 63]. The decentralized nature of blockchain ensures that data stored on the ledger is secure and tamper-proof. This security feature is crucial in supply chain management to prevent fraud, counterfeiting, and unauthorized alterations of data, thereby increasing the overall security of the supply chain [60, 62]. Blockchain technology can contribute to sustainable supply chain management by addressing sustainability challenges. It enables the tracking of products' environmental impact, supports ethical sourcing practices, and helps in meeting sustainability goals by providing a transparent view of the supply chain processes [60, 63]. Blockchain technology can enhance the efficiency of supply chain operations by reducing the need for intermediaries and improving inventory management. This efficiency leads to cost savings, faster transactions, and improved overall supply chain performance [62]. Blockchain technology aids in managing risks in operations and supply chain management by providing a secure platform for data exchange and ensuring the integrity of information. This reduces the risks associated with data breaches, errors, and fraud within the supply chain [61]. The blockchain ASRS is the implementation of blockchain technology in ASRS. This aims to enhance the efficiency, security, and transparency of storage and retrieval processes within various industries. The blockchain's decentralized and secure nature offers the ASRS the potential to benefit from improved data accuracy, reduce fraud, and enhance traceability throughout the supply chain. The use of blockchain technology in ASRS can revolutionize traditional storage and retrieval systems by providing a transparent ledger of transactions. This integration can streamline operations, minimize errors, and ensure the integrity of data related to inventory management, order processing, and logistics.

6. CONCLUSION

The evaluation and the importance of ASRS for productivity and quality improvement are discussed in this paper. The focus of ARSR is to assess the principles of control and configuration. This literature review discussed the efficiency of the other ARSRs. The implementation of technologies such as colour coding, RFID, IoT and artificial intelligence into ASRS may lead to significant improvement in warehouse operations. This technology also can improve sales management. It can raise the operational speeds, optimize storage retrieval techniques and improve overall warehouse performance. This technology will change store management as well as satisfy retailer needs when combined with ASRS.

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CONFLICT OF INTERESTS

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ETHICS STATEMENTS

No human subjects, animal experiments and data from social media platforms are involved.

REFERENCES

[1] M. R. Vasili, S. H. Tang, and M. Vasili, "Automated Storage and Retrieval Systems: A Review on Travel Time Models and Control Policies," *Warehousing in the Global Supply Chain*, pp. 159–209, 2012, doi: 10.1007/978-1-4471-2274-6_8.

[2] G. Higginbotham, "8 types of automated storage and retrieval systems (ASRS): A Deep Dive," 2023. https://us.blog.kardex-remstar.com/types-of-automated-storage-and-retrieval-systems.

[3] R. Reman, L. Rapolti, M. Ardelean, R. Holonec, C. Munteanu, and V. Topa, "A Hardware Optimized Storage and Retrieval System for Smart Warehousing Applications," 2022 International Conference and Exposition on Electrical and Power Engineering (EPE), Iasi, Romania, 2022, pp. 259-263.

[4] G. Rickman, "The problem of storage," *Roman Granaries and Store Buildings*, 1971, pp. 353-362, Cambridge: Cambridge University Press.

[5] Schulz, *The New Palaces of Medieval Venice*. University Park, PA: Penn State Univ. Press, 2004.

[6] A. Jhawar, N. Safar, and D. Rodrigues, "The impact of technology on the evolution of warehouse management and smart warehouses," *International Journal of Advanced Research in Ideas and Innovations in Technology (IJARIIT),* vol. 5, no. 5, pp. 1156, 2019. https://www.ijariit.com/manuscripts/v5i5/V5I5-1156.pdf.

[7] K. Azadeh, R. De Koster, and D. Roy, "Robotized and Automated Warehouse Systems: Review and Recent Developments," *Transportation Science*, vol. 53, no. 4, pp. 917-945, 2019, doi: 10.1287/trsc.2018.0873.

[8] E. Romain, "Optimizing Omnichannel Order Picking and Fulfillment Operations," 2013. https://multichannelmerchant.com/operations/optimizing-omnichannel-order-picking-fulfillment-operations/.

[9] Liam, "Top 17 warehouse material handling equipment items that your facility needs," 2023. https://www.yellowgate.com/top-17-warehouse-material-handling-equipment-items-that-your-facility-needs/.

[10] M. S. A. Humiras Hardi Purba, "Productivity improvement picking order," *Journal Name*, vol. 9, pp. 71-81, 2018.

[11] A. Goetschalckx, "Classification and Design of Order Picking," *Logistics World*, vol. 2, pp. 99-106, 1989.

[12] E. B. L. Van Den Berg, "Marketing and the Need for Organizing Capacity," *Urban Competitiveness*, vol. 36, pp. 987-999, 1999.

[13] M. Glover, "Warehouse Order Picking System," 2018. https://www.veeqo.com/blog/warehouse-order-picking-systems.

[14] J. A. Pazour, "Modelling the Inventory Requirements and Throughput Performance of the Picking Machine," *in Order-Fulfillment Technology*, 2012, pp. 15-22.

[15] E. Johnson, "Frazier Racking," 2013. https://www.diyracksideas.com/page/5629/.

[16] J. Elboaz, "Material handling system," 2012. https://www.articlecube.com/push-back-racking-%E2%80%93-benefits.

[17] T. Jerone, "NTL Storage Solution," 2016. https://www.yelp.com.sg/biz_photos/ntl-storage-solutions-singapore?select=-6PF2qpnCHcVbGovVuyKQg.

[18] REB Storage Systems International, "Pallet Flow Rack," 2023. https://rebstorage.com/wp-content/uploads/2022/01/Pallet-Flow-Rack.pdf.

[19] A. Nordeide and S. Rørtveit, "The Impact of Automated Storage and Retrieval Systems on Warehouse Operations," Master's thesis, Høgskolen i Molde-Vitenskapelig høgskole i logistikk, 2021.

[20] K. J. Roodbergen and I. F. A. Vis, "A survey of literature on automated storage and retrieval systems," *European Journal of Operational Research*, vol. 194, no. 2, pp. 343-362, 2009.

[21] J. A. Tompkins, *Facilities Planning,* 2nd ed. New York, NY: Wiley, 1996, pp. 731-750.

[22] K. S. Sim and E. F. Ng, "Mechanical Design of Mini Automated Storage and Retrieval Warehouse System for Electronic Components," *Applied Mechanics and Materials*, vol. 575, pp. 753-756, 2014.

[23] E. Romain, "ASRS Warehouse Information," 2019. https://www.conveyco.com/automated-storage-and-retrieval-types.

[24] D. H. Loy, "Automated storage and retrieval system," U.S. Patent US6325586B1, 1999.

[25] REB Storage Systems International, "Unit load ASRS System," 2023. https://rebstorage.com/wp-content/uploads/2021/07/Unit-Load-AS_RS-Overview.pdf.

[26] A. Gopal, C. Vengatesan, K. Gopinath, and R. Dhatchinamoorthy, "Design of automated vertical storage system for automotive applications," in AIP Conference Proceedings, vol. 2311, no. 050001, 2020, doi: 10.1063/5.0034330.

[27] M. Calzavara, F. Sgarbossa, and A. Persona, "Vertical Lift Modules for small items order picking: an economic evaluation," *International Journal of Production Economics*, vol. 210, 2019, pp. 199-210.

[28] R. Gaku and S. Takakuwa, "Simulation analysis of large-scale shuttle vehicle-type mini-load ASRS systems," in *2018 Winter Simulation Conference (WSC),* Gothenburg, Sweden, 2018, pp. 2966-2976.

[29] Y. Ma and J. Wang, "Travel time analysis for shuttle-based storage and retrieval system with middle input/output location," in *2019 16th International Conference on Service Systems and Service Management (ICSSSM)*, Shenzhen, China, 2019, pp. 1-6. doi: 10.1109/ICSSSM.2019.8887622.

[30] C. Özbaran, S. Dilibal, and G. Sungur, "Mechatronic System Design of A Smart Mobile Warehouse Robot for Automated Storage/Retrieval Systems," in *2020 Innovations in Intelligent Systems and Applications Conference (ASYU),* Istanbul, Turkey, 2020, pp. 1-6, doi: 10.1109/ASYU50717.2020.9259882.

[31] C. H. Singer, "Automated storage facility including a storage and retrieval system and a floor inventory management system," U.S. Patent US5953234A, 1997.

[32] O. V. Pilipenko, E. N. Provotorova, S. M. Sergeev, and O. V. Rodionov, "Automation engineering of an adaptive industrial warehouse," *Journal of Physics: Conference Series,* 2019, pp.1-4, doi:10.1088/1742-6596/1399/4/044045.

[33] J. Kovalcik and M. Villalobos, "Automated Storage & Retrieval System," *Information Technology and Libraries,* vol. 38, no. 4, pp. 114-124, 2019, doi: 10.6017/ital.v38i4.11273.

[34] Y. Wang, R. Man, X. Zhao, and H. Liu, "Modeling of Parallel Movement for Deep-Lane Unit Load Autonomous Shuttle and Stacker Crane Warehousing Systems," *Processes*, vol. 8, no. 1, 2020, pp.2-19, doi: 10.3390/pr8010080.

[35] P. Chockalingam, "Smart Manufacturing with Smart Technologies – A Review," *International Journal on Robotics Automation and Sciences,* vol. 5, no. 2, pp. 85-88, 2023, doi: 10.33093/ijoras.2023.5.2.10.

[36] W. C. Yuen, G. C. Lee, and H. K. Sim, "Development of an AI-enabled contactless Visitor Access Monitoring System," *International Journal on Robotics, Automation and Sciences,* vol. 5, issue 2, pp. 5-11, 2023.

[37] B. Lin, W. Lee, N. Wise, and H. C. Choi, "Consumers' Ethical Perceptions of Autonomous Service Robots in Hotels," *Journal of Hospitality & Tourism Research*, 2023, doi: 10.1177/10963480231194693.

[38] R. Belk, "Ethical issues in service robotics and artificial intelligence," *The Service Industries Journal*, vol. 41, no. 13-14, pp. 860-876, 2021, doi: 10.1080/02642069.2020.1727892.

[39] O. H. Chi, G. Denton, and D. Gursoy, "Artificially intelligent device use in service delivery: A systematic review, synthesis, and research agenda," *Journal of Hospitality Marketing & Management*, vol. 29, no. 7, pp. 757-786, 2020, doi: 10.1080/19368623.2020.1721394.

[40] S.-K. Tan et al., "Personalized healthcare: A comprehensive approach for symptom diagnosis and hospital recommendations using AI and Location Services," *Journal of Informatics and Web Engineering*, vol. 3, no. 1, pp. 117-135, 2024, doi: 10.33093/jiwe.2024.3.1.8

[41] M. M. Rashid, B. Kasemi, and M. Rahman, "New Automated Storage and Retrieval System (ASRS) using wireless communications," in *2011 4th International Conference on Mechatronics (ICOM),* Kuala Lumpur, Malaysia, 2011, pp. 1-7, doi: 10.1109/ICOM.2011.5937195.

[42] S. Guccione and U. Marjanovic, "Automatic Identification/RFID course and equipment for teaching and research," in *Proceedings of the 2008 IAJC-IJME International Conference*, 2008.

[43] Y. H. Wong, G. C. Lee, and H. K. Sim, "RFID and Facemask Detector Attendance Monitoring System," *International Journal on Robotics, Automation and Sciences,* vol. 5, no. 2, pp. 14-24, Sep. 2023, doi: 10.33093/ijoras.2023.5.2.2.

[44] Y. H. Wong, G. C. Lee, and H. K. Sim, "RFID and Facemask Detector Attendance Monitoring System," *International Journal on Robotics, Automation and Sciences*, vol. 5, no. 2, pp. 14-24.

[45] C. Palanisamy, "Smart Manufacturing with Smart Technologies – A Review," *International Journal on Robotics, Automation and Sciences,* vol. 5, pp. 85-88.

[46] M. Pingale and H. H. Kulkarni, "Design And Development of Automated Storage And Retrieval System (ASRS) For Warehouse Using IOT And Wireless Communication," *International Journal of Scientific & Technology Research*, vol. 8, pp. 105-108, 2019.

[47] M. M. Rashid, B. Kasemi, and M. Rahman, "New automated storage and retrieval system (ASRS) using wireless communication," in *2011 4th International Conference on Mechatronics* (ICOM).

[48] M. Soyaslan, A. Fenercioglu, and C. Kozkurt, "An approach of a control system for automated storage retrieval system (ASRS)," *World Academy of Science, Engineering and Technology International Journal of Mechanical and Mechatronics Engineering*, vol. 6, no. 9, 2012.

[49] K. S. Sim, Z. Y. Lim, and F. F. Ting, "Development of High Data Capacity Color Code," *International Journal of Machine Learning and Computing,* vol. 1, no. 1, pp. 10-18, 2018.

[50] Z. Y. Lim and K. S. Sim, "Multi-Color Code with High Data Capacity," *International Journal on Robotics, Automation and Sciences*, vol. 4, pp. 35-45, 2022, doi: 10.33093/ijoras.2022.4.6.

[51] Z. Y. Lim, K. S. Sim, and E. K. Wong, "High-capacity multi-coloured code system," *in International Conference on Robotics, Automation and Sciences (ICORAS)*, pp. 1-5, 2017, doi: 10.1109/ICORAS.2017.8308078.

[52] Q. Zhang, L. Yang, Y. Gao, Y. Xiang, H. O. Li, S. Sun, and Y. Xu, "Multi-colour solid-state photoluminescence from orthogonally multi-stimuli-responsive organic molecule for advanced information storage and encryption," *Chemical Engineering Journal*, vol. 459, p. 141666, 2023.

[53] M. H. Wong, B. C. Yeo, P. K. Ng, and W. J. Choong, "Data Acquisition System and Pattern Image Generations for Hand Grip Device," *International Journal on Robotics, Automation and Sciences*, vol. 3, pp. 13-18, 2021, doi: 10.33093/ijoras.2021.3.3.

[54] H. Y. Wu, Z. H. Li, H. Tan, H. Hua, J. Li, W. Hennig, and Y. L. Ye, "A general-purpose digital data acquisition system (GDDAQ) at Peking University," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 975, p. 164200, 2020.

[55] T. Bhuvaneswari, C. Venugopal, and C. C. Goh, "Voice Controlled Home Automation System Design," *International Journal on Robotics, Automation and Sciences*, vol. 5, no. 2, pp. 94-100, Sep. 2023, doi: 10.33093/ijoras.2023.5.2.12.

[56] A. Rogowski, "Industrially oriented voice control system," *Robotics and Computer-Integrated Manufacturing*, vol. 28, no. 3, pp. 303-315, 2012.

[57] B. House, J. Malkin, and J. Bilmes, "The VoiceBot: a voice-controlled robot arm," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pp. 183-192, 2009.

[58] Y. Gong and C. Poellabauer, "An overview of vulnerabilities of voice-controlled systems," *arXiv preprint arXiv:1803.09156*, 2018.

[59] S. Saberi, M. Kouhizadeh, J. Sarkis, and L. Shen, "Blockchain technology and its relationships to sustainable supply chain management," *International Journal of Production Research*, vol. 57, pp. 2117-2135, 2018.

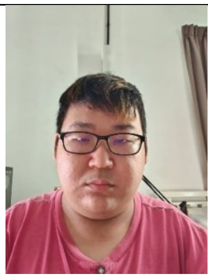
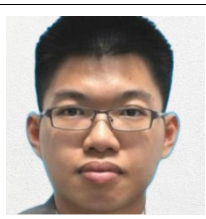
[60] S. Chowdhury, O. Rodriguez-Espindola, P. Dey, and P. Budhwar, "Blockchain technology adoption for managing risks in operations and supply chain management: evidence from the UK," *Annals of Operations Research*, pp. 1-36, 2022. Advanced online publication, doi: 10.1007/s10479-021-04487-1.

[61] R. Cole, M. Stevenson, and J. Aitken, "Blockchain technology: implications for operations and supply chain management," *Supply Chain Management: An International Journal,* 2019.

[62] A. A. Khanfar, M. Iranmanesh, M. Ghobakhloo, M. G. Senali, and M. Fathi, "Applications of Blockchain Technology in Sustainable Manufacturing and Supply Chain Management: A Systematic Review," *Sustainability*, 2021.

[63] R. Kannan and J. J. Chin, "Backup Automation Using Power Automate for Malaysian Vaccination Centres," *Journal of Informatics and Web Engineering*, vol. 1, no. 1, 2022.

BIOGRAPHIES OF AUTHORS

 Alex Low Kai Jie	**Alex Low Kai Jie** is a student of Bachelor of Electronic Engineering in Robotics and Automation. He can be contacted by email: lowhui1013@gmail.com
 Sim Kok Swee	**KOK SWEE SIM** is currently a Professor with Multimedia University, Malaysia. He is working closely with various local and overseas institutions and hospitals. He has filed more than 18 patents and 70 copyrights. He has received many International and local Awards. He was a recipient of the Japan Society for the Promotion of Science (JSPS) Fellowship, Japan, in 2018, the Top Research Scientists Malaysia (TRSM) from the Academic Science Malaysia, in 2014, the Korean Innovation and Special Awards, in 2013, 2014, and 2015, and the TM Kristal Award and International Championships of World Summit on the Information Society (WSIS) Prizes, in 2017, 2018, 2019, 2020, and 2021. He was also Fellow of The Institution of Engineers, Malaysia (IEM) and Fellow of the Institution of Engineering & Technology (IET). In year 2024, he was elected as Fellow of Academic Science Malaysia.
 Lew Kai Liang	**KAI LIANG LEW** received the B. Eng.(Hons) degree and M.Sc. in Engineering from Multimedia University, Malacca in 2019 and 2022 respectively. He is currently taking a Ph.D. degree in engineering at Multimedia University. His research interests include rehabilitation, deep learning and signal processing.