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* **Corresponding author**.

arulavanto@gmail.com

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An Integrated Warehouse System using AS/RS (Automated Storage and Retrieval System) Technology

M. Deepika[1], I Antonitte Vinoline[2]*

1 Research Scholar, PG and Research Department of Mathematics, Holy Cross College (Autonomous), Affiliated to Bharathidasan University, Tiruchirappalli-620002, Tamil Nadu, India

2 Assistant Professor, PG and Research Department of Mathematics, Holy Cross College (Autonomous), Affiliated to Bharathidasan University, Tiruchirappalli-620002, Tamil Nadu, India

Abstract

Objectives: To examine and justify the significance of Automated Storage and Retrieval System technology in minimizing warehouse inventory costs and enhancing storage efficiency for improved retailer operations. **Methods:** Automated Storage and Retrieval Systems is examined in the warehouse and analysed between the two methods namely i) with Automated Storage and Retrieval System technology ii) without Automated Storage and Retrieval System technology. The proposed methods were implemented and analyzed to evaluate their effectiveness in reducing warehouse inventory costs and optimizing storage solutions for retailers by using secondary data from Ercan Senyigit and Hakan Akkan's research. **Findings:** An integrated warehouse system is constructed in this work and comparative analysis has been made to study the effectiveness of the warehouse system in the absence and presence of Automated Storage and Retrieval System technology. A computational example is presented to show the efficiency of the system, and the results shows that the total cost of the system without Automated Storage and Retrieval System technology is $1,51,350.81 whereas the total cost of the system with Automated Storage and Retrieval System technology investment is $1,33,753.58. The findings suggest that incorporating Automated Storage and Retrieval System (ASRS) technology into warehouse inventory management leads to cost savings, streamlined operations, and improved space utilization for retailers. **Novelty:** Automated Storage and Retrieval System technology investment is integrated into warehouse systems to optimize inventory costs, leading to enhanced operational performance which remains unexplored in existing literature.

2020 Mathematics Subject Classification: 90B05.

Keywords: Warehouse inventory management; Inventory costs; Quality control; Automated Storage and Retrieval Systems; Streamlined operations

1 Introduction

The process of numbering or cataloguing objects is called "Inventory". Inventory is a valuable collection of assets in accounts and pertains to the various manufacturing levels. With the availability of stocks, both manufacturers and wholesalers/businesses can contribute to selling or producing things. J. B. Munyaka analysed the inventory management concepts and explored their applications in practice.[1] A warehouse can be defined functionally as a building in which to store bulk produce or goods (wares) for commercial purposes. Warehouses are used by manufacturers, importers, exporters, wholesalers, transport businesses, customs etc.., Storage is crucial to every company while it may appear simple to many, but it is full of many options. Warehouses come in many shapes and sizes, catering to various niches. Choosing the kind of warehouse may significantly influence order fulfilment, which subsequently has a direct impact on your customer relations. Shashank Kumar examined the transformation of warehouses between 1990 and 2019 from an evolutionary perspective.[2] Warehouse inventory management is the process businesses use to organize, track and handle goods in their warehouses. These goods can include raw materials, finished products and items in production. Manufacturers, wholesalers, distributors, retailers and ecommerce sellers need powerful warehouse inventory management to satisfy customers and fuel growth. Aidil Hanafi Amirrudin investigated the strategies for improving warehouse efficiency through inventory management practices.[3] Some warehouse management systems can also cover inventory in stockrooms or on store shelves.

Warehouse inventory management faces several challenges that can hinder efficiency and productivity. Warehouse problems can affect the speed, efficiency, and productivity of either one particular warehouse operation or the entire chain of processes that are linked with it. Inefficient space utilization often leads to cluttered and poorly organized warehouses, reducing the available storage capacity. Micaela Marziali carried out a case study on an inventory and warehouse management issue, which was effectively resolved through the application of the KPI concept.[4] Most warehouses perform multiple operations on each item, and those operations are strung together to create workflows. But if a workflow isn't well organized, you may find that the same operation is being accidentally performed more than once. These redundancies increase the labor costs and take up extra time when you have to go back and reverse the mistake. Redundancy is often noticed in order picking, which is when products are picked from their storage locations in a warehouse to fulfil an order. In smaller warehouses, order picking is a one-person job which leaves little room for error. But in a larger warehouse, multiple people work together to pick products from different parts of the warehouse to fulfill a single order. Since the same order is passed around to multiple people, there is a bigger chance for mistakes, like picking too many of the same products. Additionally, locating and retrieving items manually can be time-consuming, particularly in large warehouses, which delays order fulfillment and reduces customer satisfaction.

Labor dependency poses another critical challenge, as warehouses are heavily reliant on human workers for tasks like inventory checks, picking, and restocking. Labor shortages, high turnover rates, and the rising cost of wages further exacerbate operational inefficiencies. Mistakes in picking inventory due to human error can be costly for a warehouse in lost time. Additionally, training new employees to adapt to warehouse operations can be time-intensive and expensive. This problem becomes particularly acute during periods of high demand, such as seasonal peaks or unexpected surges, when manual systems struggle to keep up with the increased workload, leading to missed opportunities and revenue loss. Safety concerns are another major issue in manual warehouse management. Workers are often exposed to hazardous conditions, such as lifting heavy loads, operating forklifts in confined spaces, and climbing to access high shelves. These risks increase the likelihood of workplace injuries and accidents, leading to higher insurance costs and potential legal liabilities. Finally, traditional warehouse systems are often energy-inefficient, with outdated processes consuming excessive resources, driving up utility costs, and reducing overall sustainability. Ali Kamali reviewed the distinctions between smart warehouses and traditional warehouses.[5] Senyigit, E. and Akkan, H. considered an inventory system containing one warehouse and N retailers and minimize supply chain costs of the whole system.[6] These issues create a challenging environment for warehouse managers, emphasizing the need for innovative solutions to streamline operations, enhance accuracy, and improve overall efficiency. To overcome these challenges, there is a growing need for innovative solutions that enhance efficiency and accuracy. Implementing appropriate technology can help address these issues and drive profitability.

Automated Storage and Retrieval Systems (AS/RS) effectively address these issues by leveraging advanced technologies for streamlined operations. These systems maximize space utilization through vertical storage and optimized layouts, significantly increasing storage capacity. Enoch Oluwademilade Sodiya reviewed the systems of AI-driven warehouse automation.[7] Alex Low Kai Jie conducted a review of the literature focusing on the exploration of Automated Storage and Retrieval Systems in the context of warehouse operations.[8] Automated Storage and Retrieval Systems reduces retrieval times by efficiently locating and delivering items, thereby improving order processing speed and customer satisfaction. The system is usually comprised of predefined locations where machines can follow established routes to get items. These systems help to speed up manufacturing and shipping tasks. Larissa Custodio proposed a novel framework for a versatile automated warehouse.[9] Typically, automated storage and retrieval systems are used when high volume loads must be moved rapidly and accurately.

This has made AS/RS technologies one of the most popular and impactful investment options available to most operations. Each type of AS/RS operates in slightly different ways, all with the goal of speeding up warehouse processes. Each type of system outlined above automates the process of storing products in appropriate bins, shelves or other storage locations or retrieving items or loads from storage areas. They reduce the time and manpower needed to retrieve and store items. Hanan M. Hameed examined the components of automated storage and retrieval systems and highlighted the advantages of automating a company's storage operations.[10] Konrad Lewczuk studied the dependability of automated storage and retrieval system.[11] AS/RS solutions reduce the need for manual labor by automating manual, repetitive storage and retrieval tasks. Automating these tasks increases accuracy and efficiency while also freeing up human workers to focus on higher-value activities. Daron Acemoglu and Pascual Restrepo explored the impact of technology on labor displacement and reintegration.[12] During high-demand periods, Automated Storage and Retrieval Systems handles increased workloads seamlessly, maintaining efficiency and accuracy. It reduces the variable cost of operations by reducing the need for manual labor for tasks such as picking, storing, assembly and inventory restock and mitigates risks associated with workforce shortages, high turnover, and human fatigue. They also enhance workplace safety by reducing the need for manual intervention in hazardous areas and limiting human involvement in tasks such as handling heavy loads or operating at heights. AS/RS technologies represent a significant leap forward in warehouse management, delivering faster, safer, and more cost-effective operations tailored to the demands of modern supply chains.

To the best of our knowledge, there exists no literature that focuses on optimizing total costs by integrating Automated Storage and Retrieval Systems technology into a warehouse inventory management system. Optimizing the total cost in warehouse inventory management is essential for maximizing profitability and ensuring efficient use of resources. Specifically, vast research has concentrated on individual aspects, such as inventory tracking, operational efficiency, or specific cost components like labor or transportation costs, rather than adopting a holistic approach to cost optimization. This highlights a research gap, as there has been no exploration of integrated solutions that utilize advanced technologies, such as Automated Storage and Retrieval Systems, to address multiple dimensions of warehouse inventory management, including cost reduction, space optimization, and operational efficiency, in a unified framework. This is especially significant in the context of modern supply chain demands, where dynamic market conditions and fluctuating customer requirements necessitate adaptive and efficient inventory management solutions. By addressing this gap, future research could provide valuable insights into the development of comprehensive strategies that leverage AS/RS technology not only for operational improvements but also for achieving substantial cost savings. Therefore, research on warehouse inventory management by incorporating Automated Storage and Retrieval Systems to optimize the total cost is essential for developing efficient, cost-effective, and sustainable solutions. So, in this study, an integrated warehouse system is developed that incorporates Automated Storage and Retrieval Systems technology investment within a warehouse inventory management system to optimize the total costs in order to address the identified research gap and offer a unified solution for improving both efficiency and cost-effectiveness in warehouse operations.

2 Methodology

An integrated warehouse system was developed by incorporating Automated Storage and Retrieval Systems (AS/RS) technology. This study compared two strategies namely: i) with Automated Storage and Retrieval System technology, ii) without Automated Storage and Retrieval System technology. To demonstrate the efficiency of the proposed system, secondary data from the research of Ercan Senyigit and Hakan Akkan were utilized[6], and the proposed methods were implemented and evaluated to assess their effectiveness in minimizing warehouse inventory costs and optimizing storage solutions for retailers. The notations and assumptions used to formulate the proposed system are detailed in Sections 2.1 and 2.2.

2.1 Notations

The notation in this paper is as follows:

Notations	**Descriptions**
i	Retailers, $\forall i = 0, 1, 2 \ldots N$
n_i	The number of orders placed by the retailer i during t_w
d_i	Demand at the retailer per unit of time i
k_i	Fixed restock cost per order at retailer i

k_w	Fixed restock cost per order at the warehouse
h_i	Inventory storage cost per unit and per unit time at retailer i
h_w	Inventory storage cost per unit and per unit time at the warehouse
t_i	Restock interval at retailer i
t_w	Restock interval at the warehouse
Q_i	The quantity of products restocked at retailer i
TC_i	The retailer i's average total costs
C_w	The warehouse's average total costs
C_s	The system's average total costs
r_i	The ratio between the restock and the inventory storage costs for retailer i
r_s	The ratio between the restock and the inventory storage costs for the total system
α	Direct labour cost
β	Indirect labour cost
l_c	Labour cost occurred in the warehouse
γ	Damage rate of the inventory
δ	Cost of the damaged product
d_c	Damage cost of the inventory
TC_{T1}	The total cost of the system without AS/RS system
TC_{T2}	The total cost of the system with AS/RS system

2.2 Assumptions:

1. An inventory/distribution system containing one warehouse and N retailers was considered.
2. The retailers face a constant and deterministic demand and replenish their stocks from the central warehouse. The warehouse restocks its inventory from an external supplier.
3. Shortages are not allowed; lead times are negligible and fixed charged restock and inventory holding cost parameters.
4. The demand was constant and deterministic.
5. Labour is one of the most significant costs that a warehouse can incur. So, the labour cost was considered.
6. Damages may occur due to handling and storage of inventories in warehouse.
7. For an effective warehouse management, an integrated warehouse system was developed.

2.3 Problem Definition and Mathematical Formulation

In this system, the warehouse fulfils orders for every store and restocks its inventory from an outside source. Demand is assumed to be deterministic and constant, and shortages are not permitted. Lead times, labour expenses, and warehouse losses were all taken into account. According to these presumptions, the holding stock level is equivalent to the retailer's average need during the course of the order interval (t_i). However, the warehouse inventory level is different from the retailers, since each store has different demand quantities and cost characteristics, which results in different order frequencies. At different periods, these variations may cause the warehouse's stock level to rise or fall. For this reason, the warehouse's inventory level graphic is not included as retailers (linear). Warehouse inventory levels are said to be influenced by the relationship between every retailer's and warehouse's order intervals. If warehouse restock interval (t_w) is greater than restock interval of retailer (t_i), retailer replenishes more frequently than warehouse. So, the warehouse has the necessary stock for the retailer i for $(t_w) - (t_i)$ time horizon. If warehouse restock interval (t_w) is greater than restock interval of retailer (t_k) , then the retailer k do not require a warehouse to maintain inventory. This relationship results in the solutions having an impact on the objective function. If $t_w > t_i$, then we incorporate the retailer i's warehouse inventory storage costs into the objective function. An Automated Storage and Retrieval System (ASRS) has been incorporated for more effective warehouse operations.

$C_i =$ Total Restock Cost + Total Inventory Holding Costs

$$C_i = \frac{K_i}{t_i} + \frac{h_i d_i t_i}{2} \tag{1}$$

Retailer Restock Costs: $\forall i \ = 0, 1, 2...N$ retailers total restock cost at base setting up period is equal to $K_i \times n_i$. Total restock cost is converted into $\frac{K_i}{t_i}$ by $n_i \times t_i = 1$ equation.

Retailer Inventory Storage Costs: It is expected that the supplier's demands are deterministic and unchanging. The amount of inventory maintained at the intervals between the two orders equal to $\frac{d_i}{2}$. So, inventory holding cost at retailer $i, \forall i \ = 0, 1, 2...N$ is equal to $\frac{h_i d_i t_i}{2}$

$$C_w = \frac{k_w}{t_w} + h_w \sum_{i:t_w > t_i} \frac{(t_w - t_i)\, d_i}{2} \tag{2}$$

Warehouse restock Cost: Total restock cost at base setting up period is $k_w \times f_w$. With $f_w \times t_w = 1$ equality total restock cost is converted into $\frac{k_w}{t_w}$.

Labour cost: The annual labour cost is dependent on the selection of equipment. It is assumed that one operator per piece of equipment is needed. The labour cost l_c is calculated by adding the direct α and indirect β labour costs.

$$l_c = \alpha + \beta \tag{3}$$

Damage cost: Due to handling of inventories by the labour and misplacing of inventories damage costs will occur. So, the damage cost d_c is calculated by multiplying the damage rate γ and cost δ of the product.

$$d_c = \gamma \times \delta \tag{4}$$

Warehouse Inventory Holding Cost: The relationship between the warehouse and retailers alters the conceptualization of warehouse storing costs compared to the economic order quantity model. As we previously explained, warehouse stores stock just for $t_w > t_j$ retailers. This indicates that the warehouse stores the retailer i whole inventory whose order interval is smaller than the warehouse order interval $(t_w > t_i)$.

$$C_s = \sum_{i=0}^{N} C_i = \frac{k_w}{t_w} + \left\{ t_w > t_i \{ h \right\Vert w \sum_{t_w > t_{i;}\, i=1}^{N} \frac{(t_w - t_i)\, d_i}{2} \Bigg\} + \sum_{i=1}^{N} \left[\frac{k_i}{t_i} + \frac{h_i d_i t_i}{2} \right] \tag{5}$$

When this integrated function is broken down, warehouse storing inventory costs cannot be described in the conventional manner and which retailer has a greater order interval and which one has a shorter one is also unknown. The goal function can be precisely expressed once solutions have been identified. As previously mentioned, the conceptualization of warehouse holding expenses results in a change in the goal function itself once solutions are established. The warehouse storing inventory module for retailer i appears to be integrated to the goal function based on whether or not the condition between t_w and t_i is given.

Therefore, the function's outcome is dependent on the solutions, which leads to heuristic approaches. The aim is to identify integer values for the optimum solutions, and these values are utilized to determine the final optimum solutions. Heuristic algorithms ought to begin with mathematical formulations. At first, it is presumed that the warehouse contains all stocks in the system, and the derivation of the warehouse's total expenses function is taken with respect to t_w. This procedure determines the warehouse's maximum of the minimum order intervals. The starting value for the stockroom order interval search is t_w. Finding the derivative of (C_i) in accordance with t_i is another way to determine the retailers' starting order intervals.

$$d_w = \sum_{i=1}^{N} d_i \rightarrow t_w^* = \left[\frac{2k_w}{h_w \sum_{i=1}^{N} d_i} \right]^{\frac{1}{2}} \tag{6}$$

$$t_i^* = \left[\frac{2k_i}{h_i d_i}\right]^{\frac{1}{2}} \tag{7}$$

These starting values independently yield the lowest warehousing and retailer costs. Independence is stressed since all of the system's stocks are kept in the warehouse. However, once the relation between the warehouse and retailers is created, the warehouse should not maintain all stocks, which ultimately reduces the system cost from its starting value. Once a relationship is created, it can either increase or decrease for $i = 0, 1, 2...N$ and t_i values can lower the overall cost of the system. Holding inventory at places with more favorable criteria is preferred due to the varied cost parameters at different locations. This leads to the alteration in the value of t_i so as to discover to find an effective solution. The cost functions of warehouses and retailers are transformed for simple computation as follows:

$$TC_i = \left\{\frac{k_i}{t_i} + \frac{h_i d_i t_i}{2}\right\} + \{t_w > t_i\{h_w\,(t_w - t_i)\,d_i||2\} \tag{8}$$

$$TC_w = \frac{k_w}{t_w} \tag{9}$$

An automated storage and retrieval system was incorporated in the warehouse system. So, the investment costs are calculated by adding the cost of the unit load, vertical carousel model and cube storage.

$$A_c = \rho + \sigma + \mu \tag{10}$$

In conclusion,

The total costs of the system without AS/RS can be written as:

$$TC_{T1} = \sum_{i=0}^{N} C_i = \frac{k_w}{t_w} + \left\{t_w > t_i\{h \left\| w \sum_{t_w > t_{i;}\, i=1}^{N} \frac{(t_w - t_i)\,d_i}{2} \right.\right\} + \sum_{i=1}^{N}\left[\frac{k_i}{t_i} + \frac{h_i d_i t_i}{2}\right] + (\gamma \times \delta) + (\alpha \times \beta) \tag{11}$$

The total costs of the system with AS/RS can be written as:

$$\begin{aligned} TC_{T2} \quad = \quad & \sum_{i=0}^{N} C_i = \frac{k_w}{t_w} + \left\{t_w > t_i\{h \left\| w \sum_{t_w > t_{i;}\, i=1}^{N} \frac{(t_w - t_i)\,d_i}{2} \right.\right\} \\ & + \sum_{i=1}^{N}\left[\frac{k_i}{t_i} + \frac{h_i d_i t_i}{2}\right] + \frac{(\gamma \times \delta)}{8} + \frac{(\alpha \times \beta)}{2} + (\rho \times \sigma \times \mu) \end{aligned} \tag{12}$$

3 Result and discussion

There is a lack of literature focused on optimizing total costs by integrating Automated Storage and Retrieval Systems (AS/RS) technology into a warehouse inventory management. Most studies focus on individual aspects like inventory tracking or labor costs, rather than a holistic approach. This highlights a gap in research, as no studies have examined the integration of advanced technologies, like AS/RS, to address multiple factors such as cost reduction, space optimization, and operational efficiency. This study aims to fill this gap by developing an integrated warehouse system that incorporates AS/RS technology to optimize total costs and improve warehouse efficiency and cost-effectiveness.

3.1 Numerical Example:

Numerical examples were performed to demonstrate the system's effectiveness, using parameters from Ercan Senyigit and Hakan Akkan's research to validate the proposed model.[6] The retailers related parameters are given below:

Other parameters:

$\rho = 5041.946, \sigma = 7041.94, \mu = 12083.88, \alpha = 30,000, \beta = 10,000, \gamma = 1.23, \delta = 11,000$

	i=0	i=1	i=2	i=3	i=4	i=5
h_i	11	172	43	378	498	441
k_i	40	202	283	144	408	84
d_i		993	304	542	859	478

3.2 Optimal solution and comparative study

The optimum values from the developed system are given below:

The restock interval at retailer i, $t_w = 2.697$, $t_1 = 0.049$, $t_2 = 0.208$, $t_3 = 0.037$, $t_4 = 0.044$, $t_5 = 0.0282$.

The average total costs incurred by the warehouse $C_w = 54447.13$.

The average total costs incurred by the retailer C_i, $i = 0,1,2,3,4,5$: $C_w = 29.66$, $C_1 = 8306.95$, $C_2 = 2720.07$, $C_3 = 7682.1$, $C_4 = 18683.93$, $C_5 = 5950.97$.

The obtained optimum solutions for with and without the consideration of Automated Storage and Retrieval Systems technology into a warehouse inventory management system are presented in Table 1 and it shows the efficiency of the suggested paradigm.

Table 1. Optimum solutions for with and without the consideration of Automated Storage and Retrieval Systems technology into a warehouse inventory management system

Total costs of the system without AS/RS	Total costs of the system with AS/RS
$TC_{T1} = 1,51,350.81$	$TC_{T2} = 1,33,753.58$

4 Conclusion

This study emphasizes the importance of optimizing total costs in warehouse inventory management through the integration of Automated Storage and Retrieval Systems (AS/RS) technology. Current literature does not focus on optimizing total costs by integrating Automated Storage and Retrieval Systems (AS/RS) technology into warehouse inventory management. Optimizing total costs in warehouse inventory management is crucial for maximizing profitability and ensuring efficient resource use. Most research has focused on individual elements, such as inventory tracking, operational efficiency, or specific cost factors like labor and transportation, rather than taking a comprehensive approach to cost optimization. This points to a research gap, as no studies have explored integrated solutions using advanced technologies like AS/RS to address various aspects of warehouse inventory management, such as cost reduction, space optimization, and operational efficiency, within a unified framework. Addressing this gap could provide valuable insights into developing strategies that leverage AS/RS technology not only for operational enhancements but also for achieving significant cost savings. Therefore, an inventory/distribution system containing one warehouse and N retailers was considered and we have implemented Automated storage and Retrieval systems in order to reduce various inventory costs associated with warehouses and to provide better warehouses for the retailers. It automates our put away and picking processes and it will help us to automate the processes that are prone to redundancy in our warehouse. The novelty of this research lies in its comprehensive cost-optimization approach using AS/RS technology in warehouse inventory management. Unlike existing studies that focus on isolated aspects such as labor efficiency or inventory tracking, this work presents an integrated framework that simultaneously addresses cost reduction, space optimization, and operational efficiency. A computational example is presented to show the effectiveness of the system. Results shows that the total cost of the system without Automated Storage and Retrieval Systems technology is $\$1,51,350.81$ whereas the total cost of the system with Automated Storage and Retrieval Systems technology investment is $\$TC_{T2} = 1,33,753.58$. In this current era, this system is highly encouraged because it helps a lot of warehouses to achieve the results that help them in picking accuracy, reduced labor costs, better floor space utilization. A key recommendation for future research is to explore how AS/RS technology can be modified for various warehouse sizes and industries such as cold storage, pharmaceuticals, and automotive sectors. This work can also be extended by considering the AS/RS technology in e-commerce fulfillment by streamlining the picking and packing processes and other sustainability issue parameters.

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