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Optimization of Traditional Warehouse Management System using Artificial Intelligence and Machine Learning

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Abstract: Warehouses are an essential component of any supply chain. The efficient management of the warehouse is critical for the smooth and timely functioning of the supply chain. If it is not managed properly problems such as high lead time and high operational cost occur. To achieve the best results in warehouse management system of SMEs, new technologies are tested and brought into use in the industries. Artificial intelligence (AI), the ability of a digital computer or computer-controlled robot to perform tasks commonly associated with intelligent beings. Technologies developed by ML and AI can be very beneficial in ease of working of a traditional warehouse by employing intelligent robots and using AI algorithms to improve the time complexity of the warehouse. AI is going to be the next big thing at the international level and upcoming industries have promised exponential growth in industry using AI. In this paper we would help expand our knowledge in the application of AI and ML in Smart Warehouse Management System which will help us reduce lead time and operational cost in SMEs. This paper was developed during the COVID 19 pandemic. So, the physical application was not carried out by the authors and they resorted to the simulation model.

Keywords - Industry 4.0; industrial internet of things; Warehouse Management; Artificial Intelligence; Machine Learning; Supply Chain Management.

1. Introduction

The world has been moving towards a digital future and the use of Industry 4.0 Technologies has played a major role in various industries. The supply chain is vital cog of any company's operations and the activities involved in it have a direct influence on the company's performance. Warehouse is an essential component of the supply chain and the efficient functioning of the warehouse goes a long way in the growth of the company. When it comes to SMEs, the major problem they face is of managing the warehouse and its operations smoothly. The warehouse operations involve picking, sorting, transferring and tagging of the packages within and in or out of the warehouse. But inefficient layout, use of outdated technologies combined with the requirement of human labour derails their advancement. This paper deals with the problems faced by the SMEs and provide solutions to them using Industry 4.0 Technologies like Artificial Intelligence, Machine Learning and Image Processing.

2. Literature Review

In 21st Century warehouse has been an essential component in the supply chain management. Today, most of the E-Commerce companies want to ship orders as fast as possible to increase customer satisfaction. Some Companies also have guaranteed 1-day delivery commitment but this only possible when the goods from the warehouse are retrieved and sorted for dispatch very fast. (Gattorna, J. et al., 1991) For SMEs who work with small-medium sized warehouses, Automation is a better solution as opposed to increasing manpower. The warehouse system requires an automated solution (Hellingrath et al., 2109) which can individually pick and place (Wang et al., 2102) order from warehouse racks to receiving or dispatching counter.

With the advancements in AI and ML Technologies, (Sousa, A. R. and Tavares, 2013) warehouse management system has changed the way companies send and receive orders. (Andjelkovic et al., 2018) Traditional systems can be problematic because as a company's volume order increases, the system of receiving and distributing orders becomes more complex. Companies often expand product offerings, meaning warehouse management systems must adapt to new inventory and the changing business. (Toorajipour et al., 2020) A poor warehouse management system can have deleterious effect on a company's profit, making company lose money by not accurately keeping track of orders. The package picking, sorting and dispatching operations are logistic processes. (Cooper, Martha et al., 1997) They consist of picking, sorting and collecting articles in a specified quantity before shipment to satisfy customers' orders. They are the basic warehousing processes and have an important influence on supply chain's productivity. (Chen, I and Paulraj, Antony, 2004) This makes order picking and order sorting the most controlled logistic process.

Order picking and sorting involves a lot of labour and this operation constitutes a major portion of the expenditure in the warehouse. (Frazelle E.H, 2002). This has a direct impact on the efficiency and productivity of the warehouse. So, various approaches involving automation are being researched to effectively handle this operation in the least possible cost and also, by saving time. An automated system was found which assigned robots to specific zones from which they had to pick up the orders as per commands given (Kim et al. (2002a)). Currently, many industries have not adopted the automated solutions, but the use of AI and other models help to handle the operations smoothly and add their value to the operation.

In-house transportation cost is a major worry for the traditional warehouse management systems of SMEs and they are one of the biggest source of wastes, which need to be eliminated for maximum productivity. 55% of the operating costs revolve around the order picking and sorting process, (Beker, Ivan et al., 2012) making in-house transport an area of improvement. So, by using robots that use AI algorithms like Djikstra's algorithm (Hentschel, Matthias et al., 2007) to find the optimum (shortest) path from point 1 to point 2. This algorithm is used to obtain the shortest path that can be used in the WMS to serve the purpose. This will help improve the business processes and thus, an improvement in productivity can be observed.

The process of order sequencing involves the arrangement of the visits of the racks during picking operation such that it eliminates unnecessary travel time in order to improve system throughput (Hwang and Kim, 2005), which can be achieved by optimization methods and other automated solutions or heuristics (Petersen and Aase, 2004). For a single block layout, (Roodbergen (2001)) proposed different routing policies like traversal, return, midpoint, largest gap and combined with definition. The same can also be used for multi-block warehouses with minor modifications.

3. Working of Traditional Warehouse Management System

3.1 Traditional Warehouse Management System

Warehousing is the storage of goods for profit. The physical location, the warehouse, is a storage facility that receives goods and products for the eventual distribution to consumers or other businesses. A warehouse is also called a distribution center. Warehouse management (Faber, N et al., 2013) is the process of coordinating the incoming goods, the subsequent storage and tracking of the goods, and finally, the distribution of the goods to their proper destinations. Significant changes have taken place in this industry during the 1990s and 2000s as changing business conditions have forced warehouses into adapting new methods and dramatically improving their technologies.

Traditional warehouses are installations that everyone has been building for years. They function in a non-automated way, with operations performed by the company's team of workers. Here, the operators are the ones that must move to the goods, whether they go to a collection point to pick articles or transport them somewhere in-house to be packed and shipped out. (Au Yong and Hui Nee, 2009) A traditional warehouse primarily uses a manual handling system.

Following are the problems observed (Au Yong and Hui Nee, 2009) in the traditional warehouse system:

- **Predicting lead time:** The lead time is the time required to process their order, pick, pack, and ship the order, plus the time required for the truck to deliver the product to your customer's receiving dock, or front porch. Longer delivery lead times mean less satisfied customers.
- **Difficulty customizing management practices:** Lack of automated customizing management practices can lead to mishandling of products and disrupt the proper functioning of the warehouse which would in turn increase the lead time.
- **Lack of communication in regards to inventory:** Lack of communication reduces productivity. If everyone involved in making supply chain decisions is not on the same page, a warehouse is not going to be able to plan and execute shipments timely.
- **Poor Warehouse Layout:** Inadequate storage space and inefficient use of available storage are common problems in warehouses with poor layout. Poorly configured warehouses are a major cause for worry because of the inherent potential for negative impacts on profits.
- **Relying heavily on staff members to enter information manually:** In case of handling warehouse data manually, there is a high risk of human error while handling the data. Moreover, the labour cost involved for handling data is very high which has a financial effect on the management company. (Sri Krishna Kumar et al., 2010)

3.2 Industry 4.0 Technologies

Fig.: 2 Flowchart of work methodology adopted

(Source:*https://www.hackster.io/amit-maniar/industry-4-0-connecting-traditional-hardware-to-internet-bd83ce)*

Industry 4.0 is the subset of the fourth industrial revolution that concerns industry. The fourth industrial revolution encompasses areas which are not normally classified as an industry, such as smart cities, for instance.

Although the terms "industry 4.0" and "fourth industrial revolution" are often used interchangeably, "industry 4.0" factories have machines (Popescu et al., 2017) which are augmented with wireless connectivity and sensors(Liu, H. et al., 2019), connected to a system that can visualize the entire production line and make decisions on its own.

In essence, industry 4.0 is the trend (Trentesaux, D. and Thomas, A. 2012) towards automation and data exchange in manufacturing technologies and processes (Andrew C Yao and John G Carlson, 1999) which include cyber-physical systems (CPS), the internet of things (IoT), industrial internet of things (IIOT), cloud computing, cognitive computing and artificial intelligence. (Helo, Petri and Szekely, Bulcsu, 2005)

The concept includes smart manufacturing, smart factory, smart warehouse management, smart logistics, lights out manufacturing (dark factories) and Internet of Things for manufacturing (IoT).

Industry 4.0 fosters what has been called a "smart factory". Within modular structured smart factories, cyber-physical systems monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over the Internet of Things, cyber-physical systems communicate and cooperate with each other and with humans in real-time both internally and across organizational services offered and used by participants of the value chain.

The determining factor is the pace of change. The correlation of the speed of technological development and, as a result, socio-economic and infrastructural transformations with human life allow us to state a qualitative leap in the speed of development, which marks a transition to a new time era.

4 Objectives

The paper was developed to solve the problems faced by the SMEs and eliminate the problems of time and cost in the current system of the Traditional Warehouse. It uses Artificial Intelligence to reduce the path costs, to reduce the lead time, to minimize errors and in the overall maintenance of the Warehouse. It uses Machine Learning in package handling.

Also, it aims to sort the packages according to the product types using Image Processing. Thus, by reducing the lead time, finding the shortest path and sorting the packages appropriately, the warehouse operations can get more efficient and will help in the ease of operations.

5 Method

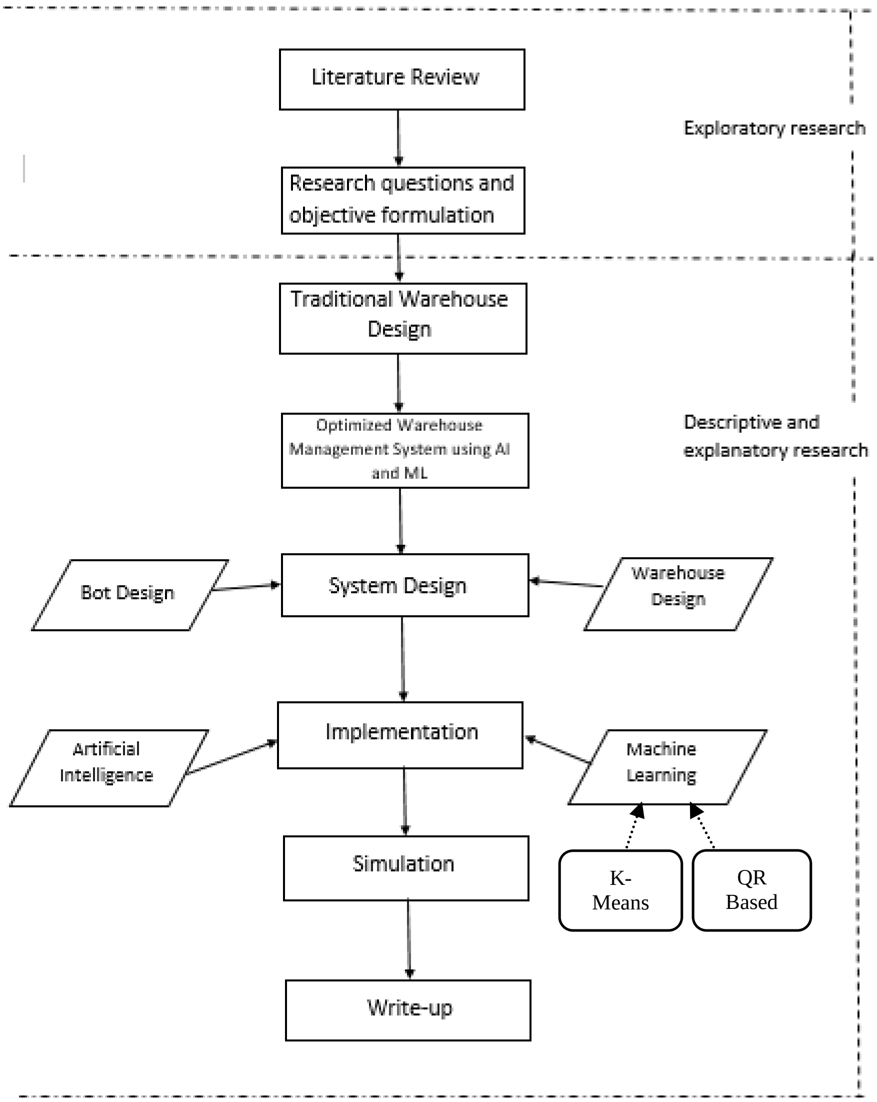

Fig.: 2 Flowchart of work methodology adopted

The objective of this paper is to discover methods to solve traditional warehouse management problems using industry 4.0 techniques. This paper chose the methodology of a systematic literature review to find out the problems faced in the warehouse, the scope of these problems, the advancement in technologies and the potential solution to these problems. This process enhances the knowledge to overcome the obstacles faced in the aforementioned context. This method helps to identify findings and gaps in the literature review and come up with possible recommendations.
The booming technologies like Artificial Intelligence and Machine Learning were studied and how they could be used to solve the warehouse management issues were evaluated.
The research was subjected to high quality research papers published in well-known journals.

The traditional WMS follows: -

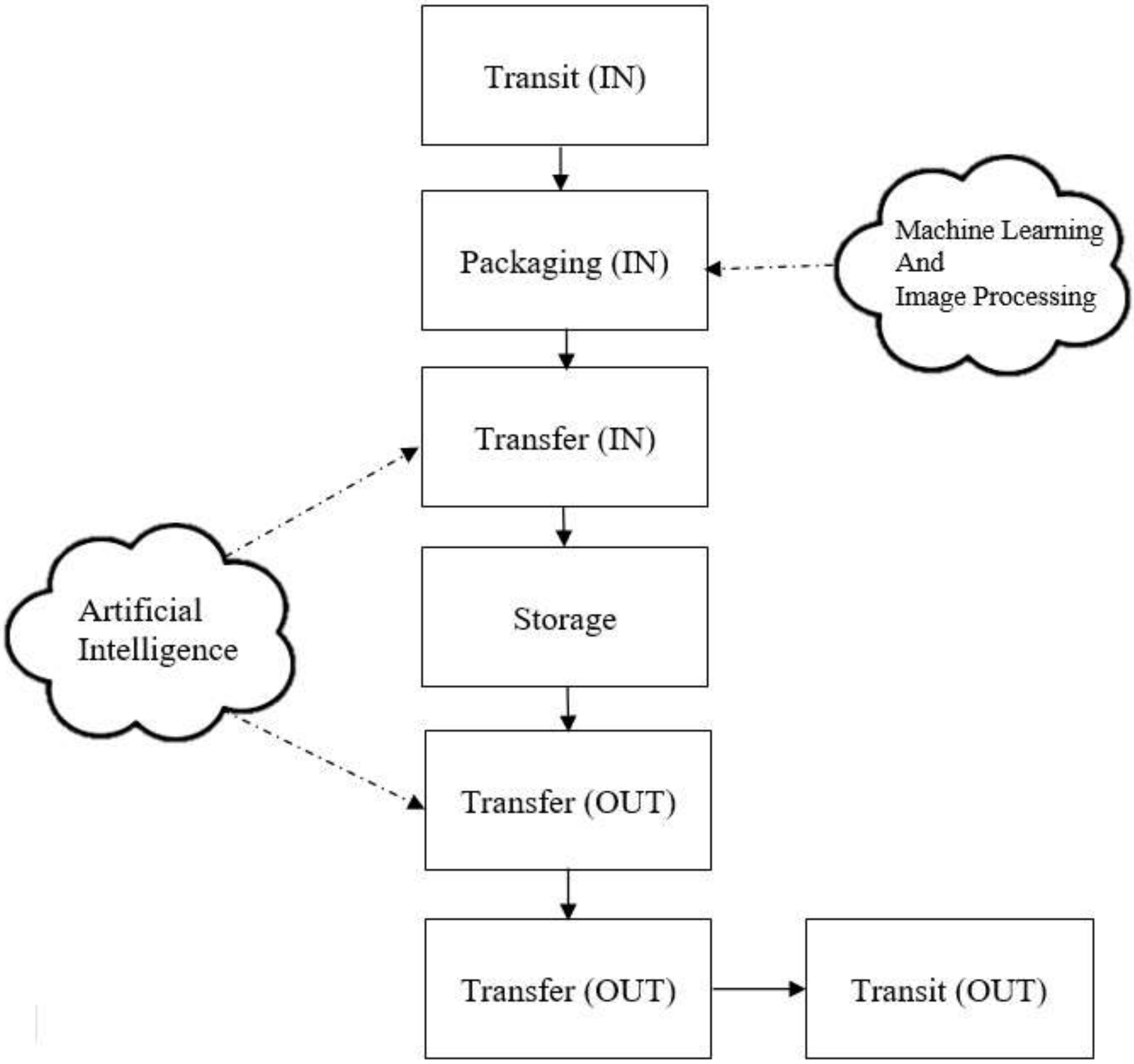

Fig.: 3 Scope of integration of AI and ML in traditional WMS

Receiving (Transit IN): To receive finished product from the manufacturing section.
Packaging: To pack the product. (Preliminary packing)
Storing: To store the products in the inventory.
Transfer: To transfer the product from its location to packaging center.
Packaging: To pack the product and generate an invoice. (Final Packaging)
Expediting (Transit OUT): To dispatch the product for delivery.

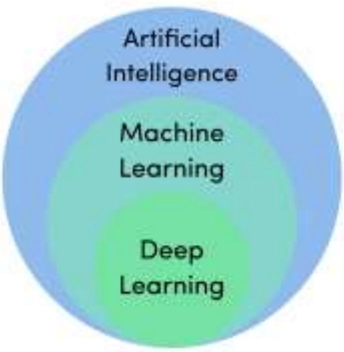

Fig.: 4 Venn diagram showing AI, ML and DL
(Source: https://levity.ai/blog/difference-machine-learning-deep-learning)

The scope of using AI and ML lies in the steps of packaging, sorting, transfer etc. The shortest path is found out using AI which helps the robot to reach its desired destination in the shortest possible time. Sorting of the products is done by ML which helps to organize the warehouse.
Thus, AI and ML helped transform the system into an effective one.

5.1 Warehouse Layout

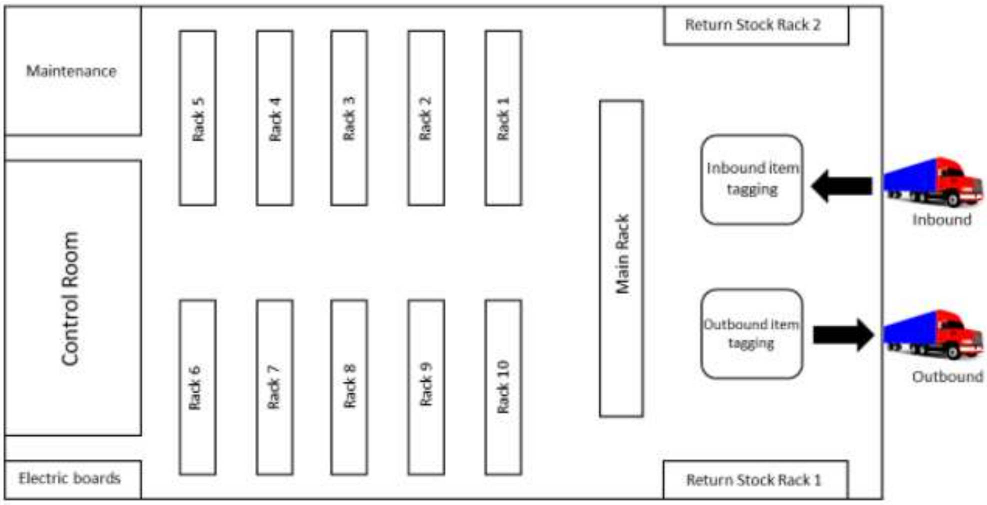

Fig. 5: Warehouse Layout

The layout of the warehouse directly impacts the efficiency of the warehouse operations. The layout should be designed such that it improves productivity, streamlines operations, saves time and optimizes robot paths. A well-executed warehouse layout design provides easy access to stored goods, minimizes travel time and improves order fulfillment rates.
While designing the layout of the warehouse, all the factors affecting business and the product details should be considered during the planning phase itself. Altering the warehouse layout after the construction starts is a costly task due to the additional material and labor costs involved and must be avoided.

5.2 Components of Warehouse Management System

5.2.1 Warehouse Design

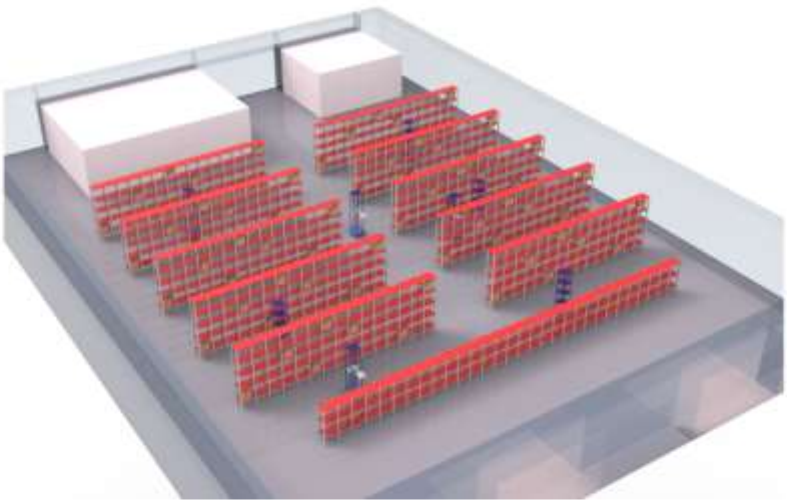

Fig. 6: CAD Model of Warehouse developed in Fusion 360

The warehouse layout consists of total 10 racks, the goods that arrive at the warehouse are tagged at the inbound tagging center and are placed on the main rack where the packages are kept. There is another main rack where the products are transited in the warehouse after being tagged. Moreover, the same main rack is used when the packages are departed out of the warehouse. The packages go through the outbound tagging center before leaving the warehouse. The above warehouse shows the different racks, Master and slave bots present in the warehouse. The maintenance and the control rooms are placed at the backend of the warehouse, the operations of the bots can be controlled from the control while their periodic and emergency maintenance can be done in the maintenance room.

5.2.2 Master and Slave Bot

Fig. 7: CAD Model of Slave Bot and Master Bot developed in Fusion 360

There are 2 types of bots in the WMS, slave bot and the master bot.
The Slave bots are used to carry the products in the warehouse. Each slave bot can carry 4 products at a time. While retrieving the product from the racks these bots use clustering algorithm for optimization i.e., travelling minimum distance to pick the products. The Master bot is used to lift the products from the racks and place it on the slave bot, for it to transfer the products to the desired location. Once the clustering algorithm is used by the slave robot to determine the products to be lifted by it, the master robot travels to the nearest slave robot to place the product on it.

Both the bots operate using the line follower mechanism. Using canny edge detection algorithm, the black strips which are placed on the floor are detected with the help of camera sensors. To implement this algorithm, OpenCV was used. The bot is programmed in such a way that it processes the image using the above-mentioned algorithm and follows the detected edges which is actually the black strip placed on the floor which triggers the movement of the bots across the warehouse.
Integrating Raspberry and OpenCV, the code is fed to the robot and is responsible for the bot's motion.

5.3 Use of Dijkstra's Algorithm for finding the shortest path

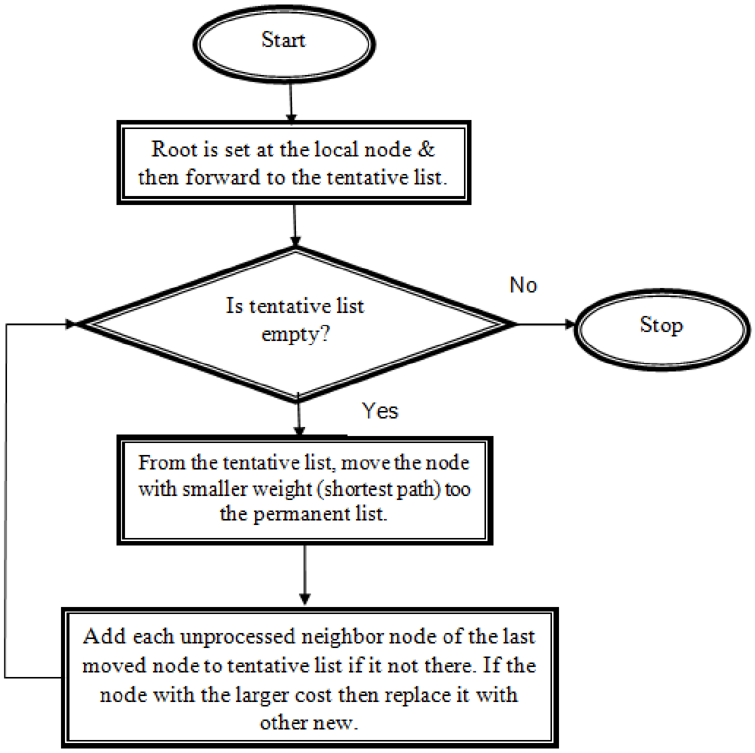

Fig. 8: Flowchart of Dijkstra's Algorithm

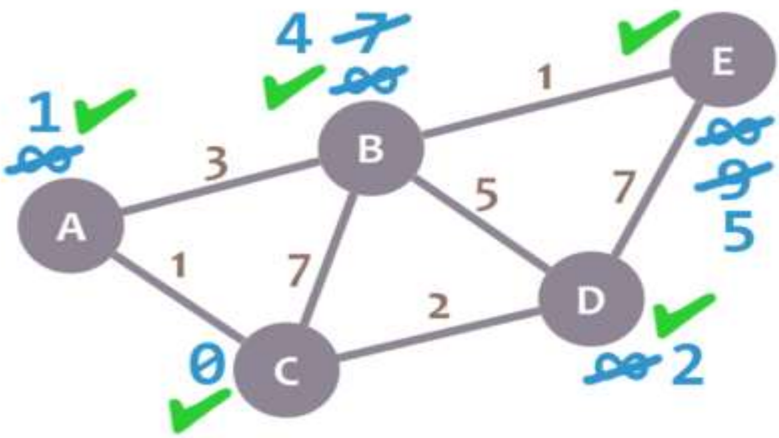

Fig. 9: Djikstra's Algorithm

(Source:*https://www.codingame.com/playgrounds/1608/shortest-paths-with-dijkstras-algorithm/dijkstras-algorithm)*

The algorithm we have used is Djikstra's algorithm. The algorithm starts by marking the selected initial node with a current distance of 0 and the rest with infinity. The non-visited node with the smallest current distance is set as the current node (Node-C). If the sum of heuristic value of the current node(C) and the edge distance connecting to the new node is less than the heuristic value of the new node then set the new node as the sum of heuristic value of former node and the edge distance. The current node(C) is marked as visited. The process repeats in case of non-visited nodes.

This enables the robot to travel the shortest path inside the warehouse from its current position to the desired destination. This reduces the time required to travel which is more in case of traditional systems.

5.4 Use of K-Means Clustering for grouping of products

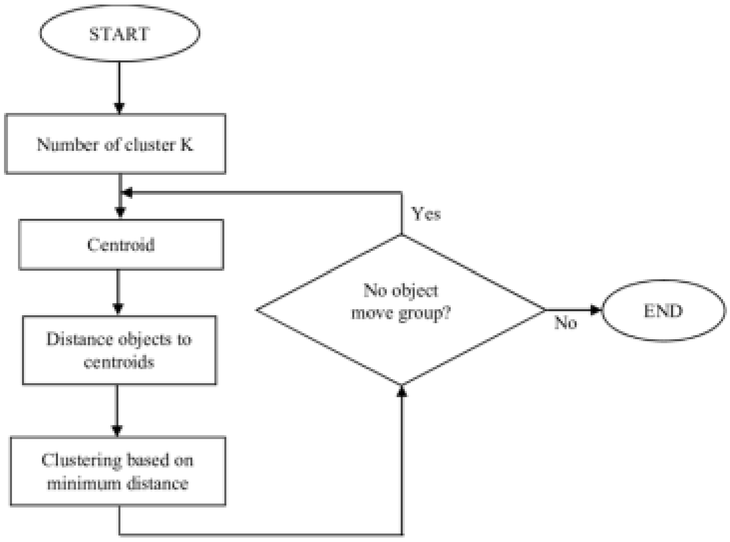

Fig. 10: Flowchart of K-Means Algorithm in WMS

In this case each robot can pick 4 products at a time and there are 4 robots hence in all 16 products can be picked at a time. In order to optimize the process of product picking by the robots K-Means algorithm is being employed. In this case 4 clusters will be formed with each cluster consisting of 4 products. The Euclidean distance of each robot will be calculated from the centroids of each of the clusters. The robots having the shortest distance from the corresponding clusters will go to that particular cluster to pick the products. Each robot will pick all the products of the corresponding cluster which it has shortest distance from and carry it to the destination node. This way the the distance travelled by robots and the time required to pick the products would reduce drastically thereby increasing efficiency.

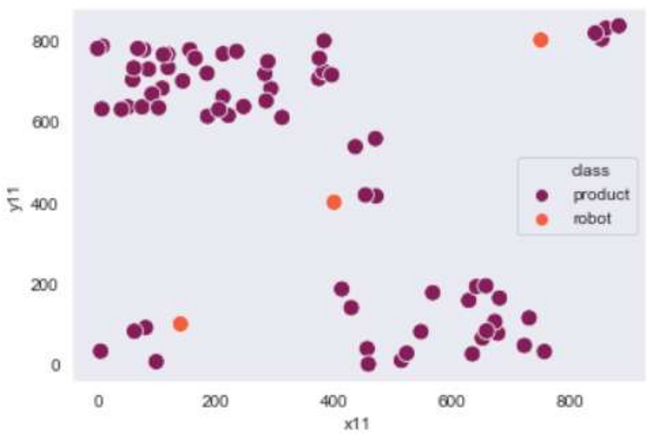

Fig. 11: Clustering Model of WMS

5.5 Image Processing for identifying the type of product

We have used OpenCV library of Python to detect the QR code which is present on the packages. Pyzbar library is also used to extract the information after detecting the bar code using the OpenCV library. These QR codes which will be present on the boxes will consists of the information about the type of product and the destination rack on which it is to be placed. Each robot present in the warehouse will have the ability to scan the QR code and extract the information using the above mentioned libraries. Once, the robot gets the desired information, it will carry that particular set of packages to their desired location.

Fig. 12: QR code Detection and Information Extraction

6 Results and Discussion

This paper identified the operations of a traditional warehouse management system and analyzed the shortcomings in it. A warehouse is an essential component of the supply chain and the efficiency and ease of operation are to be improved. It was identified that the lead time was higher in traditional warehouse systems.

6.1 Cost Analysis

Traditional WMS				Optimized WMS			
Component	Cost	6 month period		Component	Cost	6 month period	After 6 months
Labour (15)	500/day	1350000		Bots	422302	422302	Nil
Maintenance		270000		Warehouse + Bot Maintenance			45000/m
Miscellaneous		54000		Bot Maintenance			20000/m
		1674000		Workforce(6)			130000
		279000/m					195000/m

Fig. 13: Cost Analysis

To optimize the Traditional WMS, we require 6 months to build the bots and rejig the layout.

So, Traditional WMS, over a 6 month period will cost a total of Rs. 279000 per month.

The cost for making the bots is Rs.422302 over 6 months for the skilled men.

So, Initial Investment in the Optimized WMS = Rs. 422302

After this initial 6 months period, the cost the SME owner will have to spend = Rs. 195000 per month.

Total Savings = Rs.84000 per month + Time savings

Hence, the Initial Investment can be recovered in less than 5 months with an increase in productivity.

6.2 Time Analysis

Case1: Package to be placed on Rack 4 by picking them up from the main rack

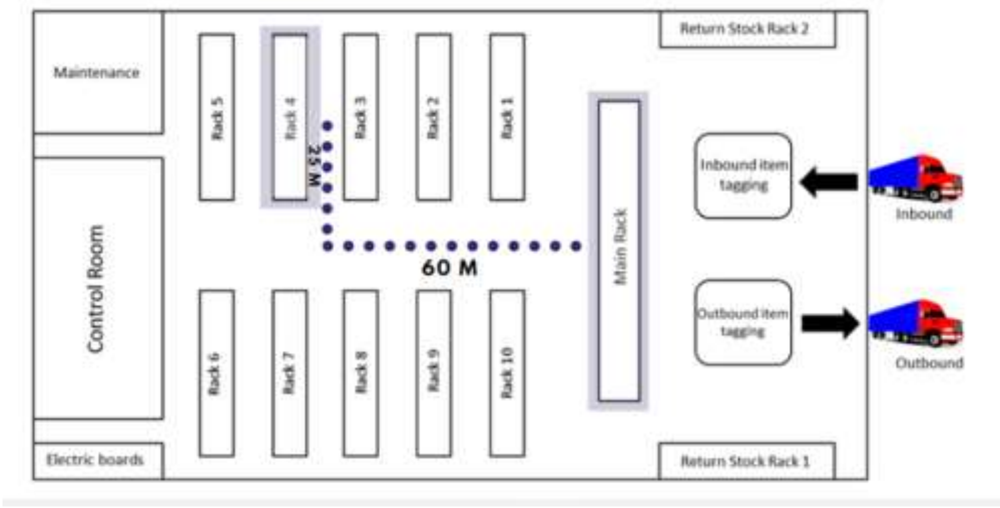

Fig. 14: Time Analysis (a)

Entity	Speed	Distance to travel	Packages	Time
Person	1.2	(60 + 25) m	2	71 s
Robot	4	(60 + 25) m	4	21 s

Table 1a. Time Calculations–Case 1

The average speed of a person while walking and carrying 2 packages is assumed to be 1.2 m/s.
The average speed of the bot carrying 4 packages is assumed to be 4 m/s.
The distance from the main rack to rack 4 is 60+25 = 85 m.
So, a person will take 71 secs to place the objects on rack 4 while the robot will take only 21 secs to place 4 packages on rack 4 in a single journey.
The person will have to return to the main rack to collect the next packages and deliver according to the destination. So, another 71 secs will be added here. But, in the case of bots, the slave bot doesn't need to return as the nearest bot to the next desired location will be doing the job.
Hence, Time Saved = 50 secs (on added delivery of 2 packages more).

Case2: Packages to be picked from Rack 4 and placed on the main rack

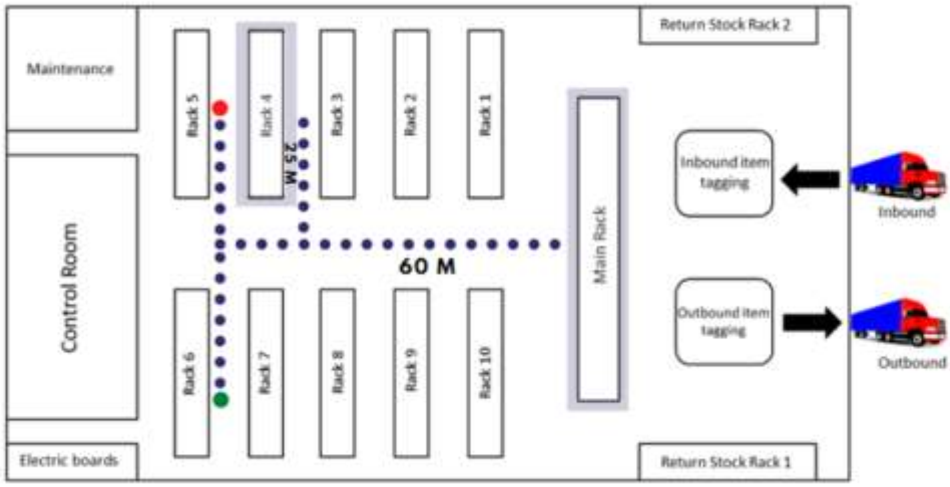

Fig. 14: Time Analysis (b)

Entity	Speed	Distance to travel	Packages	Time
Person	1.2	(60 + 25) m	2	71*2+20 = 162 s
Slave Bot	4	(25 + 20 + 25 + 25 + 60) m	4	(17.5+17.5+10+22) s
Master Bot	4	(25 + 20 + 25) m	0	17.5

Table 1b. Time Calculations–Case 2

The average speed of a person while walking and carrying 2 packages is assumed to be 1.2 m/s.
The average speed of the bot carrying 4 packages is assumed to be 4 m/s.
The distance from the main rack to rack 4 is 60+25 = 85 m.
The distance from the slave bot position ( ) to rack 4 is 25+20+25 = 70 m.
So, a person will take 71 secs to reach rack 4, pick up the packages for 20 secs and return in 71 secs. So, it takes a total of 162 secs for a person to pick up 2 packages.
On the other hand, slave bot takes 17.5 secs to reach rack 4 ; then it gives a signal to the master bot( ) closest to rack 4 to come to his position. The master bot takes 17.5 secs (which is the waiting time for the slave bot) to reach rack 4 where it places 4 packages(10 secs) on the slave bot and holds it's position. The slave bot now reaches the main rack in 22 secs. So, it takes a total of 67 secs to pick up 4 packages.
Time saved = 162 – 67 = 95 secs
Productivity = 2.0 (4 packages instead of 2)

Total Productivity = (4/2)*(162/67) = 4.835

The integration of AI and ML in the Traditional WMS helped automate the manual operations which reduced the human error and increased the speed of the operations. A proper layout supporting the robot's movements and simplifying it was designed. As the process was automated, keeping track of the movement of products got easier. The shortest path is found out using AI which helps the robot to reach its desired destination in the shortest possible time. Sorting of the products is done by ML which helps to organize the warehouse.

Thus, AI and ML technologies helped transform the system into an effective one.

7 Conclusion

This paper is able to show the potential solutions to the problems faced by SMEs in their warehouse management activities. By investigating the problem and performing a literature review on the systems as well as Industry 4.0 technologies, it can be concluded that the use of Artificial Intelligence and Machine Learning can prove to be a game changer in the field of Warehouse Management. It not only reduces the total time required for the activities, but also makes operational activities easier. These companies are recommended to use the optimized system despite the initial investment because in the long run, this is going to be far more beneficial as suggested in the paper. There's still a lot of potential solutions that can come up with newer and newer technologies coming up every year. So, this study can be further upgraded to reap better results.

Therefore, companies should start looking at Industry 4.0 Integration in their operations thus, improving efficiency and grow their company in the market at an exponential rate.

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