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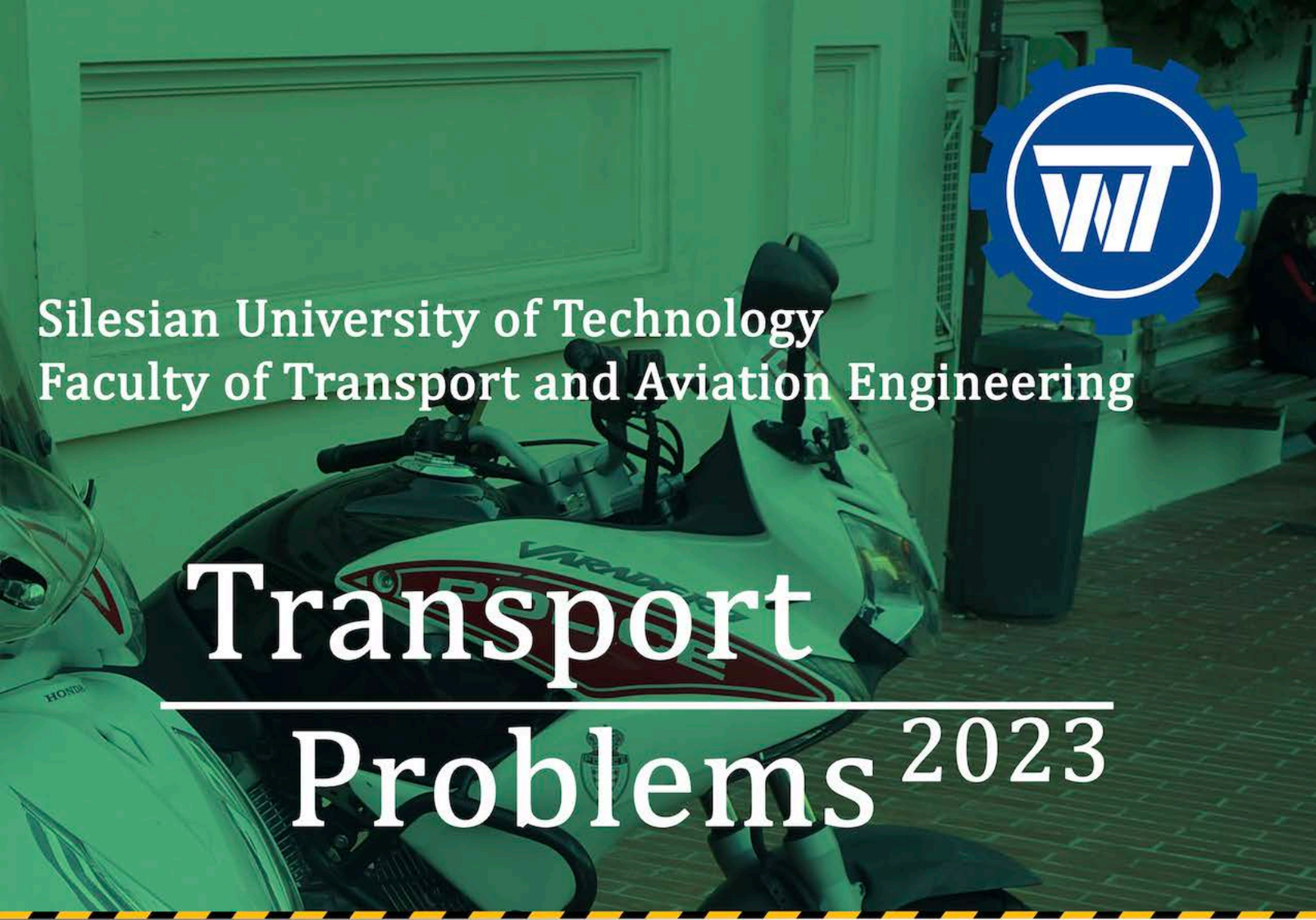
XII INTERNATIONAL SYMPOSIUM OF YOUNG RESEARCHERS



Silesian University of Technology
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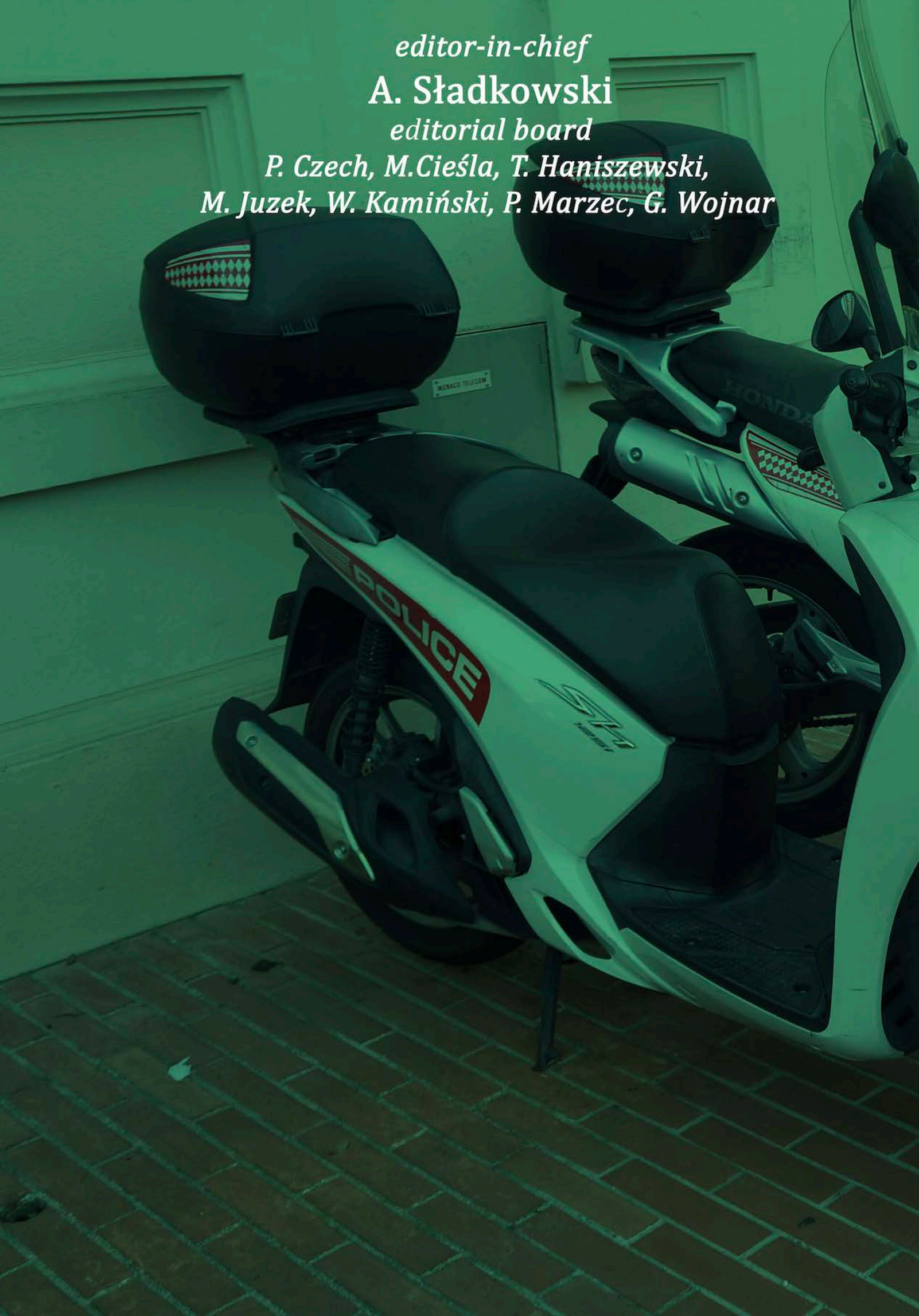

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Keywords: automated guided vehicles; warehouse automation

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THE USE OF AUTOMATED VEHICLES IN WAREHOUSES

Summary. The use and integration of automated solutions in warehouses are seeing an uptrend, while many warehouses and factories have already adopted an automated solution, many more are yet to do it, this paper will detail the major factors that warehouses need to consider before switching their operation into automation, the benefits they will get from it, as well as a presentation of the widely used robotics and their operating principles.

1. INTRODUCTION

In recent years, the consumer's lifestyle and consumption habits have seen a major shift, and their tendencies became more diverse than ever before, this change was mainly driven by the ease and widespread of e-commerce, the development of supply chains and order fulfillment centers, as well as the Sars-COVID-19 global pandemic which put a massive strain on supply chains and in-store shopping due to the lockdowns that many countries have enforced to curb the disease. All these factors have pushed consumers to turn toward other alternatives to satisfy their needs, on the other hand, companies, and their logistic partners to establish new solutions to meet this growing demand, and to counteract the effect of the pandemic, as well as to be more competitive in the market in the long-term perspective.

One of the solutions that were implemented and has seen an uptrend on the global supply chain, was the integration of automation and robotics in warehouses, to cater for the continuing growing demand and changing flexibility of the consumer market, many companies compete to put in place the latest technologies to meet the flexibility of the demand. Even though the use of robotics and automation processes in warehouses began many years ago, The Sars-COVID-19 pandemic exposed weaknesses and accelerated the pace of integration of automation in warehouses.

2. AUTOMATED GUIDED VEHICLES MARKET OUTLOOK

The automated guided vehicles market has been experiencing significant growth within the past decades, and it is expected to keep a growing trend in the next decade. Currently, the automated guided vehicle market size is valued at $2.1 billion, and analysts forecast a growth with a compound annual growth rate (CAGR) of 11.5%, reaching a market size value of approximately $6.23 billion by the year 2030.

From the factors driving this growth, the increasing demand for automation in good handling, warehousing, and logistics, across many industries, the rise in popularity for online shopping, and companies strive for increased efficiency and cost-effective technologies.

Fig. 1. Automated guided vehicles market size [2020 to 2030] in USD Billion [1]

3. THE BENEFITS OF WAREHOUSE AUTOMATION

The benefits of autonomous vehicles in warehouses are numerous, and continually expanding due to the improvement of existing technologies as well as the invention of new ones. Companies compete to launch new, more advanced, creative solutions to remain competitive in this growing market.

The first benefit of automation is the enhanced accuracy and waste reduction, by eliminating the human-induced errors due to the wrong and inadequate handling of goods and materials, as well as the almost perfect accuracy of picking the selected item. This will decrease the waste and improve the profitability margins.

Enhanced speed is another strong point of autonomous vehicles, even though the manual driven vehicles or human laborers can move quicker than an Autonomous Guided Vehicle, the latter has the advantage of accuracy and reduced time waste, and thus, an overall improvement of operating speed.

A safer work environment and reduced risk of accidents and injuries are a major advantage of an automated warehouse, this will help eliminate the liability and work accidents' insurance costs, as well as establishing a healthy workspace. And reduce the human workload significantly.

One more point of strength for AGV Solutions is the possibility to work 24 hours a day, 7 days a week, in non-stop shifts, this will boost the warehouse's efficiency and operating capacity, with minimum human intervention.

Further gains are the scalability of Autonomous Guided Vehicle Solution, which means that the company can increase and decrease the operating volume of the warehouse according to demand with minimum change to the existing installation, furthermore, the real-time inventory management, instead of the time-consuming manual inventory management and tracking. And finally, and most importantly, the reduced cost of operation of the automated solution and the relatively short ROI (Return on investment) time frame, which is the time after which the company pays off the amount invested and starts seeing profits out of it. The ROI in such a case is very short in comparison with the manual driven solutions, and that of course, depends on the complexity of the robotics and installations in the warehouse.

4. CATEGORIES OF AUTOMATION IN A WAREHOUSE

As shown in the diagram of Fig. 2, there are different categories of automation in a warehouse, depending on the technology and its extent in the warehouse operations, in both the decision-making and the goods' handling.

We define a low automated warehouse, a facility that uses minimal or basic automation technology, and that for both decision-making and goods' handling, it relies mainly on conventional material-handling equipment and manual labor.

The system automation and mechanized automation categories are an improvement of the low automation, they both utilize more automated decision-making processes and an advanced software, while the good's handling characteristics ranges from low to medium, while maintaining the need for human labor.

The sophisticated automation warehouse refers to a highly advanced facility that incorporates automation in the whole operating processes, from decision making to material handling, controlled by an advanced Warehouse management software and highly automated robotics, creating a highly efficient and productive environment.

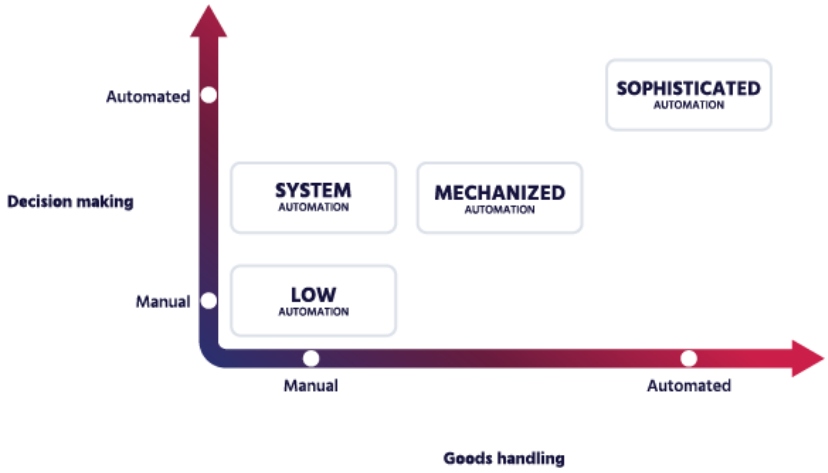

Fig. 2. Categories of automation in a warehouse diagram [2]

5. WAREHOUSE MANAGEMENT SYSTEM (WMS)

The warehouse management system (WMS) is a software that help companies manage their daily warehouse operations, its functionalities range from inventory management, barcode scanning, counting, stocking, storage, goods' reallocation, to labor management and reporting. The warehouse management system integrates with other systems such as enterprise resource planning (ERP) and Transport management system (TMS) as well as Robotics fleet management system, to ensure seamless data flow and control of warehouse operations.

The cost of implementing a Warehouse Management System can vary widely depending on many factors, the most significant factor is the complexity and size of the warehouse operations, the number of facilities or warehouses controlled by the WMS, and the license class.

We distinguish two classes of license for widely used warehouse management software, the first is the perpetual license, which offers the company the ownership of the full license and features of the software, this version is more expensive to buy and install, with prices range between $2,500 dollars and $200,000 dollars, installation fees for the perpetual version ranges between $2,400 dollars and $12,000 dollars.

The high cost of implementation of a WMS under a perpetual license comes with many advantages, such as the ability to customize the software and its functionalities to adapt to the warehouse's operations, a full set of hardware and its infrastructure installation, the implementation, integration, support, and maintenance fees are all included in the final cost.

The second class of license for a Warehouse management system is the Software as a Service (SaaS), which is a cloud-based delivery model where the software is hosted and maintained by its developer, and customers gain access to it by paying a subscription fee.

The subscription fees are considerably low, ranging from $100 dollars to $500 dollars per month, with installation costs between $1,100 and $7,700 dollars. The major drawback of the SaaS license is the limited functionality and features of the software.

To summarize, the cost of installation of WMS software depends on many variables, the type of software's license, the size of the warehouse, the volume of operations, the complexity of the network within the facility, as well as the number of warehouses.

Fig. 3 depicts an example of the approximate cost of a perpetual license of a WMS, the graph shows that installing a WMS within an automotive manufacturing facility cost more than other industries, and that due to the complexity of the automotive manufacturing facilities, and the large numbers of assembly lines, pickup and drop off points. etc., to conclude that the final cost of a WMS solution depends on the complexity of the operations within the warehouse.

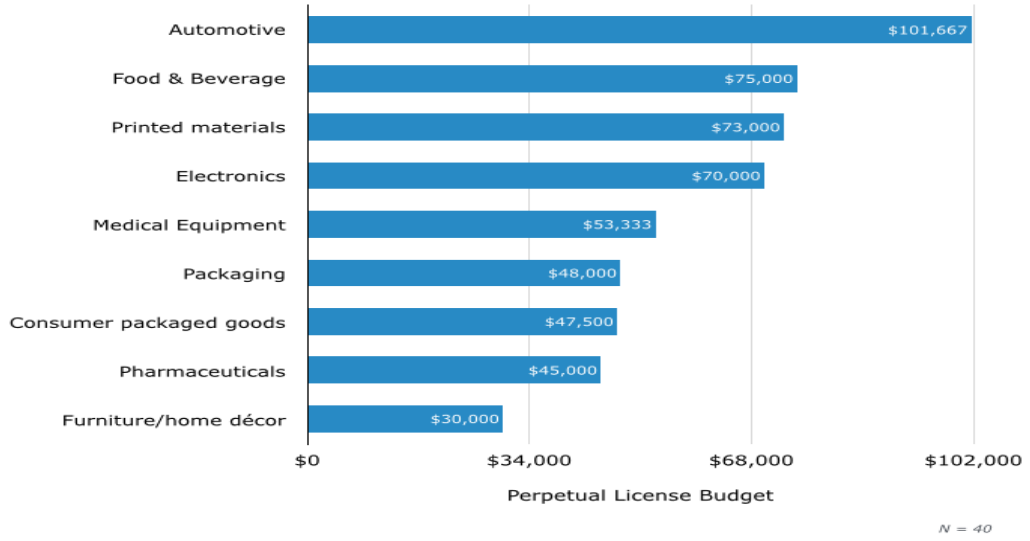

Fig. 3. Perpetual license budget by industry (Approximate numbers) [3]

6. THE MAIN FACTORS TO CONSIDER BEFORE APPLYING AUTOMATION IN A WAREHOUSE

There is no doubt that transforming into an automated warehouse operation is a big step towards efficiency and cost saving, these investments must go through intensive planning, and deep considerations for both current and future structure of the company, there are some major points to consider in such a planning, to face as less setbacks as possible when implementing the automation solution.

6.1. Brownfield or greenfield installation

Starting by choosing if the warehouse is a Brownfield or Greenfield, a brownfield warehouse or facility is the one that has already been built, and the automation network needs to be adjusted according to the

existing facility, this can pose a challenge, as the existing facility may not allow the installation of a highly efficient robotic network and thus, limiting the company's ability to adopt a solution with high degree of automation.

The second option is the greenfield, in which the facility has not been yet built, and this gives more flexibility in putting a network that will meet the needs of the warehouse, and achieve its full potential, because the facility can be built around the robotic network and not opposite as in a brownfield.

6.2. The operations of the warehouse

The operations of the warehouse and the products specification, as there are many warehouses with different operations: Production line, assembly line, packaging, distribution … etc., selecting the most convenient autonomous vehicles for the warehouse operation is vital, as well as matching these vehicles with the product specifications and count for any unexpected event, where products are of different kind of the original, most common products handled in the daily processes of the warehouse, products specifications like : the item dimensions, weight, fragility and storage conditions must all be taken into account, in addition a safety margin must be applied to counteract any unexpected event, where the products are of different specifications than the usual ones.

6.3. The human factor

The availability and efficiency of the manual handling of products is very important in assuring the efficiency of the operations, as discussed in Fig. 2, the less human intervention available, the more sophisticated and autonomous the network must be, and vise-versa.

6.4. The volume of operations and peak-to-non-peak ratio

Having an insight of the mean volume of operation throughout the year helps establish an efficient network to meet the demand, but as we may observe an increase in volumes, the installation must be capable of adjusting to the increased demand. A very large gap between normal and abnormal operations' volumes and subsequently a large peak-to-non-peak-ratio can pose a major strain on the autonomous vehicles' network, this must be foreseen and considered to calculate the adequate number of stations or robotics needed to diminish the effects of this disparity at minimal cost. An example of peak-to-non-peak ratio is the end-of-year period of discounts, in such a period many businesses experience a boom in demand, and warehouses are obliged to increase their operating volume to meet the high demand, this can pose a risk to the smooth operations of the warehouses, longer processing times and subsequentially, financial losses.

6.5. The return on investment (ROI)

The most important factor to consider as mentioned earlier is the ROI (Return on investment), this is the period needed for the company to pay-off the amount of money invested in applying the automated solution and entering profitability, having the right network, the right robotics to match the warehouse's needs is vital important to make the ROI period as short as possible. Otherwise, having more installation than needed will be a waste of investment funds, and on the other hand, having less-than-required network will require more investments to upgrade the facility's capabilities.

To emphasize on the importance of the cost and ROI for an automated solution, the chart below, indicates that almost 85% of warehouses' operators consider the cost of the solution as the leading criteria in their choice, along with the reliability and application possibilities, while other criteria were less considered.

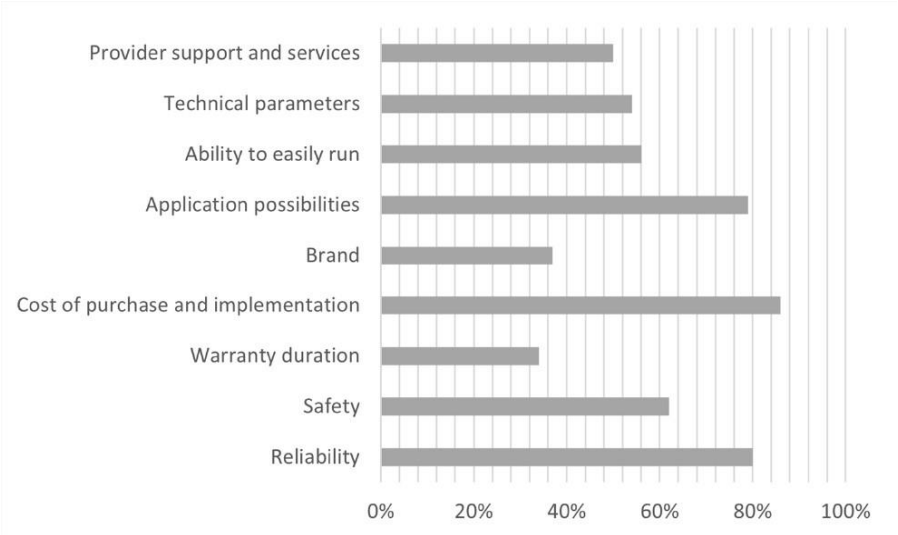

Fig. 4. Criteria for the selection of AGV solution by future users [4]

7. AUTONOMOUS GUIDED VEHICLES BLOCK DIAGRAM

As shown in the diagram of Fig. 5. An Automated Guided Vehicles (AGV)/Autonomous Mobile Robot (AMR) has many units to control its operation within the warehouse, namely: Power supply unit, Control unit, Navigation unit and Ancillary unit. In this paper we will focus on two main units to discuss: The power supply unit and the navigation unit, regarding the fact that the final cost of the equipment relies on these two components.

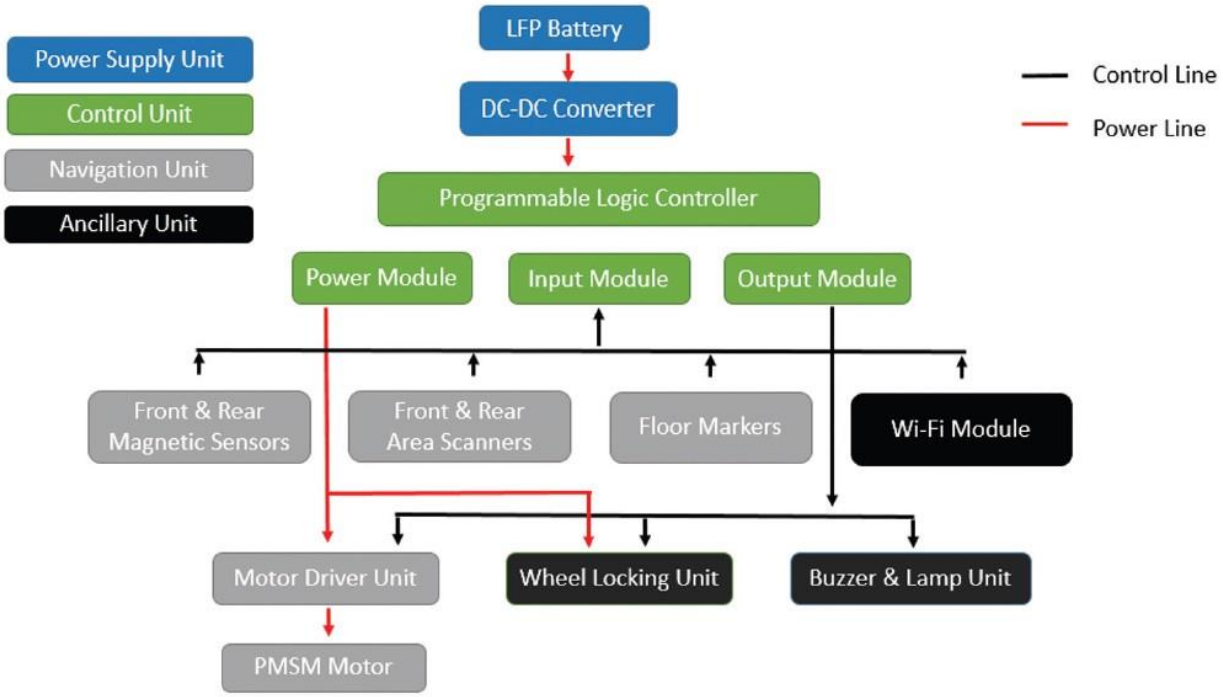

Fig. 5. AGV/AMR block diagram [5]

7.1. The power supply unit

Most AGV/AMR available on the market currently are battery powered robots, the most common batteries used are Lead acid batteries, LFP (Lithium-iron-phosphate) battery and ultra cap-battery hybrid. A scalar comparison of the three types is detailed in Fig. 6.

An overall study shows that the Lead acid batteries are less favorable for an AGV/AMR because of their long charging time and low cycle life. Other options like Ultracap-Battery hybrid and Lithium-iron-phosphate (LFP) batteries, which exhibit much improved performances.

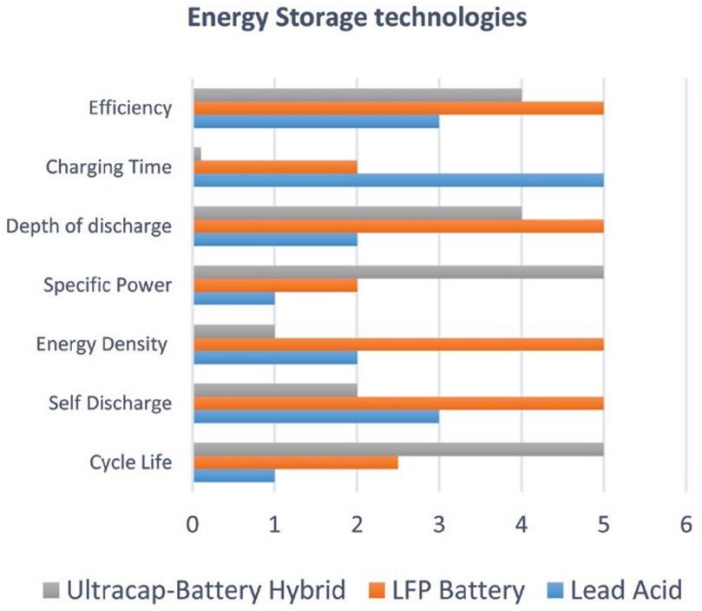

Fig. 6. AGV/AMR energy storage technology comparison [6]

7.2. Automated guided vehicles charging solutions

Different kinds of AGVs use different kinds of batteries, requiring different charging methods. The three most common charging methods are charging traction batteries, non-contact energy transfer and hybrid systems. When the AGVs require charging, there are five methods of charging schemes. The first one, and the most basic, is to manually swap from a dying battery to a new one by ordering the AGV to a charging station. The second method is to use the same approach as the first method but letting the swapping of batteries be done by a machine instead of manually. In the third method, the AGV are charged during its natural idle time, placing charging station close to natural stopping points. The fourth method should be used when there is little opportunity for charging and using non-predictable routes.

The AGV will operate until it reaches a certain percental limit and is then ordered to charge at a station until the battery reaches an acceptable level. The final method is a combination of the third and fourth method. The AGV can either charge at opportunity until the battery reaches an acceptable percentage, or to be ordered to a charging station when it reaches below the determined limit [7].

The table 1 below shows the features of each charging solution, the opportunity charging AGVs spend between 10% and 25% of working time in charging, compared to only 2% for the battery swap AGVs, and that will require the increase of automated guided vehicles number to maintain the workflow, even though, the integrated battery comes at a good price, the need for more AGVs will drive the total cost of automated solution higher, but, it needs little, to no human intervention in the charging process, and that makes AGVs with opportunity charging solution a good fit for the warehouses aiming for full automation.

The battery exchange solution provides many benefits, mainly and most importantly the very marginal charging time compared to operating time (only 2%), with low battery cost, and low labor cost, especially for the Automatic battery swap, the need for a reserve battery will influence the final cost of the automated solution, as well as the high cost of the AGVs equipped with this technology.

Tab. 1

Comparative table of advantages and disadvantages of different AGV charging solutions

Feature	Opportunity charging	Manual Battery Swap	Automatic Battery swap
Mobile Robot Availability time [%]	75% - 90%	98%	
Battery Cost	HIGH	LOW	
Need for Back-up Battery	NO	YES	
Mobile Robot cost	Average	HIGH	
Labor cost	LOW	HIGH	LOW
Charging Station installation cost	Average	LOW	HIGH
Total mobile robot system cost	Depends on Warehouse current installation		

7.2.1. Opportunity charging solution

The Fig. 7 shows a basic Automated guided vehicles charging station, the AGV, is directed automatically toward the charging station when the battery hits a predetermined level, the AGV collector will connect to a plate, mounted on the floor or on the wall, and charging will start, at the end of charging, the AGV will reintegrate to the workflow.

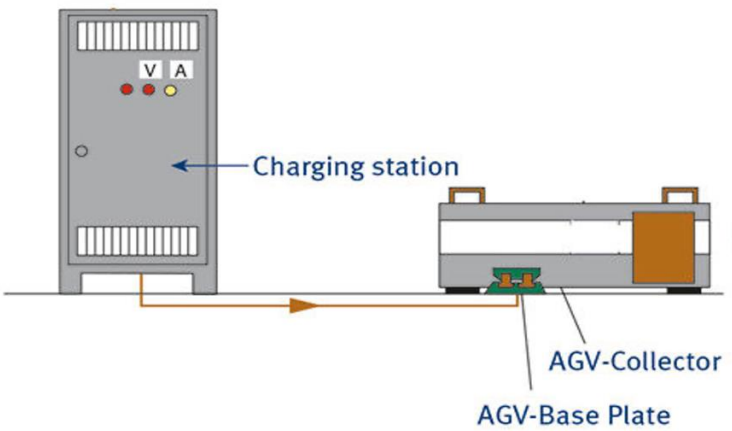

Fig. 7. Basic Automated guided vehicle (AGV) charging station [8]

7.2.2. Battery swap charging solution

There are two battery swap techniques, one relies on human intervention and the depleted battery will be changed manually with the help of a battery swap platform [Fig.8][9], and the second, will be swapped automatically with the help of a specialized robot.

Fig. 8. Manual battery swap platform [9]

7.3. Automated guided vehicle navigation solutions

Navigation technologies for automated guided vehicles are improving day to day, choosing the right navigation technique that fits the warehouse needs is of paramount importance, in this paragraph we will discuss the most common navigation techniques, their operations, advantages and disadvantages.

Before going ahead, it's worth mentioning the fundamental difference between the two types of robots mentioned in this text, Automated guided vehicles AGVs and Autonomous Mobile Robots AMRs, AGVs follow a defined path, virtual of physical, with external references using laser navigation, magnetic tape navigation, QR code navigation…etc. However, for the AMRs are not bonded to a single path, and do not require any external reference to navigate. This is a beneficial characteristic when it comes to obstacle avoidance without human intervention.

The most basic navigation technique is magnetic tape, in which the robot follows a path defined by the tape, similarly, a QR code navigation and magnetic spot navigation, both use physical references fixed on the ground to navigate. These installations are relatively cheap and easy to install and modify, but the main disadvantage is the low flexibility, and difficulty in installing complex paths.

More advanced techniques are the laser guided navigation, and natural feature navigation, the first technique uses laser deflectors that are mounted at the walls of the warehouse, while the AGV is equipped with sensors and laser emitters that emits laser beams at 360°, the beams reflected by the deflectors are received and sensed by the sensors on the AGV, calculating the location of the robot.

Natural navigation technique uses no deflectors and depends mainly on the sensors mounted on the AGV itself to determine its position and navigate its path. These two techniques being more advanced, more accurate, easier to install and cheap to maintain, than the tape techniques, they come with their own

disadvantages, any modification requires supplier intervention and the AGVs using these technologies are very expensive.

8. CONCLUSIONS

From the discussion above, we conclude that choosing the right AGV solution for the warehouse operation depends on many variables, the two major factors that decide the AGV solution final cost are the charging solution and the navigation technique, a battery swap solution might require additional human workforce to maintain the charging cycles of AGV's, but the off duty time that the robot spends out of the network is marginal, and thus, the warehouse will need less robots than a battery charging solution, in which the AGV spends a significant time charging the battery. However, the latter option requires little to no human intervention, and so reduces the labor costs.

Additionally, the navigation techniques play a big part in the pricing of the Automated system, using physical navigation methods such as magnetic tape, QR code sensors may reduce the cost on the expenses of limited flexibility. While adopting more advanced solutions such as Laser and natural navigation offers more reliability and accuracy, it comes with additional expenses as the AGVs equipped with this technology are much more costly.

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