State of the art on design and management of material handling systems

Zuin S., Sgarbossa F., Calzavara M., Persona A.

Department of Management and Engineering, University of Padua, Stradella San Nicola 3, 36100, Vicenza, Italy

(silvia.zuin.4@studenti.unipd.it, fabio.sgarbossa@unipd.it, martina.calzavara@unipd.it, alessandro.persona@unipd.it

Abstract: The recent trends in production management have forced manufacturing and assembly systems to be more flexible and efficiency. In the last years, the attention of managers has been moved to the design and management of the material handling systems. The main reasons are the increasing of products flows intensity and the more complex requirements. As a process, Material Handling incorporates a wide range of manual, semi-automated and automated equipment and systems that support logistics. The internal movement of products and resources has been influenced considerably by the technological developments. In recent decades, researchers have developed various design models to optimize the number of vehicles required and the optimized management of these in terms of routing, scheduling and location. This literature review provides the state of the art of these arguments analyzing the gap present and showing some trends for future.

Keywords: Fleet sizing problem, fleet management, AGVs, forklifts

1. Introduction

The term Material Handling (MH) identifies the discipline that studies the handling and storage of materials (generally including liquids, bulk solids, gases, etc.) that is realized in manufacturing and distribution companies. A substantial difference with the manufacturing which creates "form utility" by changing the shape, form, and makeup of material, is that MH cause "time and place utility" by the internal movement, storage and management of material (Kay, 2012). Indeed, the purpose of material handling is to make available, through the use of appropriate methods and tools, the right amount of the right material in the right place, respecting the times, sequences and conditions required and minimizing the cost (Amsted et al., 1979). Since the Material Handling activity is not properly a process, it does not add value to the product involved and it can have a relevant economic input, so it should be reduced as much as possible (Bolz et al., 1951). One of the most important development from the material Handling studies is the concept of loading units where the quantity is treated as a single mass (Apple, 1972). It is often used the term "Material Handling System", where the term system can have different meanings depending on the sphere in which it is used. In General, however, it can be said that it refers to a set of parts, called subsystems, which are correlated and pursue the same common goal to the system itself. The material Handling is also composed by subsystems and the most important are: *(i) design adopted, (ii) type of equipment used, (iii) different operation involved.* The common object for those subsystem is the lowest cost solution of material handling system (Siddhartha R., 2007).

Over the years companies have focused on the efficiency of the material Handling systems and on the selection of the correct equipment. With the development of technology and the need to reduce the time that does not create value added to the goods, we have moved towards the development and use of self-guided lines, the Automated Guided Vehicle (AGV), considered more flexible, leaving aside the manual systems such as forklifts (Hung and Liu, 2000). A very important aspect for the management and design of an efficient material handling system, with automatic vehicles that do not, is to determine how many vehicles (the size of the fleet) are needed to meet the requirements of the Material Handling System. The decision of the number of vehicles is often subject to economic analysis, as in the article by Sinriech and Tanchoco (1992) in which an economic model is presented to determine the optimal fleet size. Moreover, the number of vehicles, if elevated, can become an obstacle to the organization of the routes and congestions as in Zheng et al. (2012) and Hung et al. (2000).

In addition to the resolution of the problem related to the decision of the number of vehicles, in literature called Vehicle Fleet Size Problem (VFSP), it is also important to manage the fleet. The development of technology has also affected the scope of management, in particular: (i) tracking of the position of vehicles by means of real time instruments (RFID, UWB, etc.); (ii) scheduling of activities to be carried out and routing techniques.

An overview of these topics is possible through an analysis of the literature. The aim of this paper is to show the advancement of research especially in the design and management of fleets of vehicles used for internal handling and II) highlighting some of the research gaps present that can be ideas for future research.

This paper is organized as follow. The next section develops a conceptual framework used to describe the main sphere investigated and the categories considered. The Section 3 describes the methodology used to perform the search. Section 4 describes the results obtained from the previous section. Section 5 analyses the articles considered most relevant. The paper concludes with Section 6 highlighting the gaps present and the cues for future research.

2. Conceptual Framework

Within the warehouses the use of vehicle for handling, manuals such as industrial trucks or automated like the AGVs, is very important to ensure a correct and efficient handling. In many organizations, the management of distribution activities constitutes a major decision-making problem (Golden et al., 1984). In particular, it is interesting to be able to determine the number of vehicles needed to respond to the workload required and then manage the fleet efficiently in terms of activities to be carried out, routes, overall monitoring.

In light of what was said above, two main strands were investigated in the sphere of MHS:

- The VFSP. In particular the models used to achieve the objective (Analytical, Simulation and Hybrid);
- The fleet management. Specifically, have been considered real-time monitoring and activities of scheduling and routing within the Flexible Manufacturing System (FMS) (See Figure 1).

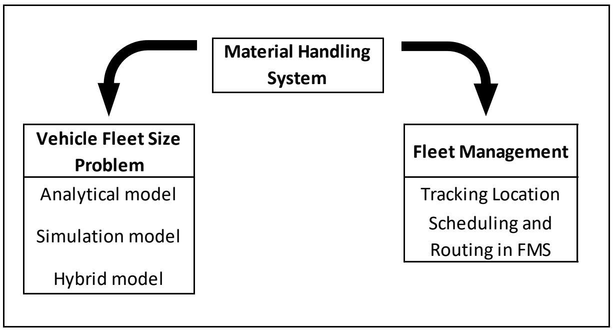

Figure 1: Analytical framework and content categories

The explanation of the factors investigated within the two contents will be explained and analysed in Section 4.

3. Methodology for literature analysis

The analysis of the literature allows to have a general view of a specific topic, which in this case is the sizing and the management of material handling vehicle. Thanks to this analysis we can also identify the current limits to present today and consequently the possible future research. The database used to search for articles is Scopus, using a group of keywords combined in such a way as to derive all related articles. The use of two groups of keywords for research is the approach used in the literature analysis of Andriolo et al. (2014). The first group of words consists of: Fleet size, Design fleet, Optim* number, fleet; While the second from: Forkift, industrial truck, pallet truck. Using a group of keywords combined in such a way as to derive all related articles. Table 1 shows the keywords; the first group consists of: *"Fleet size", "Design fleet", "Optim* number", "Fleet"*; the second of: *"Forklift", "Industrial Truck", "Pallet truck"*.

The first group belongs to the words related to the main focus of this survey, i.e. the design of the fleet of vehicles. The design is intended as the procedure and steps needed to determine the optimum number of vehicles needed to meet the workload involved. For this reason, between the words there is also "optim* number"; the use of the asterisk is to allow the database to consider correct all the words having as root the term "optim", for example optimal, optimizing, etc.

In this first search, the term *AGV systems* were specially excluded in order to have a focused vision on non-automated handling systems, which was the main objective of this study. Following the search through the keywords chosen, a further skimming was performed through selection criteria on the type of document (*Article*) in order to exclude conference paper, the Language (*English*) and the search area, considered to be the most relevant, (*Engineering, Business, Management and Accounting*), obtaining 112 Articles. The title, abstract and conclusion of all the work identified by the research have been examined to check the relevance to the topic investigated. After deleting irrelevant articles, only 2 paper remained in this step. The articles dealing with safety, collisions and software implementation of forklift were considered not to be interesting, since they were not relevant to the investigated focus, i.e. those specifically related to the design and management of forklift

Table 1: Keywords used in the systematic literature search.

	Group I	Group II	#Paper
1st Search	Fleet Fleet design Fleet size Management Optim* number	Forklift Industrial Truck Pallet Truck	424
2nd Search	Fleet Fleet design Fleet size Management Optim* number	Forklift Industrial Truck Pallet Truck AGV	739

Given the low number of paper found from the first search, it was chosen to integrate the previous research by inserting the term "AGV", thus expanding the search to automated handling systems. Then, the same selection criteria have been applied.

The second search, initially gave 739 papers; through the same filters the articles deemed relevant by this second survey are 202. Subsequently it was removed the double papers present in both searches and inspected the remaining articles by reading the title, the abstract and the conclusion to identify the most pertinent ones. At the end of this analysis, the articles selected was 16. With the snowball search have been added 3 articles to the previous, getting 19 total articles used for this literature review.

The two search stages show a significant difference in terms of the number of articles that the database has identified with the chosen keywords. Already from this first selection it is possible to notice how the quantity of articles relating to the non-automated handling systems is considerably lower than those involving the AGV.

4. Results

In this section the analyses carried out on the selected articles are presented.

The Figure 2, shows the development, that over the last ten years, has had the theme of the planning and management of the fleets of the means of material handling. The trend is quite constant over the years, in 2016 there is the biggest peak. We do not notice a gradual increase over the years and this highlights how this argument, that specifically linked to the design of the fleets, is not much debated in literature. In the last five years, however, 7 articles have been published showing a slight increase in interest in the topic.

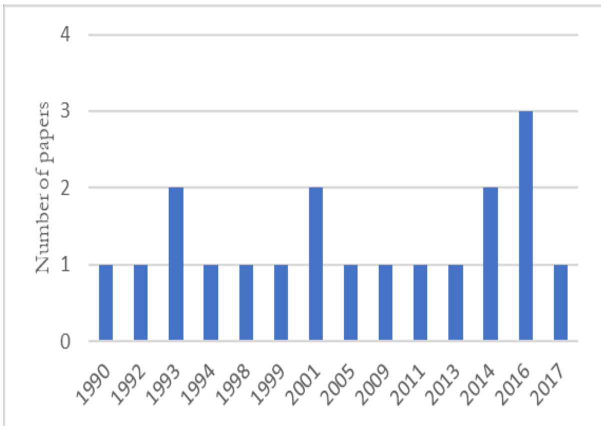

Figure 2: Number of articles per publication year

On the other hand, analysing the articles from the point of view of the journals (Without time filters as in Figure 2 whose horizon is limited to the last seventeen years) is not a marked distinction, indeed, 19 articles were published in 16 different journals. Those that are generally more related to the chosen field of research are, *Journal of Manufacturing Systems International*, *Journal of Advanced Manufacturing Technology*.

Among the selected articles there are some that have found more interest in the research, as demonstrated by the number of citations an article has received. The Figure 3 shows two indexes for each article, representing the number of citations received by analyzing two different database: Google Scholar and Scopus. The most citated are Iris et al. (2001), Rajotia et al. (1998), Kim et al. (1999) and Um et al. (2009).

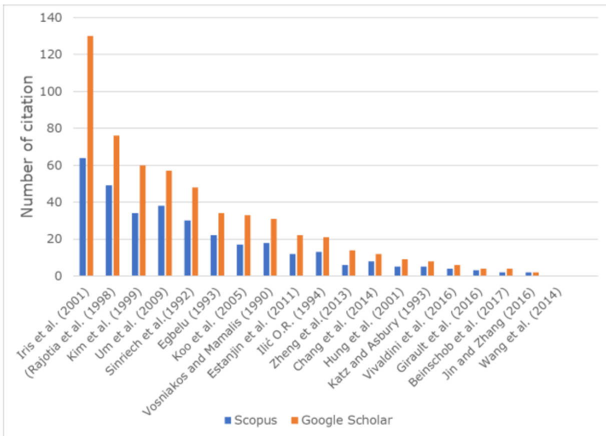

Figure 3: Number of citations per article

5. Discussion

This section explains the two main strands in the sphere of MHS and describe the different types of existing models. The order in which the arguments are addressed follows Figure 1, from left to right and from top to bottom. Thus, first considering the VSP and its models, and then the fleet management with its approach.

5.1 Vehicle Fleet Size Problem

In this section the models used for the determination of the ideal fleet of vehicle will be described and compared. All articles refer to fleets of automated vehicles, AGV. The main objectives set by most of the models shown below are the minimisation of vehicle-related costs and maximization of throughput. Being this a common problem to more reality research has developed different models and algorithms to achieve the goal. The models were grouped according to the nature of the same in: a) analytical models, b) models of simulation and c) hybrid models.

5.1.1 Analytical model

According to Buzen and Jeffrey (1984), the analytical model it is a set of equations describing the performance of a computer system. This model is able to describe the behaviour of an array of measured of different elements over a specific period of time within the computer system.

Sinriech and Tanchoco (1992) considered the problem of determining the AGV fleet through an optimization model that provides two fundamental parameters: the cost and throughput performance. Through a compromise between these two objectives it is possible to determine the AGV number sufficient to achieve the equilibrium sought. The costs taken in consideration belong to two types: operating costs, (i.e. pay-back periods, annual saving, maintenance and others); design costs, which in turn are divided into costs related to software (routing, dispatching, etc.) to hardware (vehicles, battery, charges etc). The authors suggest to combine analytical and simulation procedures to obtain the required AGV number for the system. To solve the model the article suggests the use of decision table that contending different solutions to the issue based on the trade-off ratios and target values. The strong point of this model is the ability to solve a large number of AGV problems in a very short time. Only 10 binary variables are required to solve a system containing 200 vehicles. By creating these tables, the designer enables management to consider several operation options and making more efficient decisions.

Ilić (1994) presents a simple method based on quantitative approach. The number of vehicles is estimated on the basis of the number of laps per hour made for each vehicle and the total number of laps to be carried out by the system. This method can provide an estimate of the value of the delivery distance for the layout chosen and the expected efficiency of the AGV. One advantage is to be able to test the throughput of the system after the design and by modifying the layout it is possible, also, reduce the paths.

Iris et al. (2000) propose a model and an algorithm developed for the determination of the number of AGVs required in the context of semi-automated container terminal. Specifically, the authors used a strongly polynomial algorithm. To solve the problem, you can use different solutions, that choice in this article is to build a graph based on the feasible stream in the original network. Then you determine a maximum flow from the previous network and these values will be used to determine a minimum flow. The minimum flow value determined corresponds to the minimum number of AGV required. The methodology used, however, can be generalized also in the contexts of warehouses and manufacturing.

Koo et al. (2005) present a fleet sizing procedure for an AGV system where there are multiple pickup and delivery (P/D) station. The main focus of this research is the presentation of a model of fleet sizing where the real part of the waiting time is estimated for different rules of assignment of the vehicles. These rules refer to the approximation of the things that are used precisely to determine the fleet. A queueing model was used to determine the wait time, a stochastic model to determine the fleet. Comparing this new model proposed with those already existing, there is a significant improvement in the accuracy of the estimation of the number of vehicles to be used and the waiting time.

Vivaldini et al. (2016), describe a methodology to estimate the minimum number of AGVs required in a specific time window. Two different types of algorithms are used and compared. The "shortest job first" algorithm aims to reduce the waiting time and distribute the tasks for each available vehicle. The other method is a meta-heuristic called "Tabu search", which performs an iterative search characterized by the use of dynamic memory and consists of two parts, that is the initialization and the exploration. The module proposed by the authors aim at providing much more efficient order fulfilment to the AGVs system.

5.1.2 Simulation model

It is a process that, through physical or mathematical models, creates and analyses the data to predict the performance emulating a real situation. These simulation models help the designer understand the behaviour of a specific situation, under imposed constraints.

Chang et al. (2013) studies the vehicle fleet size problem (VFSP) in semiconductor manufacturing field using a simulation method: Simulation Sequential Metamodelling (SSM). The SSM facilitates the determination of optimal number of vehicle need to design the fleet in order to minimize the vehicle cost while satisfying time constraints. Fundamental steps of this method are, in sequential order of realization, the construction of series of metamodels, to solve the approximate problem and to evaluate the quality of the obtained results. Achieved satisfactory results the algorithm ends. The advantage of SSM that it is able to take into account all the details of the manufacturing that are important and, moreover, can achieve a better computational efficiency.

5.1.3 Hybrid model

The latter method combines the use of models of the two previous groups to reach the target. It is a process that, through physical or mathematical models, creates and analyses the data to predict the performance emulating a real situation. These simulation models help the designer understand the behaviour of a specific situation, under imposed constraints.

Egbelu (1993) proposes simultaneous research on the problem of determining the optimum number of vehicles and determining the optimum size of the load unit. The goal, however, is to minimize the total manufacturing cost. The algorithm presented by the author to solve the problem is a combination of numerical research, computer simulation and statistical analysis.

Rajotia et al. (1998) have an approach that combines the use of models with the simulations to determine the required number of AGV in an FMS environment. The analytical model considers the load time, the empty travel and the time due to the wait and the congestion. These three times, considered with cumulative effect, are translated into an initial estimate of the number of vehicles needed. Finally, the use of the simulation allows to verify the initial estimation obtained with the analytical model. From this study it is possible to observe that the proposed model, even if underestimation the minimum number of AGV required, obtains results very close to the results obtained by the simulation. Therefore, it is possible to use the analytical model, with good expectations, before the simulation phase in the design of AGV.

Hung et al. (2000) use an analytical model to estimate the vehicles required for a multi-load AGVs. Two factors are used in this article, the vehicle loading capacity utilization and the job additional transport factor. The authors, to determine the values of the two parameters, use empirical and rough data. Among the results obtained and described in the article it emerges that the use of this analytical method is effective in obtaining an initial estimate of the necessary dimensions of the fleet. This, however, can be perfected using a simulation study able to retouch the results obtained previously. In addition, the use of multi-load means is advantageous in particular to reduce the complexity of traffic and achieve transport performance by using a lower number of vehicles.

5.2 Fleet Management

The management of vehicles fleets is a fundamental point to get efficient and aware shifts. In particular, the literature takes into account the aspect related to the knowledge of the exact position of the vehicle inside the warehouse; scheduling and routing, that is how the activities and paths are organized that the vehicles must perform with the objective of minimising the routes to speed up the activities. The savings that you get from an optimized routing system that has the objective of serving all the defined points along the shortest distance results in a time saving which therefore results in an economic saving. In fact, the objectives of the models concentrate more on obtaining an economic saving, avoiding waiting times due to the queues or a bad organization, and to maximize the number of activities carried out in a window of time established. The real time monitoring of the location, the creation of new routes and roadmaps are among the most used solutions in the literature.

5.2.1 Location tracking

With the continuous development of a modern industrial logistics also the tools used for the management of fleets of vehicles becomes innovative. It becomes important to know the position of the internal handling systems, both manual as the forklifts, and the automated ones, the AGV. In fact, the items chosen for comparison propose different position recognition systems to facilitate the navigation and the dispatching.

As we talk about the development of new technologies the comparison will be in chronological order to show the developments that occurred over time.

Katz and Asbury (1993) propose a system that uses small cylinders attached to an electric motor, called the target. Attached to the circumference of cylinders are small rectangular mirrors that have the function of reflecting the Luke at different frequency (40 Hz, 80 Hz and 120 Hz) and by triangulation the position of the AGV is obtained. This precession serves for a preliminary design phase. The heart of the article is the proposed system which is based on the on-line navigational data is received from the angular detection of infrared beacons, generated from predetermined locations The real time position coordinates are calculated thanks to three separate beacons. In order to obtain a correct navigation, it is essential the accuracy of the angles recorded between two consecutive beacons because they are responsible for the definitive Cartesian coordinates of the AGV. The accuracy of the AGV has been tested in static and dynamic modes.

Estanjin et al. (2011) focus on the use of sensors to optimize the forklift dispatching. This article does not apply the means of recognition of position on automated vehicles like the AGV, but on the contrary on the traditional systems of handling inside the warehouses: the forklift. Using sensor nodes it is possible to collate, in real time, a series of information about the forklifts including the position, the time of use, a history of collisions and shocks and finally the level of the battery. The data collected is transmitted via motes that form a dynamic mesh network to a base station connected to a PC. The authors have implemented a localization engine based on received signal strength (RSSI). The advantages of this engine are: (i) it is measurement-based, i.e., not a priori signal propagation is needed; (ii) it goes beyond the Gaussian assumption of the signal strength distribution; (iii) this engine demonstrates analytical performance and performance optimization through the distribution. This paper reports on an approach for integrating low-cost, power efficient sensors, probabilistic localization, and stochastic learning in a wireless sensor network-based system applied to warehouse management.

Also, in Wang et al. (2014) they refer to the manual handling systems, the forklifts. To determine the location, as in the previous article, you use real time (RFID) systems and calculate the value of the RSSI parameter. The position of the forklifts can be determined through recognition of the reference tags which are embedded at both sides of the passageway based on the three-side layout at right angle principle and their RSSI value. The use of RFID, according to the authors, helps to obtain the position of the goods loaded and unloaded by the forklifts as well as the position of the latter. The main advantage described is the creation of automatic statistics of the quantity and the position of the goods entering and leaving the warehouse, thus reducing many manual statistics and human errors that cause loss of Efficiency. Therefore, proper fleet management through real time positioning systems allows to improve the working efficiency.

5.2.2 Scheduling and Routing of AGVs in FMS

Veeravalli et al. (2002) extend the research field of scheduling and routing in the FMS with the aim to achieve a high efficiency in manufacturing lowering costs. One of the emerging contributions from this article is the introduction of the directed flow graph to represent the flow of materials. From this it is possible to derive a model to obtain the optimal distribution of the material. Through rigorous analysis and simulation experiments, the authors show that such a delivery strategy will optimize the overall performance.

Um et al. (2009) present the simulation design and analysis in a FMS context with AGVs. The aim is to maximize the operating performance of the system considering many parameters such as number, velocity and dispatching rules of AGV. The method used is a systematic analysis that merges an analytical simulation and optimization techniques which in particular is called Multi Objective Non-Linear programming (MONLP) and Evolution Strategy (ES). The first is used to design an experimental pattern for a regressive and multi factorial analysis; the second, however, is used to verify each parameter for optimization. From the results obtained there is not a significant difference between the two methods, in the design of the parameters and the critical aspects. So, you can apply both methods to design an FMS with AGVs

Vosniakos and Mamalis (1989) analyse the situation where it is necessary to facilitate both the routing and the control of the vehicles. To do this, the authors present a routing algorithm. Increasing the number of AGVs causes an increase in FMS output more marked for low velocities. However, at the highest velocity increasing the number of AGVs eventually results in less FMS output due to vehicle interference.

5.2.3 Model and methodology to manage AGVs

Kim et al. (1999) describe a heuristic procedure for control the flows of materials and in particular the movement of AGVs. The assumption on which the dispatching procedure is based is the workload balancing. The results obtained were derived thanks to simulations.

Beinschob et al. (2016) introduce a novel methodology for reaching semi-automated mapping with the main goal of reducing installation costs and time for the AGVs system. One of the innovations introduced and presented in this article is the use of scanning technology to build a virtual reproduction of the warehouse. This proposed methodology was experimentally validated in several real environments, with very promising results.

Jin and Zhang (2015) discuss a dynamic scheduling method of AGVs. The case examined is that of Multi AGV scheduling, where the constraints considered are the time of handling and the order of precedence of the activities to be carried out. The dynamic scheduling of many AGV refers to the allocation of tasks simultaneously for a multiple number of vehicles at a given time with the aim of minimizing and balancing the efficiency of handling. The major contributes are the follows: (i) scheduling for the multiple AGVs simultaneously to obtain better globally optimized solutions, (ii)A dynamic scheduling model minimizing completion time.

Zheng et al. (2012) shows a new model that can achieve greater flexibility and efficiency for a multi-AGVs system. The goal then is to reduce complexity by using this new method proposed, the regional control model, with the design of a new path. The strategy used in the multi AGVs system is based on the shortest waiting time in order to achieve the optimization the running time and a distributed control mechanism.

6. Conclusion and future research

The present paper proposed a literature review on material handling, focusing on the design and management of fleets of vehicles used for internal handling making an overview of existing models. Moreover, it is possible to identify the gaps in the literature and look for new directions for future research. What most stands out from the analysis of the literature, about the design of the fleet of vehicles and their organization, is that there is a greater attention for the automated vehicles, the AGVs, rather than on the manual ones like the forklifts. In fact, among the articles examined, only two were those closely related to the forklifts and none of these, however, dealt with the problem of the sizing of the fleet. It must be pointed out that not all the warehouses are equipped with automated handling systems, but they still use different forklifts. Possible future research could be focused on the design and management of manual handling systems. In the first analysis it is possible to make a parallelism between AGVs and forklifts, showing how the objectives that we want to achieve, i.e. reduction of idle time, better efficiency, optimum number of the fleet, are the same in manual system. In addition, a subsequent step will be to check whether models and methodologies applied to automated vehicles can also be adapted and used in the study of manual systems. Based on the articles analysed, we can observe that research has been devoted to the real time localization of forklifts in order to manage more efficiently their movements and scheduling. Therefore, one of the objectives that this future analysis could bring is to obtain hybrid handling systems, i.e. semi-automated, in which the latest generation systems are able to support and guide the operator in the scheduling of the activity to be performed considering the priorities and, above all, the proximity in terms of the path given by the localization in real time.

Summarizing the possible step of research:

- Determine the similarities between the two types of systems and to determine if the objectives achieved for the AGVs can be interesting also for the forklifts.
- Check whether the models and methodologies already present in the literature for AGV can be successfully applied to manual material handling systems.
- Take advantage of real time localization systems and merge them with theorized models to create supported autonomy systems, smart forklift.
- Deepen the knowledge of the latest technologies that are used to design and manage fleets of vehicles, assessing the advantages and potential of each.

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