Comprehensive Review of the Dispatching, Scheduling and Routing of AGVs

Kelen C.T. Vivaldini[1], Luís F. Rocha[2], Marcelo Becker[1], and António Paulo Moreira[3]

[1] EESC-USP, Mechatronics Group - Mobile Robotics Lab. S. Paulo, Brazil
[2] INESC TEC - INESC Technology and Science (formerly INESC Porto), Porto, Portugal
[3] INESC TEC - INESC Technology and Science (formerly INESC Porto), Porto, Portugal and FEUP Faculty of Engineering, University of Porto, Porto, Portugal
{kteixeira,becker}@sc.usp.br,
luis.f.rocha@inescporto.pt, amoreira@fe.up.pt

Abstract. Automated Guided Vehicle System (AGVS) has become an important strategic tool for automated warehouses. In a very competitive business scenario, they can increase productivity and reduce costs of FMS (Flexible Manufacturing System) transportation systems. The AGV System provides efficient material flow and distribution among workstations at the right time and place. To attend such requirements, AGVS involves dispatching and scheduling of tasks and routing of AGVs. Some studies have approached such procedures in a similar form, although they have different functionalities. This paper reviews the literature related to the dispatching, scheduling and routing of AGVs (Automated Guided Vehicles) and highlights their main differences in comparison with the common management of vehicles transportation systems. To obtain a theoretical base, the definitions of dispatching, routing and scheduling procedures for materials handling applications are presented and the main methods to solve them are discussed.

Keywords: Automated Guided Vehicles, Routing, Dispatching, Scheduling.

1 Introduction

Materials handling is an essential activity in any production process and its efficiency has severe impacts on the production costs. A materials handling system is applied from the start of the mass production and by using mainly manual (for lighter loads) or mechanical (forklifts, conveyors, etc.) solutions. However, in more recent years and due to the need for increasing flexibility in production systems (small series production and customization), fully automated systems (Automated Guided Vehicle Systems - AGVS or Automatic Storage / Retrieval Systems - AS / RS) have been considered the best alternative.

AGVs (Automated Guided Vehicles) are autonomous vehicles widely used to transport materials between workstations in flexible manufacturing systems and perform a variety of tasks that involve automation in industrial environments [1]. Automated logistic systems, such as warehouses, cross docking centers and container terminals frequently use AGVs to optimize their materials handling tasks [2].

A.P. Moreira et al. (eds.), *CONTROLO'2014 - Proc. of the 11th Port. Conf. on Autom. Control*,
Lecture Notes in Electrical Engineering 321, DOI: 10.1007/978-3-319-10380-8_48

AGVs are among the classes of materials handling equipment that has grown most rapidly in quantity of equipment installed in industries and become a common tool for such activities. The equipment can quickly respond to transportation patterns that frequently change and can be integrated into fully automated control systems. AGVs have been increasingly used to transfer a wide variety of application materials in the area of distribution logistics.

The system that controls the AGVs is AGVS and consists of several AGVs operating concurrently. According to Kalinovcic et al [3] and Vivaldini et al [4], the design of an AGV System requires decision making regarding the best strategies to solve the several problems associated with its functioning, such as dispatching, routing and scheduling. Therefore, the solutions that best adapt to the existing requirements imposed by the materials handling system for AGVS must be chosen.

An AGVS must be developed to ensure an efficient flow of materials during the production process and provide the necessary materials to the appropriate workstation, at the right time and in the right quantity. This control system must guarantee the coordination among AGVs in terms of both scheduling and routing, ensuring an efficient operation of the system (conflict-free, collisions and deadlocks) independently of the number of vehicles used [4-5]. If these requirements are not guaranteed, the overall performance of the production system will decline, become less efficient and generate less profit or operate at higher costs [6]. However, if these requirements are carried out as per the needs of the productive system, the control system is a viable option for the increase in enterprise competitiveness.

We emphasize that such issues, as the selection of a route, dispatching and scheduling of tasks influence the overall performance of the AGVs management system, and must be addressed for the creation of an effective AGVS. If the decision on receiving an order is taken, both dispatching routing and scheduling will be planned so that the AGV is capable of transporting pallets from the origin to their destination.

This paper contributes to the clarification of AGVs dispatching, scheduling and routing and provides a comprehensive review of the main existent methods to solve them. Furthermore, the comparison of this problem with the general transportation systems applied to common vehicles outside the industrial area will be presented in the following section.

2 AGVs Challenges

The problems inherent to Industrial Logistics based on AGVS are similar to the ones studied in the field of urban Transportation Systems (TS). In TS, the main objective is to assure that vehicles efficiently arrive at the desired destinations within a highly dynamic environment, where traffic jams and unpredicted events that may occur are either avoided or prevented. Moreover, the reduction in transport costs is a constant pressure in the logistic area.

One of the main focuses regarding Intelligent Transportation System research and urban TS is the vehicle routing problem (VRP). VRP has high applicability because it reflects the decisions that need to be taken daily by enterprises. It deals mainly with both the computation of an efficient route taking into account the environment information and each vehicle as an entity whose main objective is independent of the other vehicles. At this point, the industrial transportation system becomes differentiable.

In the case of industrial logistics based on AGVS, the AGVs work together to attend all transportation requests in both time and correct sequence, delivering products to workstations so that the production process can follow the desired production flow. Several constraints are faced by system modeling and may be related to the total time of the route and time window, at which the service should be started. If these transportation tasks are not performed efficiently, the production system is severely affected. Therefore, such objectives must not be independent of each other, but establish some relation of precedence or synchronization. Other constraints generally negligible to general transportation, such as length of the vehicle, path capacity, network layout (normally a reduced size network with uni or\and bi-directional routes), and priority of the tasks and AGVs (e.g. priority defined considering their battery level) must also be taken into account. For instance, a fleet of vehicles must be efficiently controlled with hard restrictions that can be relaxed in more general transportation systems problems. These characteristics require complex control architectures, in which the routing algorithm proposed in the urban transportation system must be complemented by dispatching and task scheduling algorithms. These three control layers must be closely related, however the integrated problem becomes considerably more complex.

3 Dispatching, Routing and Scheduling Problem

The control policy of AGVS aims to attend transport demands as fast as possible within the deadline and without the occurrence of conflicts. Co and Tanchoco [7] and Lagevin [8] defined the function of AGVS management in Dispatching, Routing and Scheduling: "Dispatching is the process of selecting and assigning tasks to vehicles, Routing is the selection of the specific paths that each vehicle will execute to accomplish its transportation tasks, and Scheduling is the determination of the arrival and departure times of vehicles at each segment along their routes to ensure collision-free travel". Vis et al [5] affirm that at least the activities of dispatching of loads to AGVs, route selection, scheduling of AGVs and dispatching of AGVs to parking locations must be performed by a controller of the AGVS. According to Le-Ahn [9], the control of AGVs requires an online scheduling or dispatching systems. Therefore, dispatching, routing and scheduling decisions can be made either simultaneously or separately.

3.1 AGVs Dispatching

In general, the dispatching rules are divided into two types of operation decisions: workstation-initiated and vehicle-initiated, depending on whether the system has idle vehicles (vehicle-initiated) or queued transportation requests (workcenter-initiated) [10]. The vehicle-initiated dispatching determines the load to be assigned to a vehicle when the vehicle is ready for the next task, whereas the workcenter-initiated dispatching determines the vehicle to be selected when loads initiate transportation requests [11].

Le-Ahn [9] presented a dispatching system as a scheduling with zero planning horizon. A dispatching decision is made when a vehicle has dropped a load, a vehicle has reached its parking location or a new load has arrived.

A dispatching system uses dispatching rules to control vehicles. Online dispatching rules are simple and can be easily adapted to automated guided vehicle management systems. The common objectives are minimization of load waiting time, maximization of the system throughput, minimization of queue length, and guarantee of a certain service level at stations.

3.2 AGVs Scheduling

Scheduling defines the allocation process of AGVs for tasks considering the time and cost operations [12] and guaranteeing conflict-free routes. Typically, the goals of scheduling are related to the processing time of tasks or use of resources (number of AGVs involved, system throughput or total travel time of all vehicles) under certain constraints, such as deadlines, priorities, etc. However, unviable results can be achieved if the functioning of the transport system does not consider the scheduling limitations [5][13].

According to Le-Ahn [9], the main goal of most scheduling problems is to transport loads (products, pallets or containers) as quickly as possible to satisfy time-window constraints. Other criteria can be the minimization of the maximum load waiting time and maximum number of items in critical queues.

However, the scheduling can be divided into two key factors: is a predictive mechanism that determines the planned start and completion time of labor operations and a reactive mechanism that monitors the progress of the schedule and deals with unexpected events (failures, breakdowns, cancellations, date changes, etc.) [13].

The scheduling system decides when and where a vehicle must perform its tasks. If all tasks are known prior to planning a period of work, the problem can be solved off-line. In practice, the changes in the tasks information after route planning complicate the off-line scheduling. In these cases, an online scheduling becomes essential. The off-line and on-line approaches are clearly presented in [9].

In the off-line scheduling case, all available tasks are scheduled at once. This previously generated scheduling must be reviewed and updated when necessary throughout the production cycle. In the on-line scheduling, the task scheduling decisions are taken in a dynamic way, i.e. decisions are made over time, according to changes in the system state [14]. Therefore, any unforeseen event in the system can be controlled automatically and efficiently by the scheduling.

Real-time scheduling is a process in which short-term decisions are made, i.e., the scheduling is based on the current state of the system and its general needs and can be used by an off-line and/or on-line method. If the scheduling uses an off-line method, the process is reprogrammed, whereas in the on-line method, the task scheduling decision is made when a change occurs in the system status.

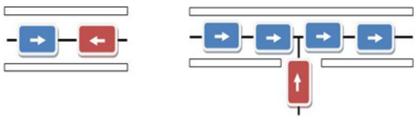
3.3 AGVs Routing

The routing problem in the AGV system can be compared with the Vehicle Routing Problem (VRP). It has been extensively addressed and an overview of the literature in this area was presented by [15-18].

Vehicle Routing refers to the process of determining one or more paths or sequences of path to be performed by a fleet of vehicles. The purpose is to visit a set of nodes geographically dispersed in predetermined locations that must be attended. According to Vivaldini et al. [2], the task of AGVs routing in an industrial environment is to find a route for each AGV from its current position to the desired destination ensuring a conflict-free travel along the selected path. In recent years, several algorithms have been proposed to solve routing problems [5][19-23]. They are classified into two categories: static routing algorithms and dynamic routing algorithms.

The difference between static and dynamic vehicle routings is indicated in the routing problem definition. In the static routing problem, the input data do not change during the path execution or in the execution of the routing algorithm. The route from node i to node j is previously determined and always used if the load must be transported from i to j. A simple solution is to choose the route of shortest distance from i to j. However, static algorithms cannot adapt to changes in the AGVs traffic system. On the other hand, in dynamic routing, the routing decision is based on real-time information (i.e., the inputs can be either changed or updated during the execution of the algorithm or even while running the route), therefore, multiple paths between i and j can be chosen [5]. Presently, the routing algorithm and execution of the path are processes that evolve simultaneously in dynamic situations, in contrast to static situations, in which the first process clearly precedes the second without overlapping [24].

In static routing, all data are known prior to the calculation of the route and do not change during its execution. The route is calculated without taking into account collision avoidance, which can dramatically affect the system performance due to possible deadlocks (Fig.1-a) and traffic jams (Fig. 1-b).



(a) (b)

Fig. 1. Static routing problem: in (a) deadlocks, both AGVs use the same route in different directions, and in (b) traffic jam, a AGV is blocked by AGVs [2][22]

In this case, an additional system must be used for collision avoidance. This change results in different traffic times which cannot be foreseen at the time of their computation, since the problems are handled only upon the execution of the routes. This is the main disadvantage of applying static routing to systems that depend on previous knowledge on the arrival time [2].

4 Revision of the State-of-the-Art

This section provides a literature review on the main methods developed for solving the problems of dispatching, routing and scheduling. The idea is not to present an exhaustive state-of-the-art review, but rather some of the most used approaches, addressing their main goals and constraints.

4.1 AGVs Dispatching

As previously mentioned, dispatching consists in allocating a task list for the transportation system (AGVs) taking into account some restrictions, like deadlines, priorities etc. Its ultimate goal is associated with the optimization of resources, respecting production times, while minimizing the number of AGVs required to maintain or maximize the production ratio [4].The main approaches are dispatching rules, meta-heuristics, and integer/mixed programming.

Using dispatching rules, Hwang and Kim [25] proposed a new task dispatching algorithm for AGVs based on restrictive rules. The information from the WIP (Work-In-Progress) and the travel time of AGVs (considered deterministic) is used for the algorithm operation. The proposed solution divides the problem of allocating a task to an AGV into a combination of 3 functions. The first takes into account the distance from a vehicle to the workstation and requests the execution of a task transportation; the other two functions weigh the urgency of that task execution, taking into account the state of the input buffer of the destination station and the output buffer of the station that requests the transportation. To assess the algorithms performance, the authors in [25] compared the proposed algorithm with some commonly used dispatching restrictions, namely modified-first-come first-serve (MFCFS) and shortest-travel-time-distance (STTD). The developed algorithm provided better results due to the shop-floor used. However, any type of trajectory concern, routing and scheduling was taken. In other words, the routes for each task were pre-defined at the beginning of the algorithm and any collision or deadlock monitoring algorithm was considered. This is a common practice in the use of dispatching rules, however neglecting deadlocks in the routing may cause severe impacts in the transportation system.

Udhayakumar and Kumanan [12] compared the genetic algorithm and the ant-colony for the AGV task dispatching problem considering Meta-Heuristics. The algorithms had a double objective function: to balance the number of tasks given to the AGVs (only two were considered) and minimize the total transportation time so that the utilization ratio of AGVs could be maximized. Other meta-heuristic functions reported in the literature are particle swarm optimization, Tabu search, etc.

For integer/mixed programming, Kasilingan [26] proposed a model to solve the problem of dispatching tasks and determining the minimum number of AGVs required. The model minimizes the total cost of the system, i.e., the sum of the total operation time of the AGVs and the cost of transporting parts between workstations and capacity of vehicles. Moreover, the model underestimates the number of vehicles required.

Rajotia, Shanker and Batra [27] presented a combination of an analytical dispatching model and a simulation approach to determine the optimum number of AGVs. The mixed integer programming model (MIP) considers time handling, load, empty travel time, waiting time and congestion. The objective of the model is to minimize the travel time of the vehicle unloaded.

In addition to the vast dispatching articles in the area of FMS (Flexible Manufacturing Systems) and port terminals (container terminals), dispatching has also been widely reported in the literature, in part due to its complexity in the management of task deadlines and minimization of the number of vehicles used applied to a complex environment and with large-scale work [28-29].

4.2 AGVs Scheduling and Routing

Vehicle routing and scheduling of tasks aim to minimize costs and ensure conflict-free operations and order fulfillment.

The vehicle routing problem consists basically in determining *m* vehicle routes and minimizing the total distance of all routes by taking into account constraints, such as assignment of each pallet to one AGV, and the cargo capacity of the AGV, which must not beexceed . In real applications, a given number of constraints, such as restrictions on task scheduling, complicates the model. The problem refers to the Vehicle Routing Problem with Time Windows (VRPTW), in which a time window [s, t] is defined for each AGV to perform its tasks [30]. Rajotia, Shanker and Batra [31] added time window to the nodes to represent the arrival and departure times which the AGVs will occupy. Other AGVs can travel through a specific node at a time point not included in one of the time window. Desrochers et al. [32] provided an overview of methods to solve routing with time-window constraints. Several studies on VRPTW have been developed: Lagrangian relaxation [17], Branch and bound methods [33], insertion heuristics[34], constrained shortest path relaxation [35], survey of approximation and optimal approaches [36], dynamic routing method [37] and genetic algorithm [38].

To solve traffic jams and congestion of AGVs, the development of conflict-free routes has emerged in the literature. Broadbent et al. [41] introduced the first concept of conflict-free and shortest-time AGV routing. The routing procedure described employs Dijkstra’s shortest path algorithm for the generation of a matrix, which describes the path occupation time of vehicles. Krishnamurthy, Batta and Karwan [42] developed a column generation method for the static routing problem in which an AGV has to move in a bidirectional conflict-free network and minimize the makespan. Maza and Castagna [21] proposed a robust predictive method of routing without conflicts. Möhring et al. [22] extended the approaches of Huang, Palekar and Kapoor [44] and Kim and Tanchoco [20] and proposed an algorithm for the problem of routing AGVs without conflicts at the time of the route computation. Klimm et al. [23] presented an efficient algorithm to cope with the problem of congestion and detours, avoiding potential deadlock situations by using a so-called static approach. Vivaldini et al. [2] proposed an algorithm based on Dijkstra's shortest path and time-window approaches to solve traffic jams and generate optimized conflict-free paths.

Chen et al.[45] also combined the methods used in [2] for a shortest and conflict-free path planning.

In the scheduling literature, Zaremba et al. [47], Veeravalli, Rajesh and Viswanadham [48] and Bing [49] proposed analytical models for the AGVs scheduling. Hartmann [50] introduced a general model for scheduling materials handling equipment (AGVs) in a container terminal such that the average lateness of a job and the average set up time could be minimized. Several types of methods have been employed to conflict-free routes of AGVs [20-23]. We can conclude the issues of routing and scheduling are often studied separately and their integration is a challenging problem.

5 Conclusions

This article has reviewed the state-of-the-art of the AGVs high-level controlling system, addressing their main challenges in comparison with other non-industrial intelligent transportation systems. Dispatching, routing and scheduling were theorically clarified and the main approaches in this area were presented.

Despite all the scientific work developed, the number of automated vehicles installed in industries over the past few years is below what is expected due to high installation costs and the difficulty in taking full advantage of the system. This fact is in part explained by the difficulty in maintaining a close interoperability among dispatching, routing, scheduling and the enterprise MRP (Manufacturing Resource Planning). This is a very complex task which is generally treated as separated problems in the scientific sphere. Furthermore, the difficulty in developing a solution sufficiently generic to be applied to a significant amount of industrial problems has also contributed to the reduced utilization of AGVs in the industrial area.

Acknowledgments. The authors would like to acknowledge Project "NORTE-07-0124-FEDER-000057" financed by the North Portugal Regional Operational Programme (ON.2 – O Novo Norte), under the National Strategic Reference Framework (NSRF), through the European Regional Development Fund (ERDF), and by national funds, through the Portuguese funding agency, Fundação para a Ciência e a Tecnologia (FCT).

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