IJTE, Vol. 8, No. 3, Winter 2021, pp. 261-278

Research Paper

Automated Guided Vehicles - A Review on Applications, Problem Modeling and Solutions

Hassan Rashidi[1*], Farzam Matinfar[2], Fereshteh Azadi Parand[2]

Received: 24. 10. 2020 Accepted: 04. 01. 2020

Abstract

In the past few decades, many research pieces were devoted to Automated Guided Vehicles (AGVs), both in hardware and software technology. Nowadays, these are popular for the automatic handling of materials, goods, and containers. They provide more efficient and flexible solutions for manufacturing and transportation systems. This paper does a survey on Automated Guided Vehicles in the real world, in port automation for automatic container handling and manufacturing systems for flexible material handling systems. The results of this survey reveal several corollaries over usage, modeling of problems, and solutions. Moreover, it presents several challenges for future research. The first challenge is to perform a simulation model that can handle multiple layouts in both container terminals and manufacturing systems. The second challenge is to work on the new technology of AGVs, which involves Industry 4.0. The third challenge is concerned with some dynamic vehicle routing strategies based on a two-tiered simulation. The fourth challenge is to develop more efficient algorithms for various problems of routing AGVs in practical applications.

Keywords: Automated Guided Vehicles, transportation, flexible manufacturing systems, port automation.

Corresponding author E-mail: hrashi@atu.ac.ir

[1] Professor, Department of Computer Science, Allameh Tabataba'i University, Tehran, Iran

[2] Assiatant Professor, Department of Computer Science, Allameh Tabataba'i University, Tehran, Iran

[3] Assiatant Professor, Department of Computer Science, Allameh Tabataba'i University, Tehran, Iran

1. Introduction

Automation and using computers in both hardware and software have several significant impacts on different systems. One of these systems is transportation, which has some major and catalytic roles in the migration, leading to the economic and social transformation of each country. One of the advanced transportation technology equipment is Automated Guided Vehicles (AGVs) [Akturk and Yilmaz, 1996]. This kind of vehicle is used mostly to develop, diversify, and develop the transport systems ([Broadbent, 1985, Hosseini and Sahlin, 2018]). They were conventionally used for manufacturing operations, but their popularity has recently been overextended to many other domain applications to transport goods/materials in storage areas and container ports. These vehicles are without drivers and increasingly becoming the standard mode of containers/goods transportation in port automation and flexible handling material in manufacturing environments. The main advantages of using AGVs are below (2H House , 2020):

- Reduction of labor costs: Increasing productivity and efficiency is the most important goal that any business wants to achieve to succeed. AGVs help achieve this goal in the long run because of their reliability and cost-effectiveness. They do not get tired during the day or need to rest. They offer higher work accuracy and can be adjusted to work on repetitive tasks that can lead to injury or endanger humans for a period of time.
- Modular growth: AGV can be used in small numbers, but as demand increases, so can the fleet. Their performance expands or decreases whenever the system needs them, and the time required to implement these changes speeds up the operational flow in the system. If needed, AGVs can also include robotic attachments as a cost-effective gateway to more advanced technology.
- Safety and Predictability: Easy to control AGVs are still a safe and secure way to transport goods through distribution and warehousing centers. The AGVs are designed, installed and run to work away from the workforce, which reduces safety concerns. What makes them particualrly useful is their ability to be operated in environments where extreme temperatures are standard, while also carrying heavier loads and reducing the risk of injury to employees.
- Minimize the risk of infection: This is the latest benefit, or at least something that all industries think about. Following the outbreak of COVID-19, all factories and property managers are concerned about the transmission of workers' diseases. Humans are an effective way of transmitting infection, so reducing the number of workers per capita minimizes the risk of transmission. Having AGV instead of people who do not add value ensures continuity of operation in the event of a lock or restriction on social movements.
- Avoid Air-pollution: In container ports and industrial plants, ships, trucks and other fossil fuel engines are the most important sources for generation of air pollution in these environments. Using AGV in these environments can significantly reduce air pollution. (Edrissi et al.2019).

The main disadvantages of using AGVs are below:

- High initial cost: As for any system that wants to invest in new technology, the initial financial cost can be a difficult obstacle to overcome. Long-term returns must be offset against a practical buying period and offset by lower labor costs. During that time, one can be sure that there may be some additional costs for maintenance. No device is perfect, and any cost should be effective in the event of a possible breakdown or disruption resulting from the operation.
- Platforms Needs: Increasing the use of AGV is highly dependent on the system being able to maximize AGV-focused strengths. The

use of AGVs increases when doing repetitive tasks, but if the platform is not ready to use them, the system may not benefit much from the investment.

- Lack of Flexibility: If the route or route needs to be changed quickly due to a new plan or unforeseen issues, it may take some time for AGV to shut down and reschedule to adapt to the new workflow. At best, a distribution center will work well like an oiled machine, but a rapidly changing warehouse demand means it can react quickly. If AGV's repetitive work cycle is commensurate with the need for rapid, regular changes to operations, they would be an ideal buying policy.The most critical problem for AGVs is scheduling and routing, for which algorithms must be developed [Qiu et al.2002].

The first problem is scheduling AGVs that involve assigning vehicles to cover the trips associated with given timetable constraints to minimize trips' total cost. Each trip in the timetable planned must be completed by a vehicle. A vehicle cannot be assigned to more than one trip at any given time. Usually, we would like to combine orders with shifts and routes so that the service constraints with business procedures are satisfied and the total costs are minimized. In today's world, this process is very complex to be completed manually. One of the leading parts of a planner in each transportation system is to generate a highly efficient schedule. The second type of problem for vehicles involves routing, which is known as Vehicle Routing Problem (VRP), an NP-hard problem. There is a broad category of the VRP ([Dondo et al.2003, Toth, 2003, Hasama et al.1998, Shih and Chang, 2001, Gribkovskaia et al.2002, Tan et al.,2000, Lau and Liang, 2001-, Mitrovic-Minic, 1998, Lűbbecke, 2000, Ghannadpour and Abdolhadi, 2017). Hsu and Huang (1994) studied the vehicle routing problem for basic operations on several particular path topologies (Hsu and Huang, 1994). These paths are Star, Ring, Linear-arrangement, H-Shape, Two-Dimensional-Mesh, Cube-Loops, *n*-Cube, and fully connected graph. To determine computational efforts and memory usage to solve the VRP, this research calculated the time complexity as $O(n^2)$ and the space complexity as $O(n^3)$, where n is the number of edges in the network graph models.

The main motivation for this paper, therefore, is to survey AGVs scheduling and routing problem. The remaining sections of this paper are structured as follows. The next section discloses the literature overusing AGVs in port automation and flexible material handling in manufacturing systems. Section 3 presents the main results of the reviews of the papers that have been studied. Section 4 provides the challenges of overusing AGVs in different systems. The final section is considered for the summary and conclusion.

2. Literature Review

Automated guidance vehicles (AGVs) are devices that follow signs or wiring or lasers that include guidance information. These vehicles automatically increase productivity and reduce costs by automating production facilities or warehouses. In this section, we review the latest researches devoted to using AGVs on land. The review reveals that the major uses of AGVs are in port automation for automatic container handling and manufacturing systems for flexible material movements, as shown in Fig.1.

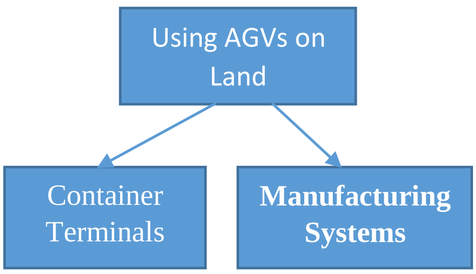

Fig.1 The category of using AGVs on Land

2.1 Using AGVs in Automated Container Terminals

The container terminals in the world have very significant roles in each economy. To have an automated container terminal, the terminal designer must use AGVs for transport containers inside the terminal. In this section, we review the latest researches done on using AGVs in container terminals in the current century chronologically.

A research did a case study for Pusan port and presented two different dispatching rules for AGVs in the port, namely the dedicated-dispatching(DD) and the pooled-dispatching (PD) [Wook and Hwan, 2000]. In the DD, each AGV is allocated to only one Quay Crane (QC) whereas in the DP, an AGV can be assigned to more than one QC in doing the delivery tasks. In both dispatching rules, there are a couple of goal. The first one is to dispatch the AGVs so that all the discharging and charging container jobs are fulfilled as early as possible. In the second goal, an objective function with aims to minimize the total distance traveled by the AGVs is considered. In this research, two integer programming models are made and then tackled by LINDO software tool. The results showed that the PD is performed better than the DD.

Another research studied the transportation problem of containers by Stacking Cranes (SCs) and Quay Cranes (QCs) between the ships in the quay-side and yard-side in the port [Böse et al.2000]. The objective of this research was to reduce the time spent for the ships by maximizing the QCs productivity. The authors examined a scheduling approach for SCs to QCs in order to minimize the turnaround time a ship. This approach was the SC-pooling, in which there is a dynamic strategy, and a preset number of SCs accomplish container transports for a number of the QCs. Based on the number of charging and dropping-off containers jobs, the SCs could be moved in the mode of double-cycle, in which empty traveling is substituted by container jobs for other QCs. The research studied two different circumstances of the SC-pooling: semi-dynamic-assignment (SDA) and fully-dynamic-assignment(FDA). In the SDA, a specified number of SCs are assigned to the QCs for only one vessel, and in the FDA, a specified number of SCs are assigned to the QCs of all ships. The problems are tackled by an evolutionary algorithm, in this research, with a simulation. The experimental results showed the impact of the number of containers in the job sequences in the FDA is not a key role when the carriers operate in the double-cycle mode.

Another research studied an integration scheduling problem of AGVs, QC, and Rubber Tired Gantry Cranes (RTGCs) with a goal to minimize the makespan of the schedule at automated terminals -]. The authors developed two algorithms for the scheduling problem (a branch-and-bound and a heuristic beam-search algorithm). In this research, the results of several dispatching rules and the heuristic algorithm were compared under different scenarios. The experimental results showed both the algorithms provided a solution near-optimal solution in a rational time with similar results. The study also showed that an arrangement on a base of a long horizon time with inaccurate data is often suitable than to consider newly available information into the planning.

Another research studied the scheduling and routing problems for AGVs and published their results in four papers ([Qiu and Hsu, 2001, Qiu and Hsu, 2002, Qiu et al.2000, Qiu and Hsu, 2000). In these papers, the authors considered two different path topologies with two scheduling strategies and then developed a conflict-free-routing algorithm (CFRA). The algorithm and strategies were applied in a case study to minimize the space required of the paths in the layouts. In order to make routes without conflicts for the AGVs, a critical condition for specific basic parameters of the path in the layout and AGVs was assumed. The effectiveness of the routing was examined in both terms of the waiting and traveling distance times of the AGVs to handle all drop-off and pick-up jobs. This research also theoretically showed that even though the routing solution took only a fixed amount of time for each AGV, then the concurrency of the AGVs movements could be obtained with a higher degree.

Another research provided a proficient dynamic arrangement algorithm system for dispatch AGVs

[Leong, 2001] with an objective to minimize charging and discharging time for a vessel. Following that work, Gebraeel et al. (2001) and then Moorthy et al. (2003) focused on the routing problem without deadlock for the AGVs while they are transporting the jobs in the port [Moorthy, 2003]. Based on a suspend-and-resume strategy, the author developed an algorithm for deadlock prediction and avoidance problems. The results of applying this algorithm for a zone-controlled layout at the Singapore port were compared with that of the current strategy of there. The simulation results and analysis disclosed that the algorithm makes enhancements in terms of throughput of the port.

Another research conducted a study on the algorithms for scheduling and routing problems of AGVs [Qiu et al.2003] and classified the existing algorithms. These algorithms are grouped into the solutions for the problem with the topologies of specific and general paths in the layouts as well as the solution for path optimization and dedicated scheduling problems. In addition, this study shows the similarities and differences between AGV planning and routing and other interrelated problems such as vehicle routing and shortest path problems.

Another research studied a couple of integer programming models for shipping vehicles to transport a job sequence of containers from quay-side to the yard-side [Zhang et al.2002]. In these models, there are several hard constraints to consider the sequence of vehicles for transporting the container. In this research, a couple of heuristic algorithms were designed for solving the models. By means of a formulation for the second model as the Lagrangian relaxation dual, a lower bound for the objective function of this model was obtained. The heuristic algorithms were applied to a virtual port with real-size, and the numerical results were reported. Based on the results, the authors developed a formulation that can help to decide on the optimum number of vehicles to transport a sequence of jobs.

Another research studied the dispatching problem of AGVs in a container port [Cheng et al.2003]. The authors formulated the problem as a network flow model to minimize the waiting time of the AGVs on the berth side. In the model, carrying one or two containers by AGVs were considered in the constraints of the model. The research developed a heuristic algorithm and tested it as a simulation considering a single capacity for AGV. The experimental and computational results of the model and algorithm showed some improvements compared with the deployment strategy used on that time in the Singapore port.

Another research addressed the dispatching problem of multi-load AGVs in highly automated container terminals [Grunow et al.2004]. This research made a mixed-integer Linear Program (MILP) model and provided some priority rules to transport container jobs inside the container terminal. The performance of the MILP model and the priority rule has been compared in different scenarios concerning the total lateness of the vehicles. A simulation is done on evaluating the priority rule approach for the capacity of one and two containers for each vehicle alongside assessing the MILP modeling approach. The experimental and numerical experiments demonstrated the performance of the priority rules-based over the MILP model approach.

Another research developed a decision support system (DSS), in which an integrated approach is proposed for operations in a port [Murty et al.2007]. This research focused on the system that reacts adequately to uncertainty in the conditions of operation and the changes in container jobs over time. One of the components in the DSS determines the minimum number of vehicles and estimate the number of vehicles required each half-hour over a planning time horizon for every day. At the end of every planning time period, the system uses the most recent information for the next period of time. Following the operation of the ports in Hong Kong with a simulation, the research demonstrated the workloads could be estimated with a rational accuracy over the horizon. This research proposed a planning horizon of four hours for updating the decisions on transportation problems in the port.

Another research formulated the static and dynamic scheduling problem of AGVs in container terminals [Rashidi and Tsang, 2005], as minimum cost flow (MCF) models. In the model, the objective function has three terms (i.e., traveling time of the AGVs in the paths of the terminal, waiting time of the AGVs on the quay-side, and the delay of the fulfilled the jobs). To tackle the model, this research made some progresses on the standard network simplex algorithm (NSA) and found a new algorithm, known as $NSA^{+,}$ for the static problem. To complement NSA^{+} for the dynamic problem, the research presented an incomplete algorithm, known as Greedy Vehicle Search (GVS). To evaluate the relative advantages and disadvantages of NSA^{+} compared with that of GVS, these algorithms were applied to the dynamic automated vehicle scheduling problem.

Another research developed a dispatching method for automated lifting vehicles (ALVs) in automated port container terminals [Nguyen and Kim-. The ALVs are capable of lifting container jobs from the ground by themselves. This research considered buffer spaces in the yard-side and quay-side and deliberated how to dispatch the ALVs by exploiting information of the locations in pick-up and delivery points and the time in future delivery jobs. A mixed-integer programming model (MIPM) is made for assigning optimal delivery jobs to ALVs, and then it is solved by ILOG suite software. This study developed a technique for transforming the buffer-space constraints into time-window restriction and a heuristic method for decreasing the computational time spent by the MIPM to solving the problem. The numerical experiments were performed to compare the values of objective function and computational times of the heuristic method with those of the optimizing algorithms in ILOG. This research also analyzes the impacts of the number of ALVs on the operation of the dual-cycle mode and the buffer capacity on the efficiency of ALVs.

Another research developed three solutions for the problem of the single-load and multi-load vehicles scheduling in container terminals [Rashidi, 2010]. He formulated the problem as Constraints Satisfaction and Optimization Problem (CSOP). If the vehicles are Single-Load, the problem is formulated as the minimum cost flow model. This model is solved by the premier performance algorithm, that is, the Network Simplex Algorithm (NSA). When the capacity of the vehicles becomes multi-load, the feasible solution is very large, and the problem is solved by the simulated annealing method (SAM). In this research, three strategies for providing a starting solution to the SAM is designed and implemented when the SAM begin its execution. During the iterations of the SAM, a neighborhood function, based on a customized function for the problem and SAM, is used. The third solution proposed is a combination of NSA and SAM. This combined solution is applied to the heterogeneous capacities of vehicles in the scheduling problems. In the simulation done, many of the same random generated problems are solved by the SAM with the proposed approaches. Then, the results are compared.

Another research studied an integrated scheduling problem of automated guided vehicles (AGVs) and Quay Cranes (QCs) [Homayouni et al.2011]. Then, they formulated the problem as a Mixed Integer Linear Programming (MILP) model. The objective function of the model is to minimize the makespan of all the charging and discharging containers jobs for a set of QCs. This model is solved by a customized SAM. In the research, the effects of two sets of control factors, and three cooling procedures to find a solution to the SAM were examined. A comparison of the different results of the MILP model and the SAM clearly showed the reasonable efficiency of the proposed SAM in finding convenient solutions for the scheduling problem.

Another research studied a multi-objective optimization model(MOOM) for the scheduling problem of autonomous Stacking Cranes (SCs) in

Automated Container Terminals (ACTs)[Cai et al.2012]. This research considers the transportation problem with three goals in the objective function (i.e., the SCs waiting and travel times, as well as the completion time of high-priority container jobs). This model is formulated as a time-windows problem with pick-up and drops-off in the arrangement of binary integer programming. In the model, the weighted sum of each goal in the objective function is examined as a representative instance of the autonomous SC scheduling problem. A precise algorithm, based on the branch-and-bound with column-generation methods, is developed for solving the multi-objective optimization problem.

Another research developed a model and designed a strategy of owning and renting the problem of trucks in arrangements with Internal Trucks(ITs) in container terminals [Wang et al.2014]. In this research, the integrated problem of scheduling and storage allocation is decomposed into two stages, and a two-level heuristic approach is developed. The first stage determines the daily operations of the ITs, and in the second stage, the truck employment strategy is specified based on the results at the first level.

Another research studied the allocation container transporting problem among Automated Lifting Vehicles (ALVs) [Zhicheng et al.2014]. The authors developed a real-time dispatching model for allocation and ALV dispatching problems in container terminals. In the model, a set of events activates a new instantaneous dispatching of the ALVs. In this research, an Adapted Hungarian Algorithm(AHA) is applied to solve several instances of the dispatching problem.

Another study researched port automation and published their results in a book [Rashidi and Tsang, 2016], in which the authors review the research devoted to scheduling and dispatching of AGVs. Generally, in each port, there are many vehicles/AGVs to carry container jobs. This book also developed six advanced algorithms for the treatment of the scheduling problem of AGVs in ports. The research reported in the book represents a comprehensive package that can address the static and dynamic scheduling problems of AGVs. This research is the primary reference book for researchers and port authorities, as well as graduate students and professionals in the field of operation research. For professionals, it supplies novel and efficient algorithms for solving the minimum cost flow (MCF) model. For the students, it provides the most comprehensive review in the field of operation research along with a smooth formulation for the problems in the automation of ports. The contents of this research book are divided into two major segments. The first segment explores various decisions over the problems in modern container terminals and then classifies the decisions into five scheduling problems.

Another research studied a parametric network flow problem over time in the graph models [Nicola et al.2017] and proposed an algorithm to solving the maximum problem that can be used in dynamic discrete environments. The proposed algorithm repeatedly finds the maximum flow in the dynamic networks for a set of values for the parameter values, in their increasing order. In each iteration, the algorithm calculates a new breaking point for the maximum parametric dynamic flow value function and the maximum flow by minimizing the transit time. The dynamic flow in the time-space network is augmented through the quickest trajectories from the source node to the sink node while avoiding the explicit time expansion of the network.

Another research developed an approach for the problem of scheduling automated transport vehicles to ensure the smooth flow of containers in container terminals [Rahman and Nielsen, 2019]. In this approach, there are a model of mixed-integer programming and two meta-heuristic algorithms for achieving the quality of schedules within a rational amount of time. The experimental results showed a noteworthy reduction in the differences between the earliness or lateness and the appointment time of container delivery jobs. It also represents that the proposed approach is capable of ensuring smooth distribution of containers by dispatching AGVS in an integrated fashion. Moreover, it makes some improvements in the operational performance so that it could be used for the uniform movement of material in production environments.

2.2 Using AGVs in Flexible Manufacturing Systems

In this section, we review the latest researches done on using AGVs in manufacturing systems in the current century chronologically.

A research designed a hybrid approach to solve a problem of scheduling and routing of AGVs without conflicts in a flexible manufacturing area ([Chaudhry et al.2011, Corréa et al.2007]). The problem considered simultaneous scheduling and consignment as a master problem, and routing the AGVs without any conflicts as a sub-problem. So, the hybrid approach consists of a decomposition method where the scheduling (i.e. the master problem) is formulated with constraint programming and the conflict-free routing (i.e. the sub-problem) with mixed-integer programming. Moreover, several logic cuts are produced by solving the sub-problems and then used in the master problem for pruning the optimal solutions whose routing paths contain conflicts.

Another research considered artificial intelligence techniques into the design and implementation of an automated guided vehicle (AGV) to improve its autonomy and flexibility. This research introduced a complete system on a board, comprising designs of both hardware and software to develop an AGV that works in dynamic industrial environments as a flexible material handling system (FMHS). The system contains a laser navigation sensor for localization and a laser scanner for security issues. The hardware architecture of this research is instantiated in a CPU that is connected through a CAN bus (i.e., a robust vehicle bus standard for microcontrollers) to low-level controllers. In the design process, the research considered simplicity, robustness, flexibility, and safety. The main finding of this research is a prototype that can operate in structured and partially dynamic manufacturing environments. The prototype was verified effectively in a real factory where the AGVs operate in a FMHS to move pallets between the production lines and storage areas.

Another research addressed the problem of concurrent scheduling of a couple of AGVs and several numerically controlled machines(NCMs) in a flexible manufacturing system (FMS) [Chaudhry et al.2011]. The objective function of the problem is to minimize the makespan for the NCMs and AGVs. This used a spreadsheet-based genetic algorithm (SBGA), i.e., an add-in, a domain-independent, and general-purpose GA to the spreadsheet software, to solve the problem. This research provided a dataset with 82 instances of the problems and showed that the experimental results are comparable to the previous approaches.

Another research focused on a configuration of tandem automated guided vehicle (TAGV) for optimizing the production time and handling material devices [Fazlollahtabar et al.2012]. The authors used Monte Carlo simulation and considered an effective time parameter in an automated flexible manufacturing system (AFMS). Due to various configurations of TAGVs in the AFMS, the material-handling actions are accomplished. In the simulation, many stochastic data are produced by several corresponding probability distributions functions, respected to various time parameters, and the TAGV breakdowns during the movement of materials.

Another research reviewed literature over different approaches to optimize AGVs systems-. They studied two substantial problems of dispatching and routing AGVs used in manufacturing, transshipment, transportation, and distribution systems. The research categorizes the approaches into mathematical methods (heuristics and exact), simulation studies, meta-heuristic techniques, and artificial intelligence techniques.

A research reviewed an in-depth study on transport operations that used in the material handling equipment [Héctor et al.2014]. The authors underlined the existing industry trends with developments, and then provided a classification framework for transportation systems based on the scientific researches published in the journal up to 2012. The research also discussed the challenges in the current operational paradigms of transport operations. The classification framework makes some distinguishes between the decision problems in: (a) comparing the types of vehicles; (b) specifying the number of vehicles; (c) routing vehicles; (d) scheduling vehicles; and (e) collision and deadlock avoidance in moving of vehicles.

Another study worked on the scheduling problem of AGVs and implementation in manufacturing systems [Nageswararao et al.2014]. The objective is to minimize delivery costs and enhance productivity in the optimization problem of the entire fleet of AGVs. This research developed a Binary particle swarm Vehicle Heuristic Algorithm (BPSVHA) for the scheduling problem of AGVs and machines, with respect to adopting robust factor function and minimization of mean tardiness. The experimental and computational results show the BPSVHA provided a better solution than the existing methods.

A research proposed a meta-heuristic gravitational search(MHGS) algorithm for the synchronized scheduling problem of machines [Medikondu et al.2017]. The problem involves two automated guided vehicles with the same attributes in a flexible manufacturing system. The MHGS algorithm is applied to solving several problems, and the results demonstrated its suitability to minimize the makespan. It completed the assigned jobs faster with conceivable savings of the resources, comparing with the results of the existing approaches.

A research worked on Particle Swarm Optimization (PSO) combined with Memetic Algorithm (MA) and presented a solution, known as Modified Memetic Particle Swarm Optimization Algorithm (MMPSO) [Chawla et al.2018]. The objective is to find some initial solutions that be feasible for the scheduling problem of poly-load AGVs with minimum traveling and waiting times of the vehicles in the Flexible Manufacturing System. The primary experimentations showed the proposed MMPSO was able to make a balanced solution with exploitation for both the methods in the global search of the PSO and local search of the MA. Moreover, the experimental results showed the proposed MMPSO could find an operational and feasible initial solutions that is efficient for the poly-load AGVs scheduling problem.

A research focused on Industry 4.0 is the next generation for the manufacturing industry [Mehami et al.2018]. This research utilized internet technologies of radio frequency identification (RFID) labels for monitoring and control motion resolutions. This research emphasized three aspects, including configurability, customizability, and flexibility, that have rarely been considered in sequence of jobs, to effectively implement an intelligent AGV system. A simulation on the logistics inside the manufacturing environment demonstrated that a smart factory using the two types of AGVs.

Another research proposed a decentralized motion planner for AGVs scheduling problems in a flexible manufacturing system [Demesure et al.2018]. A scheduler is designed into the motion planner, with capabilities to update the destination and source of AGVs locations during the navigation to complete the transportation tasks. The proposed approach is performed in two steps. In the first step, the planner recognizes several paths in such a way to escape collision conflicts that previously identified by a central administrator. The recognized paths are then communicated with nearby AGVs, that represent the intentions of the AGVS. In the second step, the information in the recognized paths is communicated with nearby AGVs, that represent the intentions of AGVs. In the second step, the pre-recognized paths of neighbors are considered to create a collision-free paths by some priority policy. The experimental and numerical results showed the feasibility and pertinence of the proposed approach, with a more appropriate solution compared with considering only the decentralized scheduling of AGVs.

Another research developed a non-linear integer mathematical programming model in order to group several machines into a number of rings to make an efficient configuration for AGV system in Tandem layout [Rahimikelarijani et al.2019]. The model minimizes both inter-ring and intra-ring flow by a balanced-rings strategy to balance workload in the system simultaneously. This research significantly considers multiple-load AGVs, which has the ability to reduce fleet size and waiting time of works. Moreover, a modified variable neighborhood search method is applied for large size problems. The results indicated that using multiple load AGV instead of single load AGV will reduce system penalty cost up significantly, and has good accuracy for small and medium-size problems.

Another research developed a distributed system of multi-agent to scheduling problems of the robotic flexible assembly cells [Maoudj et al.2019]. The objective of the scheduling problem is to minimize the makespan and concerned with allocating and sequencing of the robots, subject to satisfying the constraints of products and robots. The proposed system addresses the problem by using a compliant approach supported by a local, a supervisory, and a remote, the agents that are autonomous robots. In designing these agents, a negotiation protocol is considered for satisfying their local objectives and providing an optimized global solution. This protocol is based on common dispatching rules for coordinating the individual decisions of the agents.

In this year, a research focused on a dynamic scheduling problem, where several machines and AGVs move with a stable speed in a shop floor [Gu et al.2020]. This research makes a mathematical model with an objective of makespan minimization and then develops a bio-inspired optimization approach (BIOA) to tackle the problem in the flexible manufacturing environment. To verify efficiency of the approach in practical application, BIOA and other dispatching approaches are examined. The experimental results illustrate that the BIOA provides better performance. Moreover, it optimizes the quality of integration scheduling of the machines and AGVs in real-time.

3. The Main Results of the Reviews

Table1 summarizes the major researches devoted to the decision, scheduling and/or routing vehicles in container terminals. This table shows the researchers (year), modeling approach and solutions (algorithms/Method/Software), size of the problems, and experimental results.

Table 1. The major researches done around using AGVs in container terminals

[Reference]	Modelling (Algorithm/Method/Software)	Size of Problems (Number)	Experimental Results
[Bose et al.2000]	Integer Linear Programming Model (Evolutionary Algorithm)	Ships (Four), QCs(Two) for each ship and SC (Six)	Applied to a real port so that it improves the performance
[Wook and Hwan, 2000]	Mixed Integer Linear Programming Model (LINDO software)	Ships (One), QCs (Two), AGVs (1 to 5), and container Jobs (15 to 30)	Pooled Dispatching is better than Dedicated Dispatching
[Thurston and Hu, 2002]	Multi Agent Model (Paradigm Merging Plan)	Ship (One), AGVs (Twelve)	A distributed multi agent architecture and Provides a feasible optimization Solution
[Zhang et al.2002]	Mixed Integer Linear Programming Model (Two heuristic algorithms: Forward and Backward Search)	Internal Trucks(30 to100)	A better solution provided by Lagrangian relaxation
[Cheng et al.2003]	Minimum Cost Flow Model (Network Simplex Method)	AGVs(Twenty), QCs(Sixteen)	Minimum cost flow provides a better solution than First-Input-First-Output rule
[Grunow et al. ,2004]	Mixed Integer Linear Programming Model with priority rules (CPLEX 7.0 software)	Ships (One), S-Layout : QCs(Three), AGVs(Three); L-Layout: QCs(Six), AGVs(Six)	Performance of MILP and priority rule is almost the same for the small layout
[Corréa et al.2007]	Constraint and Mixed Integer Programming Model (ILog Solver 5.2 and CPLEX 8.0 software)	AGVs(Six)	A decomposition method to solve the integrated scheduling and conflict-free routing problem
[Nguyen et al.2009]	A Mixed Integer Programming model (ILOG CPLEX software)	Ships (One), ALVs(1 to 4) per QC, Number of Operations for each QC(1 to 2), (4 to 12), Buffer Capacities(1 to 2)	Improves in the completion time of operation for ship, reduces delay time of QCs, and total travel time of ALVs
[Rashidi, 2010]	Constraint Satisfaction and Optimization Model (Network Simplex Algorithm with Simulated Annealing Method)	Ships (One), QCs(Seven), AGVs (Fifty)	Network Simplex Algorithm offers a reasonable initial solution when Simulated Annealing Method begins its execution for Multi-load AGVs
[Cai et al.2012]	A Binary Integer Programming Model with Multi-objectives (Column Generation with Branch-and-Bound)	Ships (One), SC(Nine)	Multi-objective model provides a flexible and effective solution compared with single-objective function
[Wang et al.2014]	Mathematical Programming Model (Two-Level Heuristic Algorithm)	Ships (One), Trucks (15 to 54) in Owning and Renting	Better solution than an empirical method for using different types of truck in yard
[Rashidi and Tsang , 2016]	the scheduling problems of AGVs (Network Simplex and Its Extensions)	Ships (One), AGVs (Fifty)	Optimal Solution for both static and dynamic Problems
[Rahman and Nielsen, 2019]	A Mixed Integer Programming Model(two meta-heuristic-based algorithms)	Ships (One), AGVs (Twenty)	Decreases the differences between the appointment time and actual time of operation for container delivery tasks

Table 2. The major researches done around using AGVs in Manufacturing systems

[Reference]	Modelling Problem(Algorithm)	Number of AGVs/Robots in Experiments	Main Results
[Corréa et al.2007]	Master Scheduling problem: Constraint programming (Pruning), Sub-problem: Conflict-free routing (Logic cuts)	Six AGVs	Simultaneous assignment with conflict-free routing of the vehicles
[Barberá et al.2010]	Incorporates artificial intelligence techniques (navigation system for localization)	Five AGVs, operating for 16 hour per day	Generate a Prototype with abilities to operate in semi-structured and dynamic environments
[Chaudhry et al.2011]	Concurrent scheduling model of machines and AGVs (spreadsheet-based genetic algorithm approach)	Two AGVs	A benchmark consist of 82 samples of the problems
[Héctor et al.2014]	Review different transport operations (different paradigms)	Not given- reviewed papers up 2012	New classification scheme for transport operations
[Ali and Wasif , 2017]	The flow of materials/elements between different components of a FMS (Planning and controlling strategies)	An AGV	An Integrated framework for implementation of AGVs
[Nageswararao et al.2017]	Simultaneous Scheduling of Machines (Meta-heuristic gravitational search algorithm)	Two identical AGVs	Minimizes the makespan and completes the jobs faster, potential savings of the AGVs usage
[Chawla et al.2018]	Scheduling of multi-load AGVs (Particle Swarm Optimization integrated with Memetic Algorithm)	20 AGVs	A reasonable initial solutions when PSO begins its execution for the problem of multi-load AGVs
[Mehami et al.2018]	Industry 4.0 as the next generation for the manufacturing industry (adding internet technologies)	Two types of AGVs (Karl and Jimmy)	A smart AGV system that can be configured, flexible, and customized
[Demesure et al.2018]	Scheduling of automated guided vehicles (Decentralized motion planning)	25 Agents (AGVs)	The feasibility and the applicability of the proposed strategy
[Rahimikelarijani et al.2019]	Scheduling an AGV with a group of a number of machines (Non-linear integer mathematical programming model)	Configuration for AGV system in Tandem layout	Reduce system penalty cost up to 44%
[Maoudj et al.2019]	Controlling and Scheduling Robotic Flexible Assembly Cells (Distributed multi-agent system)	15 Robots	The effectiveness and the robustness of the system
[Yoshitake et al.2019]	A robotic system with an AGV for order picking-up in logistics warehouses(Real-Time-Holonic Scheduling)	An AGV	Effective solution of the proposed method for the larger operational area and possibly mixed with lower-volume the picking orders
[Gu et al.2020]	Mathematical and dynamic model (A bio-inspired approach)	Two AGVs and four machines	Bio-inspired optimization approach provides a better performance in the schedule

From appraising this part, we can drive the following corollaries:

- **Corollary-1**: The survey reveals that most researches focused on using AGVs inside of container terminals. Moreover, significant researches devoted to the problem of scheduling and routing the AGVs.
- **Corollary-2**: As can be seen in Table 1, most researches considered the problem as mixed-integer programming model.
- **Corollary-3**: The biggest problem in terms the number of AGVs used in the experiments, so far, that have been solved are the samples in ([Rashidi, 2010, Rashidi and Tsang, 2011]). After that, the biggest problem is the samples in the [Zhang et al.2002].
- **Corollary-4**: The problems can be classified into four groups: (a) general path topologies, (b) path optimization, (c) particular path topologies, and (d) dedicated dispatching problems.
- **Corollary-5**: In the general path topologies for the layout of container terminals, the solution methods can be categorized into three methods, i.e. Time-window, Static, and Dynamic methods.
- **Corollary-6**: In the path optimization problem, the models are classified into three classes, i.e. Integer Linear Programming model, the Intersection Graph model, and the Binary Integer Programming model.
- **Corollary-7**: In the particular path for the layout of ports, the three kinds of topologies could be designed and considered, namely the circle, linear, and mesh topologies.

Table2 summarizes the major research done over using AGVs in manufacturing systems. The table displays the researchers (year), modeling approach (algorithm), number of AGVs/robots in the experiments, and main results. We can drive the following corollaries:

- **Corollary-8**: We found only one research that works on Tandem Layout [Rahimikelarijani et al.2019].
- **Corollary-9**: So far, the biggest problem that solved in the experiments is the instances of 20 AGVs [Chawla et al.2018].
- **Corollary-10**: The meta-heuristic methods are rarely used in manufacturing systems-. It is due to they cannot find the optimal global solution for the problem to which most manufacturing systems need.
- **Corollary-11**: Artificial intelligence techniques are rarely used in manufacturing systems [Ali and Wasif, 2010]. It is due to these techniques cannot find the optimal global solution for the problem to which most manufacturing systems need. Most artificial techniques use some navigation systems and localization methods.
- **Corollary-12**: The new technology of AGVs involves Industry 4.0, the next pace of equipment in the manufacturing industry. This is formed by the addition of some technologies of the internet to the optimized and automation systems.
- **Corollary-13**: Multi-Load AGVs are rarely used in manufacturing environments [Chawla et al.2018]. It is due to many manufacturing systems need to perform efficient solutions with higher flexibility.
- **Corollary-14**: The variants of Vehicle Routing Problem (VRP) for AGVs are not seen in the experiment and research. These variations are in terms of time, capacity of vehicles, the number of depots, type of delivery, vehicle with/without backhauls, and control of the vehicle. These terms can be combined together so that a wide ranges of vehicles can be studied, such as periodic-VRP, VRP with time-windows, capacitated-VRP, capacitated-VRP with time-windows,

split-delivery-VRP, multiple-depot-VRP, stochastic-VRP, VRP with backhauls, VRP controlled with satellite services, and so on. They need more attention and efforts to be considered in future research and in practical environments.

- **Corollary-15**: Dynamic environments for scheduling and routing AGVs problems are rarely seen in both port automation and manufacturing systems.
- **Corollary-16**: Most of the proposed methodologies in AGVs systems have been studied by research laboratories or academic institutions, and their applicability in an industrial environment is relatively restricted.

4. The Challenges Over Using AGVs

This section presents major challenges overusing AGVs in different systems. One of the challenges is to perform a simulation environment that can be holder multiple system layouts in both container terminals and manufacturing systems (See **Corollary-4** to **Corollary-8**). In these systems, we may have a varying number of AGVs, and a diverse number of lanes as well as pedestrians moving around the systems.

The second challenge is to work on the new technology of AGVs that involves Industry 4.0 (See **Corollary-12**). This is formed by additional internet technologies to the optimized automation system, which can utilize radio frequency identification (RFID) labels to identify and motion control purposes, possibly integrated with Internet of Thing (IoT) technologies.

The third challenge is to work on some approaches for the dynamic problem of scheduling and routing vehicles based on a two-tiered simulation (See Corollary-15). It can operate in two steps. At the first step in the leading simulation, at the time of each routing solution for an AGV, sub-simulations are produced for each alternative route. Then in the second step, the experimental performance provided by these sub-simulations is used to create the routing solution in the leading simulation.

The fourth challenge is to develop more efficient algorithms for the variety of AGV routing problems (AGVRP) in practical applications (See **Corollary-16**). Some specific variations are capacitated AGVRP in which a fixed fleet of AGVs with unit capacity must service many requirements for a single good and ARP with time windows in which there is an additional restriction on time to service demands.

5. Summary and Conclusion

Nowadays, the two main arms of the shipping industry and manufacturing industry, must be upgraded and smartened. The infrastructure of these industries is equipped with new and intelligent technologies of automated guided vehicles. This paper surveyed using automated guided vehicles in the automation of ports and manufacturing systems. In the survey, we considered modeling problems and solutions. Nowadays, these automated guided vehicles generally are mobile vehicles without drivers or robots that used in transportation systems (De Ryck et al.2020, Nicola et al.2017, Stopka, 2020]). This paper shows that the AGV systems are a new topic for research mostly used in both port automation and manufacturing systems. In these systems, guide paths, pick-up and drop-off station locations, idle positions, and dispatching instructions for the AGVs must be developed. Moreover, future research must respond to the challenges and develop more effective algorithms for different path layouts where AGVs are used for a variety of scheduling and routing problems. Undoubtedly, the productivity of both industries, the shipping industry, and the manufacturing industry, are affected by three main factors: service quality, service speed, and total costs. These factors play a major role in competitiveness, which in today's highly competitive business seems to be crucial in the challenges.

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