Simulation-based Multiple Automated Guided Vehicles considering Charging and Collision-free Requirements in Automatic Warehouse

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Abstract – **The deployment of automated guided vehicles in the automated warehouse has a great impact on the capacity in handling logistics activities. Simulation offers practical feedback and analytical solution at a designing stage of engineering applications. As for automated warehouse system, the optimal set of the combination of automated guided vehicles and workstations are highly depended on the size, dimensions, layout structure of the warehouse and working process. In this paper, the operations in the automatic warehouse were simulated to determine possible scenarios of the warehouse setting regarding the demand pattern of the packaging order. In the automatic warehouse, the racks are transferred by the automated guided vehicles to the workstations. FlexSim software developed the simulated model and validated by the suggested layout from the case company. To estimate the possible setting with the highest order turn-over rate, varies scenarios were considered in the model. As a result, the estimated layout and warehouse setting were suggested.**

Keywords - **FlexSim, automatic warehouse, simulation, automated guided vehicles**

I. INTRODUCTION

Automatic warehouse offers numerous advantages, including higher productivity, improved and increased predictability of quality, advanced consistency of processes and the most vital part to entrepreneur, lowered reliability on the workforce to reduce human labour costs as well as mistakes. Therefore, more and more industries heavily rely on automation in their daily process. Manufacturing industry gains significant return from using automation to conduct assembly processes, automated storage and retrieval systems (ASRS), deposit and retrieve goods and Automated Guided Vehicles (AGV) and transport weighted cargo or materials around the factories, online transaction processing systems existed in the e-Commerce and logistics. Entrepreneurs emphasis on reducing costs on storage and transportation to raise the total profit by using AGV.

AGV is a driverless, steerable, wheeled industrial truck, which is driven by electric motors consuming electrical energy in batteries. It follows the predefined paths along an aisle to deliver materials from one point to another. Meanwhile, it can load and unload cargos automatically. AGV is controlled by Automated Guided Vehicle System (AGVS) that is a computer controlled material handling system comprising several microprocessors. Amazon, Volkswagen, BMW, Deutz and Denso are the examples of implementation of AGV into manufacturing processes. The increased number implies that AGV is playing an important role in present manufacturing industry.

Simulation has frequently been applied to a wide range of industries. Miro and White [1] applied software TELEGRIP to simulate a manipulator that is constructed by mechanical and electrical equations of motion. Murphy and Perera [2] showed simulation could be used in aerospace industry based on its high flexibility and integration ability in product design, development and manufacturing efficiency. Kobayashi, et al. [3] calculated the Nanofillers distribution in nanocomposite resin and its stress-strain curve with multi-scale simulation technologies. Wang, et al. [4], with the aid of hybrid simulation, studied coupled dynamics of the interconnected Transmission and Distribution system.

Simulation can be separated into static models, which do not include time like an evaluation of complex integrals by choosing sample values and dynamic model, which include time to observe the result of systems changes over time [5]. For dynamic models, variations due to time can be simulated by two ways: they are a discrete model and continuous model [6]. Neradilova and Fedorko [7] suggested using simulation on AGV systems. In this way, virtual manufacturing processes is shown, and the most important part is that the system can be verified and optimised. Possible methods are to adjust existing functionality by the direct intervention into the source code and to write a separate program and its correlated connection to the desired block. Yao and Fujimura [8] conducted a multi-load AGV system on JIT production environment. It aimed to assess the improvement generated by the AGV system in JIT production environment and the performance of it under a higher demand of system productivity.

This project studied on simulation of using underride AGV in an automatic warehouse. In different industries, AGV can be designed to acquire distinct skills to suit the changed environment.

II. PROBLEM FORMULATION

AGVs keep contact to the Guidance Control System (GCS) through WLAN. Meanwhile, the superordinated computer gives transports orders to GCS via LAN. Simultaneously, a telephone which is connected to VPN, is linked to the computer and used for long-distance diagnoses. Cardarelli, et al. [9] introduced a cloud robotics architecture to improve AGV system. A cooperative data fusion system is utilized to collect data from distinct sensing origins. This keeps updating the global live monitoring of the working context to control the AGVs in an optimised way. The system includes three major systems, including (1) AGV control system, (2) vehicle dispatching and (3) tasking assignment problem on the workstations.

A. Integrated AGV system

An AGVS guidance control system consists of both hardware and software. It is centred around a computer program which runs on one or more computers. It serves to coordinate multiple automated guided vehicles and assumes the task of integrating the AGV system into internal operations. In a manufacturing system, there are more than one workstations performing a variety of tasks. A part or unit load is required to give frequent visits to provide kinds of service. In this case, demands for vehicle dispatching occurs. Dispatching means the decisions or methods to select an AGV to pick up or deliver material. Egbelu and Tanchoco [10] classified dispatching problem into two categories and suggested some heuristic rules to solve the issues. This problem involves selection of a vehicle from the idling sets of vehicles to travel to a single workstation and perform the task. The task problem can be divided into several subproblems, including workstation-task assignment problem, vehicle-task assignment problem, multi-attributes dispatching problem and routing problem.

B. Sensor, zone and deadlock control

Sensor control and zone control are the important elements of the automatic warehouse. Sensing devices like sonic, optical sensors and bumpers are popular to be installed on the vehicle to detect the presence of other vehicles along the same route. The reflected Infrared Photoelectric sensor is able to obtain the control information on the traffic lane by encoded and expressed with a specialised barcode. Color-sensor is a valid approach to enhance effectiveness and flexibility compared to using magnetic sensors tracks. AGVS with zone control means the guide paths are divided into a variety of disjoint zones where each zone is available for one vehicle at one time, as described in **Fig. 1**. Ideally, if each vehicle is responsible for one zone, no collision will occur. Indeed, this method lowers the chance of collision, but not elimination. Assume that, V_d travels from Z_3 to Z_4 and V_a travels from Z_1 to Z_2, if V_d is going to Z_3 and Va is going to Z_1 before V_b leaves Z_4, and V_c leaves Z_2, deadlocks are resulted by competing for the usage of the common circular guide path.

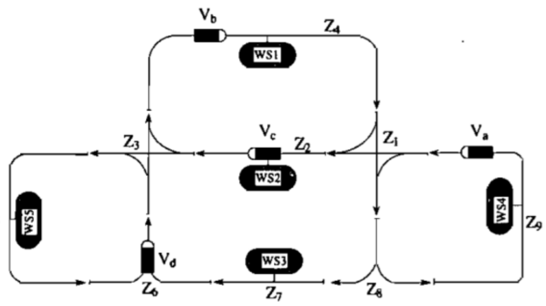

Fig. 1. Scenario of the zone control

To resolve deadlock problem, Shao, et al. [11] adopted a semaphore-based traffic control model. In the model, two semaphores: Binary Semaphore (BS) and Counting Semaphore (CS) are used for intersections and bidirectional paths correspondingly. They are composed of a counter, a maximum resource count, a nowner and waiter list. Under the rule of First-In-First-Out (FIFO), owner and waiter lists are served to store AGV's ID occupying and waiting for certain resource respectively. BS is set to 1 implying only one AGV can own BS at one time while C_{max} of CS is set to any integer decide by available resources. All queues are set to be empty. Four operations are defined to BS as well as CS.

II. METHODOLOGY

A. The setting of the simulation environments from case company

The setting of the simulation environments has imitated the floorplan of the case company. Firstly, there are control points for the AGVs to follow the paths. Secondly, there is a corridor between every two rows of racks as well as at the centre as a path. A real-time Swarm Robots Control Center monitors and provides controls to the whole environment. Workstations are for the staff to operate. Charging stations are needed for the AGVs to charge electricity. To generate and run a simulation model, variables, conditions and assumptions are vitally important to be clear in the circumstances. Tables I-IV showed the activities conditions from the domain expert and the case company.

TABLE I
The warehouse setting in simulation software

Elements	Parameters
Size of the warehouse	Length: 36 m Width: 28 m
Number of racks	24
Racks Transportation Requests	Continuously
Simulation Time	7,200 secs
Rotation distance	Radius: 1 m
Loading and Unloading Time	5 secs
The direction of movement of AGV	4 directions: forward, backward, turn left, turn right
Direction of routes	Main paths: One-way Spur paths: Two-way

TABLE II
The AGV motion setting in simulation software

AGV motions	Empty	Load
Acceleration	5 m/s	4 m/s
Deceleration	5 m/s	4 m/s
Forward speed - straight	5 m/s	4 m/s
Forward speed – curved	4 m/s	3 m/s
Forward speed - spur	4.5 m/s	3.5 m/s
Reverse speed – staight	5 m/s	4 m/s
Reverse speed – curved	4 m/s	3 m/s
Reverse speed - spur	4.5 m/s	3.5 m/s

TABLE III
The charging station setting in simulation software

Charging requirement	Parameters
Power consumption	Empty – 5 A Loaded – 10 A Idle – 1A
AGV charging conditions	Battery Capacity (AH): 100 Recharge (A): 60 Battery Recharge Threshold (A): 10 Battery Resume Threshold (A): 80
The distance between each workstation and AGV charging station	1 m

TABLE IV
The workstations setting in the simulation software

Workstations requirement	Parameters
Workstation conditions	Maximum Content: 1 Process Time: 120 secs

B. *Model building using FlexSim*

FlexSim is a very versatile integrated simulation development tool. It provides a simple method to set up the simulation parameters and input. A variety of statistics with corresponding outcomes are generated on various objects. FlexSim is a discrete-event, object-oriented simulator developed and owned by FlexSim Software Products, Inc. of Orem, Utah. Its animation can be shown in the tree view, 2-D, 3-D and virtual reality. Usually, it is used to build models of flow systems or processes by using drag-and-drop model-building objects. The main objectives of using FlexSim are to improve production efficiencies, reduce operating costs through simulation, experiments and optimisation of dynamic flow systems. It allows end users to introduce and simulate new conditions for the model and analyse their effects and results.

In **Fig. 2**, the main paths are all single-way. The Spurs are all two-way so that the AGV can perform loading and unloading operations and follow by returning to the main path. Curved paths are set in the turning points to be closer to the real situation. 3 rows of racks are set on the top side of the warehouse, charging stations are set in the lower part, and the Workstations are set in the lowest part. The number of Workstations and AGVs can be modified based on the assumptions to seek the optimised scenario(s).

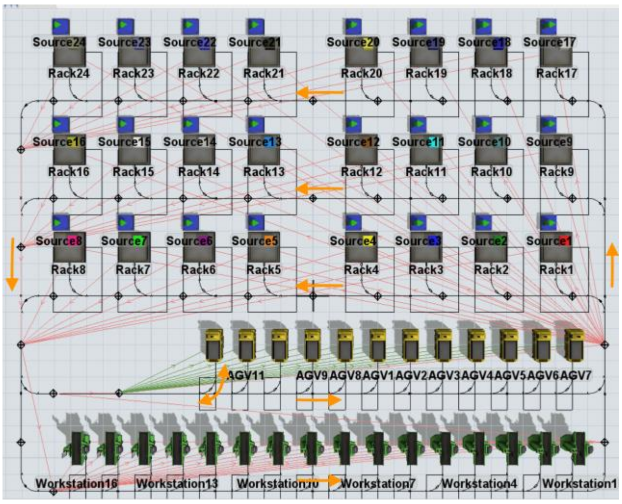

Fig. 2. Completed simulation model according to the setting of the case company

III. RESULTS AND DISCUSSION

A. *Validation of the simulation model*

To obtain accurate results and data from the simulation models, examination of the models is inevitable. Before starting the simulation, several confirmations should be made.

- The above settings are identical to each source, rack venue, AGV and Workstation
- No broken route exists
- Main routes are single-way, and spur routes are two-way
- Control areas are placed on every spur routes
- All sources, rack venues, AGVs, Workstations and relationships are linked to correct control points with a correct sequence

Meanwhile, testing of the simulation model is essential, and several confirmations should be made:

- No deadlock occurs
- No collision occurs
- Sources, rack venues, AGVs and Workstations are in operations
- AGVs follow the routes to load and unload
- AGVs recharge when the capacity reaches the threshold

B. *Scenario development*

In this project, there are totally 86 scenarios given that 69 of them are distinct scenarios with different numbers of AGVs and Workstations as stated in Table V. Meanwhile, 17 of them are optimised scenarios with the center route.

TABLE V
Combinations of the numbers of AGVs and workstations

/		Number of AGVs									
		1	2	3	4	5	6	7	8	9	Sub-total
Number of Workstations	1	√	√	√							3
	2	√	√	√							3
	3	√	√	√	√						4
	4		√	√	√	√					4
	5		√	√	√	√					4
	6		√	√	√	√					4
	7		√	√	√	√	√				5
	8			√	√	√	√				4
	9			√	√	√	√				4
	10			√	√	√	√	√			5
	11			√	√	√	√				4
	12				√	√	√	√			4
	13				√	√	√	√	√		5
	14					√	√	√	√		4
	15					√	√	√	√		4
	16						√	√	√	√	4
	17						√	√	√	√	4
Sub-total		3	7	11	11	12	11	7	5	2	69

C. Simulated results

Given the results collected from the precedent session, this part will discuss the optimised models by comparisons between each other in several measurements, including (1) total maximum output, (2) maximum output per workstation, (3) maximum output per AGV and (4) other observations.

It is a common belief that under the defined assumptions, the warehouse has its highest output in a preset time frame. All the highest output results regardless of the number of AGVs are chosen to form a bar chart. From 1 workstation to 8 workstations, the number increases vigorously and suffers a slow rising from 9 workstations to 10 workstations. The output ascends significantly when the 11th Workstation is added and continues with a slow and stable growth until the 16 Workstations scenario. When the 17th Workstation is installed, the output stop mounting, which implies 16 Workstations reaches the maximum capacity of the warehouse and is the optimised situation as stated in **Fig. 3**.

The total maximum output from the precedent session is divided by the corresponding number of the workstations to become the average output per workstation. The trend rises from 1 Workstation to 7 Workstations, which arrives at the highest average output and then start declining to 10 Workstations. A slight inclination occurs when the 11th Workstation is added and is followed by a gradual drop trend. As a short conclusion, the Workstations work with greatest efficiency and effectiveness in scenarios of 7 Workstations. The combinations between numbers of Workstations and AGVs can be seen in **Fig. 4**.

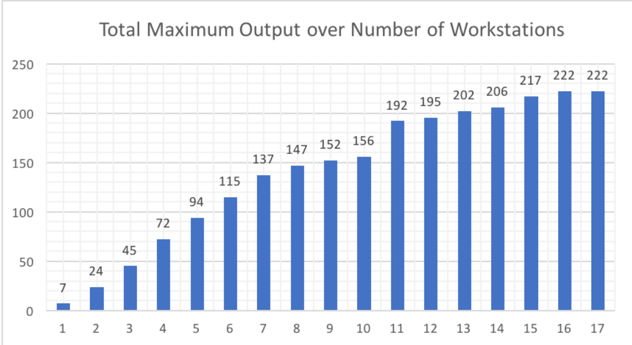

Fig. 3. Total maximum output over the number of workstations

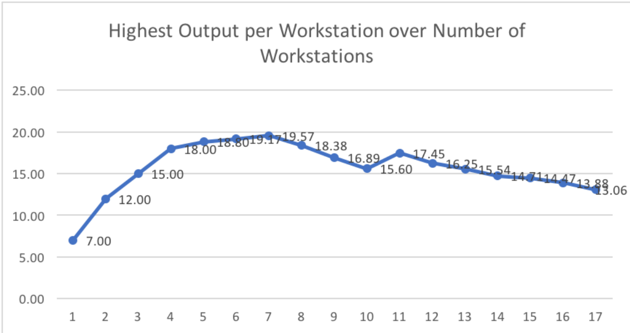

Fig. 4. Highest output per workstation over the number of workstations

This session intends to find the highest productivity of an AGV. All scenarios' outputs are divided by corresponding number and AGV. For example, the case with 3 Workstations and 4AGV has an output of 45. 45 is divided by 3 to obtain 15 outputs per AGV. After the division, the highest ratio of each circumstance with a distinct number of the workstations is gathered and form a line chart as **Fig. 5**. The trend rises from 1 AGV to 8 AGVs and suffers several fluctuations. In the context of 10 and 11Workstations, the ratios of output per AGV are the highest, which are the combinations of 10 Workstations and 3 AGVs and 11 Workstations and 3 AGVs.

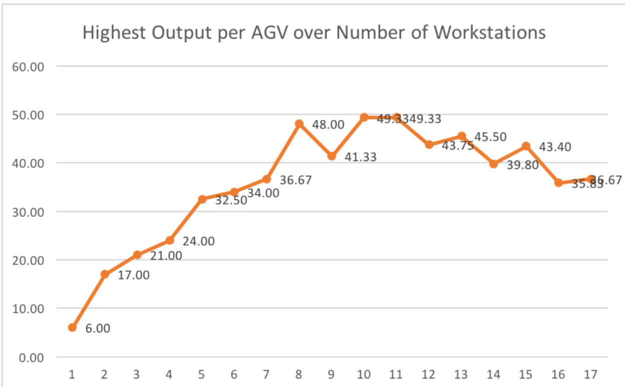

Fig. 5. Highest output per AGV over the number of workstations

Other observation suggested that adding a centre route was intended to relieve the problem of traffic jams. For example, When AGV 1 is occupying area rack 21, simultaneously, AGV2 is leaving from 20. If a centre route is available, it can provide another feasible route (s) to prevent traffic jams and enhance the overall efficiency and performance as shown in **Fig. 6**.

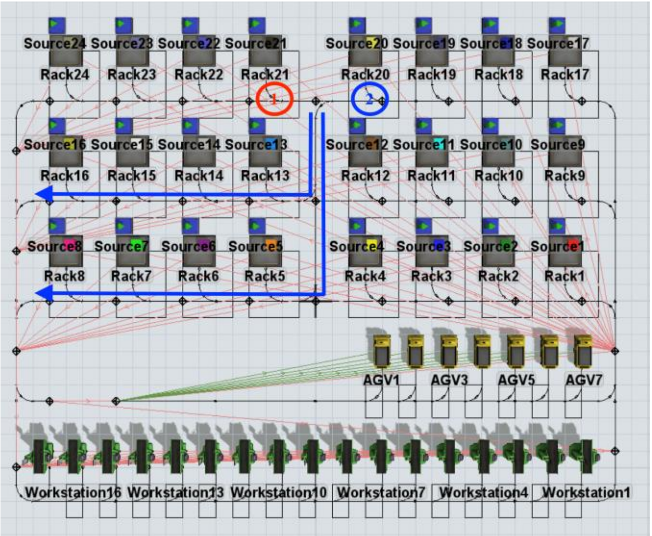

Fig. 6. An example of prevention of traffic jam

The results could offer a general perspective and expected the performance of the automated warehouse. The company could determine the possible setting of the number of AGVs and workstations regarding the performance, financial cost and the estimated throughput of the system.

IV. CONCLUDING REMARKS

As the technology of AGV becomes, mature as well as convenient, many simple and repeated works like transporting goods by using workforce are replacing AGV. With the reference of Amazon model and AGV as well as simulation’s information, knowledge and features from the literature review, simulation models were built in simulation software FlexSim and followed by obtaining results. Based on the assumptions, results and analysis of optimised scenarios with numbers of AGV and Workstation, the highest output per Workstation, the highest output per AGV, some special features like more blockings occur when numbers of AGVs and Workstations increases and is constant respectively as well as the effectiveness of the centre route.

In the future, with an objective to eliminate the limitations found during this project as well as extend its scope, there will be some improvements, including collection of practical data, adding operators in the models, exploring the influences of the directions of routes and, last but the least, assessing the effect carried out by battery-charging problem.

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