Anticipating Action Decisions of Automated Guided Vehicle in an Autonomous Decentralized Flexible Manufacturing System

Rizauddin Ramli, Jaber Abu Qudeiri, and Hidehiko Yamamoto

***Abstract*—**Nowadays the market for industrial companies is becoming more and more globalized and highly competitive, forcing them to shorten the duration of the manufacturing system development time in order to reduce the time to market. In order to achieve this target, the hierarchical systems used in previous manufacturing systems are not enough because they cannot deal effectively with unexpected situations. To achieve flexibility in manufacturing systems, the concept of an Autonomous Decentralized Flexible Manufacturing System (AD-FMS) is useful. In this paper, we introduce a hypothetical reasoning based algorithm called the Algorithm for Future Anticipative Reasoning (AFAR) which is able to decide on a conceivable next action of an Automated Guided Vehicle (AGV) that works autonomously in the AD-FMS.

***Keywords*—**Flexible Manufacturing System, Automated Guided Vehicle, Hypothetical Reasoning, Autonomous Decentralized.

I. INTRODUCTION

THE Flexible Manufacturing System (FMS) is an advanced production system in which many different standards may be used and many product types can be produced in the same line, and is controlled by computers and equipped with a transportation system that will deliver any work piece to any machine in any sequence [1]-[4]. The FMSs are equipped with several CNC machines and Automatic Guided Vehicle(AGV). An AGV based material handling system is designed and implemented to gain production the flexibility and efficiency. The major difference between an FMS and a conventional job shop is that the human tasks are automated in the FMS. On the other hand, an AGV functions as an unmanned, computerized system that is capable of understanding external guidance signals in order to deliver a unit load from origin to destination [5].

In order to gain the desired objective, the planning of the FMS decision making is crucial because it influences subsequent decision planning such as scheduling, dispatching, etc. Accordingly, one of the major problems encountered for scheduling is the AGV scheduling and controls. An effective AGV controller is needed to monitor the equipment status and regulate the work piece movement, so that the right material can be moved to the right place at the right time which is the basis of Just In Time (JIT) philosophy [6]. Furthermore, since the concept of FMS has been recognized to imply the ability to accommodate change, it is an essential aspect in FMS to adopt flexibility.

Flexibility is an attribute of contemporary manufacturing systems which is necessitated by the time-based competition underlying current manufacturing strategy. Generally, the areas of changes are constantly dealing with the changes in product design and capacity requirements that are variable results from the pressure of the competitive market. Typically, the planning of a FMS is characterized as being online, in real-time mode and of a short-term nature that responds to frequent changing of the production order [7].

So far, the routing algorithms for AGV are often divided by either a centralized approach or a decentralized approach. For a centralized approach, the route planning of AGV systems is determined by centralized decision making, which handles the entire system [8]. The Petri Net approaches [9],[10] are a useful way to analyze the conditions to avoid deadlock in AGV systems. Dispatching algorithms [11], and Genetic Algorithms (GA) [12],[13] have also been studied to cope with AGV routing problems.

In the autonomous decentralized system, the AGV routing is generated by several decision making subsystems. One of the approaches is zone control [14],[15], where the AGV system can be divided into several non-overlapping regions, which restricts the available AGV for a time. Nishi *et al.* [16] have proposed a distributed routing method for multiple mobile robots using a Lagrangian decomposition and coordination technique. The original problem is decomposed into an individual routing problem for each AGV. Most of the conventional research on autonomous decentralized real time scheduling systems for AGV are based on agent decision selection and object orientation method [17],[18]. In the method, the fastest action that can be finished at the existing time is selected as the action that should be taken for the agent.

In this paper, we propose an anticipative technique for the next action of AGV that includes an advance prediction of action in a few steps, which will be able to enhance the

Manuscript received December 5, 2006.
Rizauddin Ramli is with the Intelligent Manufacturing Systems Laboratory, Faculty of Engineering, Gifu University, 501-1193 Japan, on leave from the Department of Mechanical and Materials Engineering, University Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia (Phone: +81-58-293-2550; Fax: 81-58-293-2550; e-mail: k3812205@ edu.gifu-u.ac.jp).

Jaber Abu Qudeiri is with the Intelligent Manufacturing Systems Laboratory, Faculty of Engineering, Gifu University, 501-1193 Japan (e-mail: k3812203@edu.gifu-u.ac.jp).

Hidehiko Yamamoto is with the Department of Human and Information Systems, Faculty of Engineering, Gifu University, 501-1193 Japan (e-mail: yam-h@gifu-u.ac.jp).

efficiency condition of the overall FMS. In this way, we develop an Algorithm for Future Anticipative Reasoning (AFAR) of the next action decision of AGV. By using this algorithm, we adopt a hypothetical reasoning technique that will decide the conceivable next action from the competition hypothesis. However, in normal hypothetical reasoning, the increasing of the number of agents in Autonomous Decentralized FMS (AD-FMS) will also increase the number of conceivable next actions which will result in the deterioration of the hypothesis ratio. In this research, we will try to resolve this problem by the proposed technique.

II. Autonomous Decentralized FMS

A. Basic Function of AD-FMS

A schematic diagram of basic elements of an AD-FMS structure from the view of information processing is shown in Fig. 1, where it comprises the basic elements of an AD-FMS that are of several numerical control (NC) machine tools, robots, transportation systems, computer systems, controllers and warehouses. Each of these components communicates and exchanges their information while they decide on what action to perform and how to control the production components. The NC machine tools do not only concentrate on NC machining centers(MC) but it also may comprise any of the machining units in the AD-FMS system such as lathe machines, turning machines, etc. On the other hand, the transportation system functions as a device to transfer the work piece between the parts warehouse, product warehouse and machining centers.

In this paper, we consider the transportation system as an AGV that operates as alternative devices to other material handling such as forklift or conveyers. The advantages of the AGV system include improvements in flexibility, space utilization, safety and overall operating cost. The AGV systems are highly flexible, since their route can usually be changed quickly, and vehicles can be dynamically rerouted. Regarding space utilization, the AGV does not create physical barriers on the factory floor as conveyers do, and they can also share aisle space with other users. However, the benefits of AGV in an AD-FMS are not easy to realize. Specifically, scheduling and control algorithms are needed to run the advance systems efficiently. In this case, scheduling and the control problem of an AD- FMS is inherently complex and difficult to solve because AD-FMS is a highly dynamic and highly integrated system.

B. Model of AD-FMS

In this paper, the model of the AD-FMS that we study consists of multiple agents inside a factory that is shown in Fig. 2. The agent can be divided into a parts warehouse, product warehouse, transportation systems for material handling (AGV) and several MCs. The movement of the AGV inside the FMS is restricted on the dashed line grid with equal speeds. The MCs can machine several types of parts and the machining time for each type of machining process is fixed. Moreover, there also exist multiple types of MC that can perform the same machining task. The similar types of MC are called MC groups, and they are represented as MC1, MC2, … and each MC in these groups is identified by MC1-1, MC1-2,… etc.

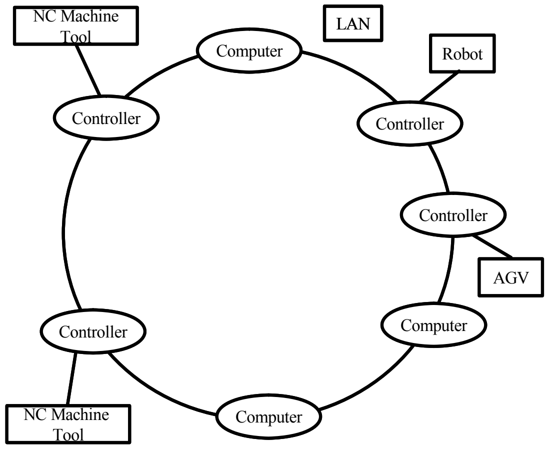


Fig. 1 Relation of information processing between elements in AD-FMS.

Furthermore, the information exchange and cooperation between each agent in this AD-FMS is described as follows. The AGV transmits the information of what type of part and where it is going, the parts warehouse transmits the information of what type of part that it prepares, and the MC transmits the information of what type of part that is currently machined and the time remaining to finish the machining process. All the information that is transmitted is taken by the needed agent as materials to perform the next action.

C. Problems in AD-FMS

It is necessary to optimize the huge combination efficiently that is produced with the AD-FMS. However, even now if it has the ability of an efficient computer, it is considerably a difficult problem to obtain the optimal solution. For instance, if the scheduling problem is a problem of the combinations and the candidate of all the solutions can be enumerated, it can search for the best solution from among them. However, normally, the combination becomes large with the increase in the types of parts. If all these large combinations correspond directly to the control of the machine tool, the breakdown of the control computer, and the changes in the production plan, etc, it becomes extremely complex to design such an efficient AD-FMS. In other words, it is one of the major problems to construct a real-time AD-FMS. Generally, the problems that happen in constructing the method in AD-FMS are described as follows:

The method of deciding an autonomous action:

Unlike the centralized approach, where all the action decisions are made by a central system, all the agents in the AD-FMS have to decide their own decisions quickly and then execute the action. Therefore, it is important to develop a highly efficient and high-speed algorithm, which is not available in the general method.

The method of achieving cooperated action:

In order to perform an autonomous action, each agent should behave as an individual with an intelligent system, so that they can communicate and understand the behavior of the other agents. However, the control systems of this method are extremely crucial and to structuralize the algorithm is a troublesome task.

The communication cost:

To implement a cooperative action between each agent, much information needs to be transferred between agents which require a sophisticated telecommunication system. It required a lot of money to realize a telecommunication system in the AD-FMS.

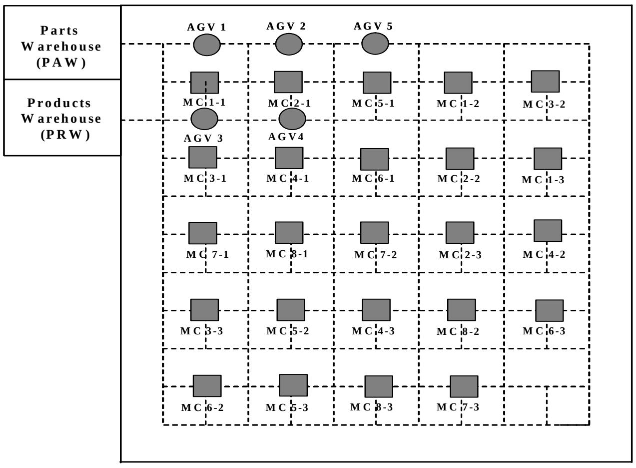


Fig. 2 Model of AD-FMS

III. Hypothetical Reasoning of AGV Decision

A. Algorithm of Hypothetical Reasoning

One of the characteristics of an AD-FMS is the ability to assign several tasks between each MC in the same MC groups which can do the same machining process, resulting in the realization of enhancing production efficiency [19], [20]. This task assigning process is done by the AGVs. During this process, due to the interlace between the AGV travelling distance or time with the waiting time in front of the MC, the operating condition of the system is highly influenced by the action taken by the AGV; i.e., where it will move or to which MC it will go or whether it should go to take the finished part, etc.

In conventional methods, the action planning of the AGV action is done by a pre-decided scheduling system that does not consider an unexpected problem such as MC troubles and machining delay time. Once this unexpected trouble occurs, the production plan needs to be re-scheduled. Furthermore, in the case of an AD-FMS where many MCs and AGVs are mixed together, it is difficult to schedule an effective instruction for the AGV about where it should go and which part should be input.

In this paper, the processing procedures that we adopt are described as follows ;

(1) The usage of information from each agent
(2) The inference of a few steps of AGV action
(3) The forecasting of the AD-FMS operating condition.

In order to implement these procedures, we propose an Algorithm for Future Anticipate Reasoning(AFAR) which is able to forecast the next action decision in the real-time production scheduling of the AGV, that is based on Hypothetical Reasoning Technique(HRT). Hypothetical reasoning is the activity of evaluating the effect of the actions that affect a given domain that is now an established subfield of knowledge representation [21]-[23]. In this paper, the AFAR's real-time production scheduling is done by using 2 types of hypothetical reasoning; the first hypothesis is the Action Decision Hypothetical Reasoning (ADHR) that decides where the AGV will move to and the second hypothesis is the Part Input Hypothetical Reasoning (PIHR) that decides the kinds of parts to be input onto the production floor. Moreover, by using both of these hypotheses, ADHR and PIHR are then combined as a Hypothetical Reasoning of Varied Order Selection (HR-VOS).

The next action decision for AGV is related to many reasons, such as the existence of many MCs with the same machining process, the transportation of the product to the product warehouse, the input of new parts to the AD-FMS, the existence of other AGVs that are doing the same action, etc. Due to these reasons, the action decision necessitates not only a single action decision but it could also be a multi action decision that is based on the action decision selection branch. Attentively, if the AGV selects one choice from the selection branch, and then based on the selected branch, each of the agents inside the AD-FMS is given moving and working instructions. Furthermore, when the AGV meets the condition that is required to do the selection again, then it will re-select one of the choices from the action decision selection branch. In this way, the operating condition in the AD-FMS is realized by the continuous process of selecting the AGV next action decision. In other words, as shown in Fig. 3, the operating condition of AGV is eternally broadening like a tree structure, where the node is assumed as the next AGV action.

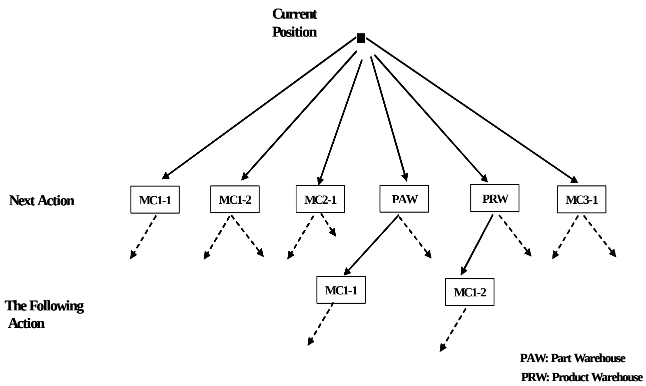


Fig. 3 Operation conditions of AGV

Fig.4 shows the outline of the proposed hypothetical reasoning process. The tree structure shows the form of retrieval vertically. In every stage of the tree structure, the retrieval will be done until it finds FALSE results and it will return back to one stage back and start the retrieval process again at another selection branch. The peak of the tree structure is set as the last AGV action with the hypothesis depth 0 and the

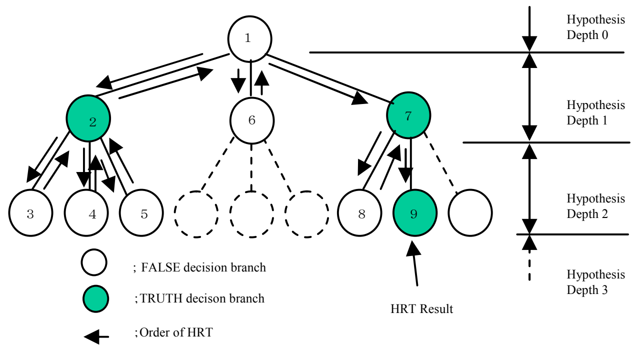


Fig. 4 Hypothetical reasoning

hypothesis depth under this stage represents the action that is taken by the AGV. Similarly, the hypothesis with depth 1 has its own selection branch under it with all of them having their own selection branch, respectively. In Fig. 4, the selection branch and the arrows connecting the selection branch show the hypothesis simulation that is called Inside Hypothetical Simulation (IHS). The hypothesis simulation runs as if the end of the arrow is TRUTH, then by doing the task following the selection branch, it will display the result of the simulation.

The algorithm of the IHS is performed according to the following steps.

Step1: The existing AGV hypothesis depth is set as 0.

Step2: For the next hypothesis depth, if the selected branch is FALSE, then the farthest left side branch is selected and assumed to be TRUTH.

Step3: Run simulation to the selected branch.

Step4: Based on the simulation result, the selection branch is judged whether it is TRUTH or not.

Step5: If the simulation result is FALSE, then go to STEP 6. If it is TRUTH, then go to STEP 8.

Step6: In the depth of the same hypothesis that has been judged to be FALSE, if the left side of the selection branch that has not yet been judged as TRUTH or FALSE is then it is selected and assumed to TRUTH, and go to STEP 3.

Step7: Go up to another depth of hypothesis and go to STEP 6.

Step8: If the hypothesis is above a set value then go to STEP 9, if not go to STEP 2.

Step9: If the selection branch becomes TRUTH, then the hypothetical reasoning is finished.

Two types of hypothetical reasoning, the ADHR and PIHR can be used by recalling each other, respectively. For instance, when one AGV is moving from one place to the parts warehouse under the ADHR, if the hypothesis is judged as TRUTH, then after it arrives at the parts warehouse, it will become the next hypothesis. Then, when the AGV takes a part from the parts warehouse under the decision of PIHR, next it will execute the ADHR for the next action. Furthermore, when the hypothetical reasoning is being performed, only one AGV will carry out the hypothesis. In other words, when the hypothetical reasoning is performed by one AGV, another AGV will only start the hypothesis after the first AGV finishes its hypothesis.

In the hypothetical reasoning technique, in the case where there is a selection branch with the same level of efficiency, the higher ranking of the selection branch will be selected, i.e. the possibility of selecting a higher ranked selection branch arises. For example, when there are two selection branches with the same efficiency in existence, the selection branch that is precedently judged to be TRUTH will be automatically carried out. Here, we use the characteristic of hypothetical reasoning to bring the products production rates to be closer to its target by using the hypothetical reasoning of varied order selection(HR-VOS) that changes the selection order. With HR-VOS, it arranges the order that relates to the most insufficient product in that time to become a higher rank according to the selection order function which depends on the production situation.

IV. Anticipating The AD-fms Conditions

In this paper, we propose a novel idea of forecasting future conditions in the AD-FMS. The terms that relate to AFAR are defined as follows:

Definition 1. Standard of TRUTH/FALSE judgments

From the result of IHS that shows the operation rates of the AD-FMS, we can judge whether the inside of the hypothetical reasoning has any contradictions or not based on the following 6 standards. If the standard is not achieved, then it is judged that a contradiction has occurred.

[Std 1]: Total MC operation rates are above 75%
[Std 2]: Total MC operation rates are above 50%
[Std 3]: Total MC operation rates are above 25%
[Std 4]: Total MC operation rates are above 0%
[Std 5]: Total AGV operation rates are above 50%
[Std 6]: Total AGV operation rates are above 0%

Definition 2. Function of machine selection priority *M(MCN)*

A target value is set to check how much time remains until the MC completes the machining process, which is shown in (1). The MC with higher selection priority means that it still has many tasks remaining and is given a top priority to be selected as TRUTH.

$$M(MCN) = \sum_{n=1}^{PN} MProT(n) \times \left\{ ProRate(n) - \left(\frac{CompPt(n) + \frac{1}{2} ProPt(n)}{AllCompPt + \frac{1}{2} AllProPt} \right) \right\} \quad (1)$$

where,

MCN	: Number of MC types
PN	: Numbers of production types
MProT(*n*)	: Machining time of product *n* at *MCN*
ProRate(*n*)	: Production rates of product *n*
CompPt(*n*)	: Numbers of product *n* that have completed machining process
AllCompPt	: Numbers of all that have completed machining process
ProPt(*n*)	: Numbers of part *n* at AGV or MC
AllProPt	: Numbers of all parts at AGV or MC

Definition 3. Function of parts warehouse selection priority
It is a value of determining the number of parts that are under machining or tranferring process, which can be defined as,

$$F_p = \left(1 - \frac{max.parts.N - AllProPt}{max.parts.N}\right) \times destination.N \tag{2}$$

where,
max.parts.N : Maximum number of possible part input
destination.N : Total numbers of destinations, i.e., AGV, MC, parts and product warehouse.

Definition 4. Function of product warehouse selection priority
Determine the inverse of F_p as follows,

$$F_f = destination.N - F_p \tag{3}$$

Definition 5. Value of part selection priority $V(n)$
Equation (4) shows a value of how many parts *n* that are not loaded into the production line. The higher value will prompt the AGV to take a part from the parts warehouse and input it into the line.

$$V(n) = TotalProT(n) \times \left\{ \frac{ProRate(n)}{100} - \left(\frac{CompPt(n) + \frac{ProPt(n)}{2}}{AllCompPt + \frac{allProPt}{2}} \right) \right\} \tag{4}$$

where,
TotalProT(n) : Total time for processing part *n*

Definition 6. Value of Task decentralization
In the case where a similar MC from the same group exists, it is required to standardize the task. Equation(5) calculates the standardization of MC operation rates. In other words, a MC with a lower production rate has a higher value of task decentralization, that results in the MC to be selected easier.

$$F_d(MCN) = \frac{1}{MC.Effeciency} \tag{5}$$

where,
MC.Effeciency : Operation rates of *MCN*(%)

Based on these definitions , we have developed an algorithm for parts input and AGV action decision corresponding to HRT. The algorithm decision parts input is designed as follows :
STEP1 : Add one depth to the hypothesis depth.
STEP2 : By using $V(n)$, decide the part selection order.
STEP3 :Select the highest selection branch in the part selection order.
STEP4 :Run a simulation assuming that the selected branch is TRUTH.
STEP5 :Based on the simulation result, judge whether it is TRUTH or FALSE.
STEP6 :Go to next selection branch and repeat STEP4.

A. AGV with Intelligent Knowledge(AGV-wIK)

In this paper, we consider the AGVs as intelligent agents that are able to adopt knowledge, transmit their information to each other and understand another AGVs behavior. If one AGV can understand the behavior of another AGV, it is possible to avoid their collision, and to cooperate in their task together. Here, we define each AGV as having 6 types of intelligent knowledge, i.e. *Routing* knowledge, *Self* knowledge, *Sending* knowledge, *Others* knowledge, *Answer* knowledge and finally *Avoidance* knowledge. These 6 types of knowledge are divided into 2 types : long term memory and short term memory. *Sending*, *Answer* and *Avoidance* knowledge are kept in the short term memory, while *Routing* knowledge, *Self* and *Others* knowledge are kept inside the long term memory. An example of this knowledge is shown in this section; *Self* knowledge(see Fig. 5).

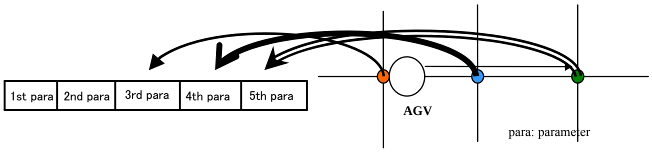


Fig. 5 *Self* knowledge

The first parameter and second parameter indicates the name and emergency command of the specified AGV respectively. The third, fourth and fifth parameter indicates the position of the location that the AGV has just passed, the next position that the AGV will go to and the next position after that. All of these information are transmitted to other AGV, so that they can share and exchange their information to avoid collision between them.

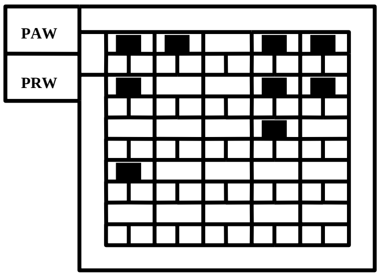
V. Numerical Experiments

A. Model of Production Floor

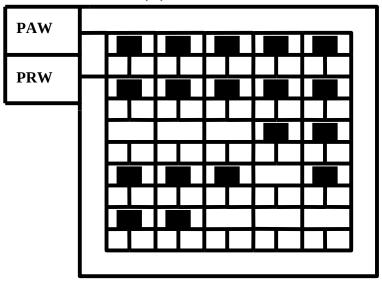
The production floor is a 60m × 60m square. (The parts warehouse and the product warehouse are located outside of the floors). The distance that an AGV is able to move is 5 m from the inside floor wall. It is assumed that the entrance to the parts warehouse and product warehouse use the shortest route from the grid. Furthermore, the positions of MCs are located at the edge of the grid of the AGV route. In this research, in order to facilitate the dynamic AD-FMS simulation, the following assumptions are made.
・The maximum numbers of AGVs are 5. The AGV moves on the grid on the floor, and the traveling speed of the AGV is constant, but it depends on the type of carried parts and products.
・The maximum types of MC are 8 types and the maximum numbers of the same type of MC are 3 types. The position is assumed as the entrance of parts handling position.
・The maximum numbers of part types are 9 types with each type only being processed a maximum of 8 times.

B. Simulation Condition and Results

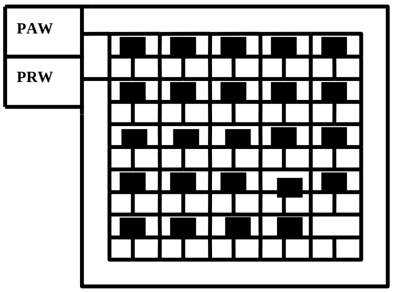
In this paper, 3 kinds of simulation conditions were performed to ascertain the effectiveness of our proposed algorithm of AGV-wIK. The position of the parts warehouse, product warehouse, and MCs on the production floor are configured as shown in Fig. 6. The position of MCs (represented by ■) and the numbers of AGVs are changed in each different simulation condition. Each simulation time is 8 hours and the numbers of AGV used in each simulation condition are 3 :4 :5. In Condition-1, we ran 3 types of simulations with different numbers of AGV are performed with the following conditions: 3 types of products with the rates of each product and production ratios as P1 :P2 :P3=5 :6 :3. Next, in Condition-2 , we ran 3 types of simulations with 6 types of products with the following conditions: The rates of each product and production ratios as P1 :P2 :P3 :P4 :P5 : P6=5 :6 :3 :3 :2 :1. Finally, in Condition-3, we ran 3 types of simulations with different numbers of AGV under the following condition: 9 types of products with the rates of each product and production ratios as P1 : P2 : P3 : P4 : P5 : P5 : P6 : P7 : P8 : P9 = 5 : 6 : 3 : 3 : 2 :1 : 4 : 5 : 2.



(a) Condition-1



(b) Condition-2



(c) Condition-3

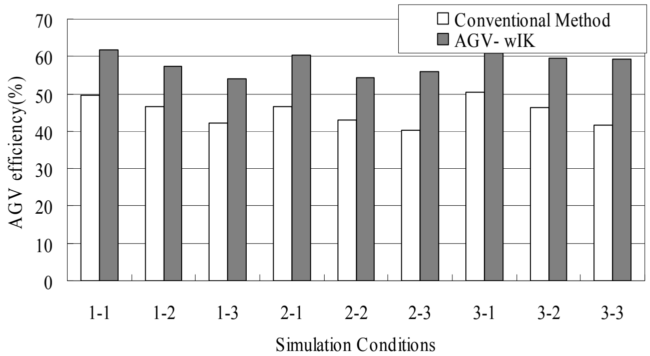
Fig. 6 Location of MCs in each condition

In order to verify the effectiveness of AGV-wIK, we also ran simulations with the same condition without intelligent knowledge (i.e. Conventional Method) where the moving destination is decided and fixed. In Fig. 7(a), each Condition-1, Condition-2 and Condition-3 indicates that the efficiency of AGV becomes better with AGV-wIK than using the Conventional Method. Similar results obtained where the number of AGV collisions are reduced as shown in Fig. 7(b). This proved that our proposed technique works effectively.

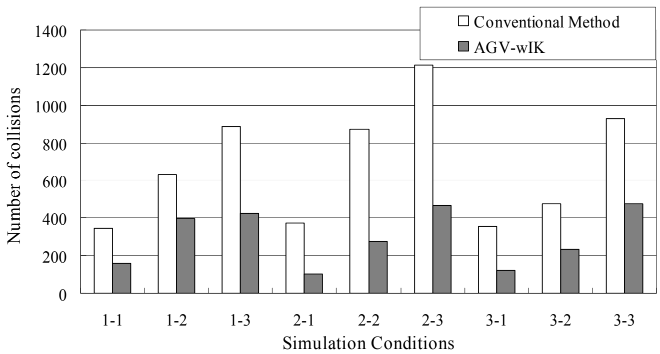
VI. Conclusion

In this paper, we proposed a technique of anticipating the next action of AGV that includes an advance prediction of action in a few steps, which will improve the efficiency of Autonomous Decentralized Flexible Manufacturing System (AD-FMS). The technique, Algorithm for Future Anticipative Reasoning(AFAR) is used to forecast the next action decision of AGV. By using the AFAR, we adopt a hypothetical reasoning technique that will decide the conceivable next action from the competition hypothesis.

Simulation results show that the efficiency of AGV in AD-FMS increased. The numbers of collisions are also decreased, which means we can obtain a proper navigation for the AGV. It confirmed that our technique is useful in collision avoidance.



(a) Average efficiency of AGVs



(b) Number of AGVs collisions

Fig. 7 Simulation results

References

[1] M. P. Groover, "*Automation, Production System and Computer Integrated Manufacturing*", New York: Prentice Hall, 1987

[2] M. Kaighobadi, and K. Venkatesh, "Flexible Manufacturing Systems: an overview", *International Journal of Operations & Production Management,* vol. 14, pp.26-49, 1994.

[3] G. G. Kost, and R. Zdanowicz, "Modeling of manufacturing systems and robot motions", *Journal of Materials Processing Technology,* vol. 164-165, pp. 1369-1378, 2005.

[4] S. Takukawa, "The use of Simulation in Activity-Based Costing For Flexible Manufacturing Systems", *Proc of the 1997 Winter Simulation Conference*, pp. 793-800, 1997.

[5] P. E. Guy, and A. Castleberry, *The AGV Handbook.* Ann Arbor, Michigan: Braun-Brumfield, Inc., 1991.

[6] T. Ohno, *Toyota Production System: Beyond Large-Scale Production* , Productivity Press, 1998.

[7] K. Hitomi, *Manufacturing Systems Engineering: A Unified Approach to Manufacturing Technology, Production Management, and Industrial Economics*, 2nd Edition, CRC Press, 1996.

[8] T. Nishi, M. Ando, and M. Konishi, "Experimental Studies on a Local Rescheduling Procedure for Autonomous Decentralized AGV Systems", *Robotics and Computer Integrated Manufacturing*, vol. 22, pp. 154-165, 2006.

[9] J. W. Yoo, E. S. Sim, C. Cao, and J. W. Park, "An Algorithm for Deadlock Avoidance in an AGV System", *International Journal of Advance Manufacturing Technology*, vol.26, pp. 659-668, 2005

[10] N. Wu, and M. Zhou, "Resource-oriented Petri Nets in Deadlock Avoidance of AGV Systems", *Proc. IEEE Conf Robot Automation*, pp. 63-69, 2001.

[11] S. H. Kim, and H. Hwang, "An adaptive dispatching Algorithm for Automated Guided Vehicles based on an evolutionary process", *Int. Journal of Prod Economics*, vol. 60-61, pp. 465-472, 1999.

[12] M. Ficko, M. Brezocnik, and J. Balic, "Designing the layout of single- and multiple-rows flexible manufacturing system by genetic algorithms", *Journal of Materials Processing Technology*, vol. 157-158, pp. 150-158, 2004.

[13] G. Ulusoy, F. S. Serifolu, and Ü. Bilge, "A genetic algorithm approach to the simultaneous scheduling of machines and automated guided vehicles", *Computers & Operations Research*, vol. 24, pp. 335-351, 1997.

[14] J.-H. Chen, and S.-Y, Ho, " A novel approach to production planning of flexible manufacturing systems using an efficient multi-objective genetic algorithm", *International Journal of Machine Tools and Manufacture* , vol. 45, pp. 949-957, 2005.

[15] Y. C. Ho, " A dynamic zone strategy for vehicle-collision prevention and load balancing in an AGV system with a single-loop guide path", *Computer in Industry*, vol. 42, pp. 159-176, 2000.

[16] T. Nishi, M. Konishi, and S. Hasebe, "An Autonomous Decentralized Supply Chain Planning System for Multi-Stage Production Processes", *Journal of Intelligent Manufacturing*, vol. 16, pp. 259-275, 2005.

[17] R. C. Arkin, and R. R. Murphy, "Autonomous Navigation in a Manufacturing Environment", *IEEE Transactions on Robotics and Automation*, vol. 6, pp. 445-454, 1990.

[18] W. Shen, "Distributed Manufacturing Scheduling Using Intelligent Agents", *IEEE Intelligent Systems*, vol. 17, pp. 88-94, 2002.

[19] H. Yamamoto, "AGV's Actions Decision by Reasoning to Anticipate Future in Decentralized Autonomous FMS", *Proceedings of 2000 Japan-USA Symposium on Flexible Automation*, 2000.

[20] K. Kouiss, H. Pierreval, and N. Mebarki, "Using Multi-agent architecture in FMS for dynamic scheduling", *Journal of Intelligent Manufacturing*, vol. 8, pp. 41-47, 1997

[21] A. Provetti, "Hypothetical reasoning about actions: from situation calculus to event calculus", *Computational Intelligence*, vol. 12, pp.478-498, 1996.

[22] M. Baldoni, L. Giordano, and A. Martelli, "A modal extension of logic programming: Modularity, beliefs and hypothetical reasoning", *Journal of Logic and Computation*, vol. 8, pp.597-635, 1998.

[23] D. Poole, "A methodology for using a default and abductive reasoning system", *International Journal of Intelligent Systems*, vol. 5, pp.521-548, 1990.

Rizauddin Ramli is a tutor at the Department of Mechanical and Materials Engineering, Faculty of Engineering, Universiti Kebangsaan Malaysia. He received his B. Eng from Kyoto University of Japan in 1997 and his M. Eng of Mechanical and Systems Engineering from Gifu University, Japan in 2005. Currently, he is a PhD student at Intelligent Manufacturing Systems Laboratory, Faculty of Engineering, Gifu University Japan. His major fields of study are genetic algorithm, production system simulation and robotics.

Jaber Abu Qudeiri received his B. Eng from University of Jordan, Jordan in 1992 and his M. Eng. of Mechanical and Systems Engineering from Gifu University, Japan in 2005. He is a PhD student at Intelligent Manufacturing Systems Laboratory, Faculty of Engineering, Gifu University, Japan. His major fields of study are genetic algorithm, production system simulation, CAD/CAM and production system design layout.

Hidehiko Yamamoto is a Professor in the Department of Human and Information System Engineering, Gifu University, Japan. He received his B. Eng. and M. Eng from Nagoya Institute of Technology, Japan. After graduated, he joined Toyota Industries Corporation and developed many production lines for automotive parts. During working for Toyota, he received his PhD from Nagoya Institute of Technology, Japan. His research interests include production engineering, intelligent system, automations and knowledge learning.