Real-time Decision Making of Agents to Realize Decentralized Autonomous FMS by Anticipation

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Summary
One of the new computer technology for controlling production systems is an autonomous decentralized Flexible Manufacturing System (FMS). The autonomous decentralized FMS aims at high production efficiency by giving self-control or decentralizing the plan, design and operation of FMS. This paper discusses the intelligent real-time decision making necessary for realizing an autonomous decentralized FMS with Automatic Guided Vehicles (AGVs) and Machining Centers (MCs). This research develops a real-time production control method called Intelligent Decisions by Anticipation and Simulations with Hypotheses (IDASH) based on the predictions that foresee not only current production situations but also anticipate future ones. IDASH can be seen that multi-production that keeps the target production ratio is possible even though neither AGV actions' plans nor parts input schedules are given beforehand. Especially, it can be shown that the method will operate a FMS without influencing the production ratio even when unpredicted troubles happen, which is often seen in an actual factory.

Key words:
Hypothetical reasoning, Intelligent system, Autonomous decentralized system, FMS.

Introduction

With the development of network technology and information communication technology, the basic technology of a new production system has been developed. One of the directions it can take is a decentralized autonomous Flexible Manufacturing System (FMS). The decentralized autonomous FMS aims at high production efficiency by giving self-control or decentralizing the plan, design and operation of FMS. This paper discusses the basic computer system necessary for realizing a decentralized autonomous FMS with Automatic Guided Vehicles (AGVs) and Machining Centers (MCs).

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In general, if it is possible to make plans by considering near future trends and information, it is considered wiser than acting blindly. As the AGV actions' decision, this idea is introduced. This research develops a real-time decision making for AGV actions based on the predictions that foresee not only current production situations but also anticipate future ones. Also, the developed decision making method is applied to a decentralized autonomous FMS. Because of the results, it can be seen that multi-production control that keeps the target production ratio is possible even though neither AGV actions' plans nor parts input schedules are given beforehand. Especially, it can be shown that the method will operate a FMS without influencing the production ratio even when unpredicted troubles happen, which is often seen in an actual factory.

There are a few researches for a decentralized autonomous FMS [1]-[4]. They do not consider what will happen in FMS. This research's characteristic is to foresee the near future situations of FMS. In this point, the research is different from the ordinal researches.

2. BASIC CONSTRUCTION OF DECENTRALIZED AUTONOMOUS FMS

The construction of a decentralized autonomous FMS that this paper deals with is shown as **Fig. 1**. It shows a Parts Warehouse that supplies parts for a factory, a Products Warehouse for finished parts from MCs, some AGVs that carry parts and some MCs are arranged. Each AGV carries one part. AGVs move on the dotted lines of the figure at a uniform velocity. MCs can work several kinds of parts and each of the parts has decided manufacturing processes and manufacturing time. Some MCs do the same kinds of work processes. The set of the same type MC is called a Group MC and is distinguished by describing subscripts, for example, ${}_gMC_1$, ${}_gMC_2$, ⋯ . Each MC in the same Group MC is distinguished by attaching a hyphen and figures after the name of Group MC, for example, $MC_{1\text{-}1}$, $MC_{1\text{-}2}$, ⋯ .

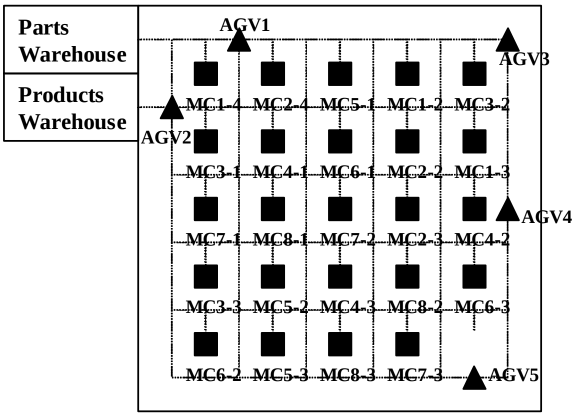

Fig. 1 FMS model

Note that later sentences uses the term " parts ". The parts meaning is not limited to the same variety but includes different varieties.

The contents of information exchanges and cooperative actions between each agent in a decentralized autonomous FMS is basically the following. The Parts Warehouse sends the information on the names of parts that are in the Parts Warehouse. The AGV sends both the information on the name of the part that the AGV currently has and the information on its next destination. The MC sends both the information on the name of the part it is currently manufacturing and the information about the remaining manufacturing time. When necessary, an agent uses the received information to make the agent movement decisions.

3.1 Outline of Future Foresee Reasoning

One of a FMS's characteristics is to realize efficient production by jointly sharing manufacturing operations among the MCs in a Group MC that has the same manufacturing processes. The parts delivers by AGVs are responsible for the sharing operation. Because the AGV moving distance and time and the waiting time in front of each MC bay are inexplicably linked with FMS operating efficiency. According to which parts the AGV will deliver to which MC and which part the AGV will take, the FMS operating efficiency can change much.

With the predetermined scheduling for AGVs' movement, which is the ordinary method, it is difficult to deal with unpredicted troubles such as manufacturing delay and machine breakdown. If the ordinary method is used, once this kind of unpredicted trouble occurs, re-consideration of the production schedule must be necessary. Moreover, in a FMS that uses many AGVs and MCs, it is difficult to make a predetermined schedule for efficient AGV movement order and parts delivering order.

In order to solve the problems, this research adopts the following process procedure : ① use each agent information, ② foresee several future steps of probable AGV actions, ③ foresee probable FMS operating situations. *I*ntelligent *D*ecisions by *A*nticipation and *S*imulations with *H*ypotheses (**IDASH**) to decide the AGV's next moving actions based on the prediction results of ③ is proposed and solves the above mentioned problems. IDASH resembles a chess strategy that moves a piece after anticipating the several alternatives for one move. The decisions by IDASH are both where the AGV moves next and which part it carries next. In this way, predetermined parts delivering schedule is not needed.

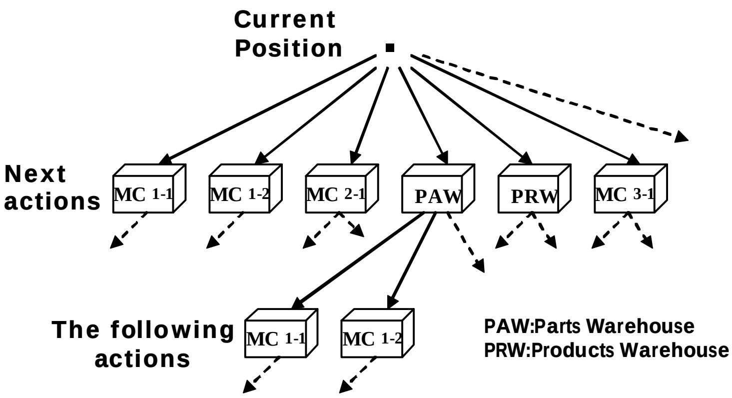

Fig.2 Tree construction of FMS situations

3. REASONING TO ANTICIPATE FUTURE

The probable action (**Next Action**) that a AGV will take next is not decided as a single action but as many actions because there are some MCs that are doing the same manufacturing process jointly, maybe the AGV transfer finished parts to the Products Warehouse, or maybe deliver a new part into the FMS from the Parts Warehouse, and there is a possibility that another AGVs will make the same action. Hypothetically, if an AGV chooses one of the above actions, in an actual FMS, each agent in the FMS keeps doing its chosen operation. When an AGV needs the choice of Next Action again, it chooses a single Next Action from among the possible choices again. In this way, the operating situation of a FMS is expressed as the choice process of unending cycle of AGV Next Actions. That is, it is expressed as a tree construction which includes nodes corresponding to possible AGVs Next Actions. The tree construction can be extended infinitely, as shown in **Fig.2**. The strategy of IDASH considers the possible Next Actions that the AGV will be able to take locally a few steps ahead as a foreseeable range, as well as globally foreseeing phenomena happening in the FMS in a near future and, then going back to the present, decides which choice should be chosen at present. In order to do IDASH, by the hypothetical reasoning which considers the choices that the AGV will be able to take as competitive hypotheses, the decision process is controlled.

3.2 Future Foresee and Competitive Hypotheses

Hypothetical reasoning regards events that can happen simultaneously as competitive hypotheses, classifies each hypothesis among them into a true hypothesis and the rest false hypotheses, then hypothetically continues to reason with the true hypothesis and follows the true hypothesis till a contradiction occurs [5]-[9].

Based on hypothetical reasoning, IDASH tentatively decides AGV Next Actions a few steps ahead locally and foresees FMS operating situations globally. In this situation, what are established as competitive hypotheses strongly depends upon IDASH executions. This research establishes competitive hypotheses in the following way.

Considering the Next Action that an AGV will be able to take from a standpoint of the AGV, two kinds of actions are possible, ① where it will move next, ② which part it will take next. This classification is reflected in the two kinds of competitive : competitive hypotheses for moving places (**C-hypotheses-move**) and competitive hypotheses for parts (**C-hypotheses-parts**). C-hypotheses-move may be analyzed into three types : (1) move to MC bay to exchange parts, (2) move to the Parts Warehouse to input new parts , (3) move to the Products Warehouse to deposit parts when all manufacturing processes are finished. As the elements of C-hypotheses-move, each MC (MC_{1-1}, MC_{1-2}, ⋯), the Parts Warehouse and the Products Warehouse are established. As the elements of C-hypotheses-parts, each part (P_1,P_2,P_3, ⋯) is established.

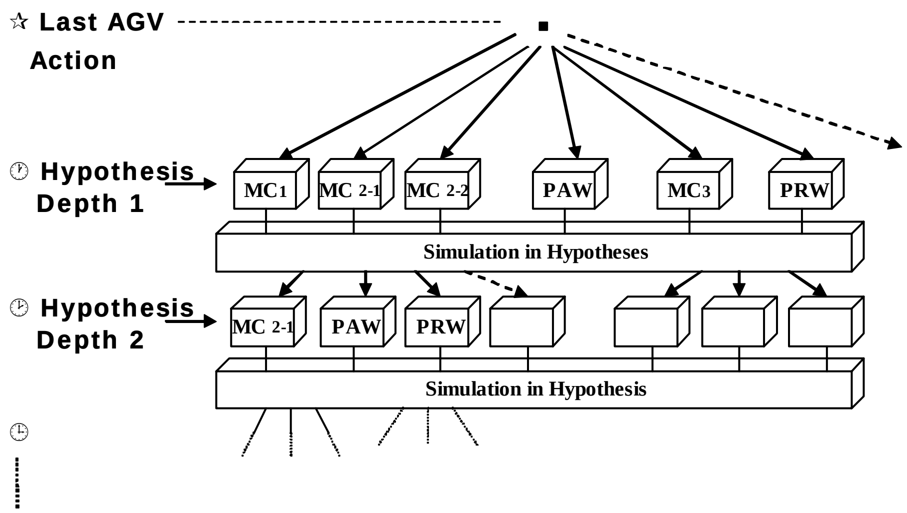

Fig.3 IDASH tree construction

Now, the functions of IDASH will be described. When an actual FMS is operating , IDASH beforehand foresees near future FMS operating situations. This means the thinking process called IDASH begins just before an AGV in the actual world has to choose its Next Action. When IDASH begins, the first step is to search all possible next actions that the AGV could take. The actions are called **Next Action Set** . The next step is to choose a single Next Action from among Next Action Set. The third step is to simulate with all agents what would happen if the Next Action is chosen as the AGV's next action till a certain AGV needs to choose a Next Action. This simulation is called **Simulation in Hypotheses (SiH)**. In carrying out SiH, the situation comes that an optional AGV in the simulation searches Next Action Set. In other word, this situation is that an AGV in SiH has to make a decision which place the AGV moves next as an AGV in the real world has to. At this time, the Next Action Set is re-searched, one Next Action is chosen from among the Next Action Set and SiH is carried out again. By the results of the SiH that is followed by the choice of a Next Action, FMS future operating situations can be seen again. That is, IDASH can be shown as tree construction where the three layers repeatedly lie one upon another : ① the action choice that an AGV in the actual world took last, ② the Next Action Set of the AGV in the actual world, ③ Next Action Set of an AGV in SiH, as shown in **Fig 3**.

In **Fig 3**, the layer corresponding to one depth from the root of the tree construction is called one step hypotheses depth (D_{hy}=1), the node set belonging to hypotheses depth is called foreseeing actions one step ahead (Foresee[1]). Foreseeing actions located below each node of the foreseeing actions of one step ahead corresponds to hypotheses depth 2 (D_{hy}=2) and are called as foreseeing action of two step ahead (Foresee[2]). In the same way, foreseeing actions corresponding to hypotheses depth are expressed as three step ahead, four step ahead, ⋯ . Then, IDASH considers foreseeable actions an optional n step ahead, Foresee[n], as a foreseeable range, regards foreseeable actions in each layer as competitive hypotheses and carries out the reasoning control by regarding one optional foreseeable action among each layer of competitive hypotheses as a true hypothesis and the remaining foreseeable actions as false hypotheses. By judging FMS operating situations n steps ahead, the actual AGV Next Action is decided.

The algorithm to carry out IDASH is described as below. First, the terms used in the algorithm are defined.

[Definition] Standard to Judge True and False : Standard to judge the contradictions in hypothetical reasoning with the results of FMS total operating efficiency gained by the executions of SiH. The standard has ***s*** kinds of standards' range. If the standard is not satisfied, it is judged that a contradiction occurs. Some concrete examples are :

- ***if*** FMS total operating efficiency is over ***e***(1)%, it is true,; ***if*** under, false.
- ***if*** FMS total operating efficiency is over ***e***(2)%, it is true,; ***if*** under, false.
- ***if*** FMS total operating efficiency is over ***e***(3)%, it is true,; ***if*** under, false.

…

- ***if*** FMS total operating efficiency is over ***e***(***s***)%, it is true,; ***if*** under, false.

as ***e***(1) > ***e***(2) > ***e***(3) > ⋯ > ***e***(***s***)

[Definition] Group MC Selection Priority Value, *Fm* : The values indicates the aim how long each Group MC will operate and is expressed as Equation (1). The Group MC that has the large Priority Value is considered to have many jobs left and the priority ranking that is selected as a true hypothesis is given a high ranking .

$$Fm(gMc.N) = \sum_{Pn=1}^{Pn=Pn'} gMc.process.time(Pn) \times \left\{ \frac{production.rate(Pn)}{100} - \left(\frac{finished.parts.N(Pn) + \frac{inprocess.parts.N(Pn)}{2}}{all.finished.parts.N + \frac{all.inprocess.parts.N}{2}} \right) \right\} \quad (1)$$

gMc: name of Group MC

Pn:parts variety （*Pn*=1～*Pn'*）

gMc.process.time(*Pn*): time that Group MC needs to manufacture parts *Pn*

production.rate(*Pn*): target production ratio (%) of parts *Pn*

finished.parts.N(*Pn*): number of parts *Pn* when all processes are finished (number of parts *Pn* in Products Warehouse)

inprocess.parts.N(*Pn*): number of parts *Pn* that are in process or in being transferred (number of parts *Pn* that AGV or MC has)

all.finished.parts.N: number of all parts where all processes are finished (number of all parts in Product Warehouse)
all.inprocess.parts.N: number of all parts that are in process or being transferred (number of all parts that AGV or MC has)

[Definition] Parts Warehouse Selection Priority Value, *Fp* : The value indicates how many parts are in process or in being transferred and is expressed as Equation (2). This value becomes the priority ranking for competitive hypotheses. The value is an integer after being rounded off.

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

max.parts.N : possible maximum parts input number (sum of AGVs and MCs)
destination.N : number of parts destinations (sum of AGVs, MCs, Parts Warehouse, and Products Warehouse)

[Definition] Products Warehouse Selection Priority Value, F_f : The value indicates the parts condition of the Products Warehouse and is expressed as Equation (3). The value corresponds to the priority ranking in competitive hypotheses.

$$F_f = destination.N - F_p \quad (3)$$

[Definition] Parts Selection Priority Value, *V(Pn)* :The value indicates how many parts are still waiting to be input into the production line and is expressed as Equation (4). The part that has a large Priority Value has a high rank order of priority that is taken from the Parts Warehouse by AGVs and is input into the production line.

$$V(Pn) = all.process.time(Pn) \times \left\{ \frac{production\,rate(Pn)}{100} - \left(\frac{finished.parts.N(Pn) + \frac{inprocess.parts.N(Pn)}{2}}{all.finished.parts.N + \frac{all.inprocess.parts.N}{2}} \right) \right\} \quad (4)$$

all.process.time(*Pn*); total manufacturing time for parts *Pn*

[Definition] Job Variance Value, F_d(MC.N) : In the case of a Group MC that has the same type MC, it is necessary to keep the job equality among MCs, that is, each MC should be doing an equal amount of work. In order to do this, the Job Variance Value F_d(MC.N) expressed with Equation (5) is adopted. The equation is based on MC operating efficiency. The MC whose operating efficiency is low becomes a large Job Variance Value and this MC is likely to be chosen for work.

$$F_d(Mc.N) = \frac{100}{Mc.efficiency} \quad (5)$$

Mc.efficiency ; operating efficiency of Mc.N (%)

[Algorithm of IDASH]
Step1 : Establish hypotheses depth D_{hy}=1 and the Standard to Judge True and False ***s*** =1.
Step2 : Search all Next Actions (Foresee[D_{hy}]) that can be foreseen and classify them into competitive hypotheses elements of C-hypotheses-move and C-hypotheses-parts, as shown in Equations (6) and (7). The elements are established so that the left side element in the parentheses has a high priority. At this stage, the ranking is tentative.

C-hypotheses-move＝｛Parts Warehouse, Products Warehouse, MC_{1-1}, MC_{2-1}, ･･･｝(6)

C-hypotheses-parts＝｛P_1, P_2, P_3, ･･･｝(7)
Step3 :Confirm the current position of an AGV that needs to decide its next action and carry out the following rule.
If { the AGV location is in the Parts Warehouse and the AGV does not have parts}
Then{Go to Step5}
Else{Go to Step4}
Step4 : Carry out Hypothetical Reasoning for Moving Decisions from Step4-1~Step4-9.
Step4-1 : Replace MC, the element among competitive hypotheses C-hypotheses-move, with Group MC that the MC belongs to, as shown in Equation (8). At this time, repeated Group MCs are integrated into one Group MC. The resulting Group MC is called a **Competitive Group MC**.

C-hypotheses-move = ｛Parts Warehouse, Products Warehouse, ${}_gMC_1$,, ${}_gMC_2$, ${}_gMC_3$, ⋯｝ (8)

Step4-2 : Find Group MC Selection Priority Value *Fm* for each Competitive Group MC among competitive hypotheses C-hypotheses-move and renew the elements' row of competitive hypotheses C-hypotheses-move by changing the Group MC row with the highest Group MC Selection Priority Value *Fm* first.

Step4-3 : Find Parts Warehouse Selection Priority Value, *Fp* and Products Warehouse Selection Priority**,** F_f and renew the elements' row of competitive hypotheses C-hypotheses-move by inserting Parts Warehouse and Products Warehouse in the priority ranking positions among competitive hypotheses C-hypotheses-move, whose positions correspond to acquired Parts Warehouse Selection Priority Value, *Fp* and Products Warehouse Selection Priority**,** F_f .

Step4-4 : Randomly Select an optional competitive Group MC, ${}_{g}MC_{\alpha}$ from among competitive hypotheses C-hypotheses-move.

Step4-4-1 : Search all MCs belonging to ${}_{g}MC_{\alpha}$, call it $MC_{\alpha-\beta}$ and find their MC's Job Variance Values, $F_d(MC_{\alpha-\beta})$.

Step4-4-2 : Compare each value of Job Variance Values, $F_d(MC_{\alpha-\beta})$ and make a list called MC_{α}-List such that MCs form a queue according to the Job Variance Value with the highest value first, like Equation (9).

$$MC_{\alpha}\text{-List} = \{MC_{\alpha\text{-}1},\ MC_{\alpha\text{-}2},\ MC_{\alpha\text{-}3},\ \cdots\} \quad (9)$$
$$\text{as } F_d(MC_{\alpha-1}) \geqq F_d(MC_{\alpha-2}) \geqq F_d(MC_{\alpha-3}) \geqq \cdots$$

Step4-4-3 : Renew the elements of competitive hypotheses by replacing ${}_{g}MC_{\alpha}$ with MC_{α}-List.

Step4-4-4 : Renew the elements of competitive hypotheses C-hypotheses-move by giving the remaining competitive Group MC the repeated processes from *Step4-4-1* to *Step4-4-3* .

Step4-5 : Select the action whose priority ranking is No.1 from among the elements of competitive hypotheses C-hypotheses-move, corresponding to the left end element, establish it as a true hypothesis and establish the remaining elements as false hypotheses.

Step4-6 : By using a true hypothesis, carry out SiH till an AGV must make its Next Action choice and calculate FMS total operating efficiency ***E*** at the time when SiH stops.

Step4-7 : Perform the following rule.

If{ e(s)≦*E* }, **Then**{ Go to Step6}

Else{ Admit that a contradiction has occurred and go to Step4-8}

Step4-8 : Perform the following rule.

If { An element that has not been chosen as a true hypothesis among the competitive hypotheses C-hypotheses-move still exists }

Then { Replace a true hypothesis with a false hypothesis, select the next priority ranking element among competitive hypotheses C-hypotheses-move as a true hypothesis and return to step4-6 }

Else {Go to Step4-9}

Step4-9 : Perform the following rule.

If { Hypothesis depth D_{hy}=1}, **Then** { Establish s←s+1 and return to Step2}

Else{ Backtrack after establishing D_{hy}←D_{hy}−1 and select the next priority ranking hypothesis element among competitive hypotheses of the layer D_{hy} as a true hypothesis. If the selected hypothesis belongs to C-hypotheses-move, return to Step4-6. If not, go to Step5.}

Step 5 : Carry out Hypothetical Reasoning for Parts Decisions from Step5-1 to Step5-6.

Step5-1 : Calculate Parts Selection Priority Value *V(Pn)* for ***n*** kinds of parts *Pn* among competitive hypotheses C-hypotheses-parts and renew the elements in competitive hypotheses C-hypotheses-parts by changing the parts row with a large Parts Selection Priority Value *V(Pn)* .

Step5-2 : Select the part whose priority ranking is No.1 from among the elements of competitive hypotheses C-hypotheses-parts, corresponding to the left end element, establish it as a true hypothesis and establish the remaining elements as false hypotheses.

Step5-3 : By using that true hypothesis, carry out Simulation in Hypotheses till the AGV is forced to make its Next Action choice and calculate FMS total operating efficiency ***E*** at the time when Simulation in Hypotheses stops.

Step5-4 : Perform the following rule.

If { e(s)≦*E* }, **Then**{ Go to Step6}

Else { Admit that a contradiction occurs and go to Step5-5}

Step5-5 : Perform the following rule.

If { An element that has not been chosen as a true hypothesis among competitive hypotheses C-hypotheses-parts still exists }

Then { Replace a true hypothesis with a false hypothesis, select the next priority ranking element among competitive hypotheses C-hypotheses-parts as a true hypothesis and return to step5-3 }

Else {Go to Step5-6}

Step5-6 : Perform the following rule.

If { Hypothesis depth D_{hy}=1}, **Then** { Establish s←s+1 and return to Step2}

Else{ Carry out backtracking after establishing D_{hy}←

$D_{hy}-1$ and select the next priority ranking hypothesis element among competitive hypotheses of the layer D_{hy} as a true hypothesis. If the selected hypothesis belongs to C-hypotheses-move, return to *Step4-6*. If not, go to Step5.}

Step6 : Perform the following rule.

If { $D_{hy} < n$}, **Then** { Establish s←s+1 and return to Step2}

Else {Go to Step7}

Step7 : Select a true hypothesis in hypotheses depth D_{hy}=1 as the next action of an actual FMS and execute the actual FMS.

ranking the possibility to be selected as a true hypothesis from among competitive hypotheses by using Group MC Selection Priority Value, Parts Warehouse Selection Priority Value, Products Warehouse Selection Priority and Job Variance Value and adopts the hypotheses generating method based on the priority ranking to make true and false hypotheses.

Let me describe the hypotheses generating method based on the priority ranking. The method has three processes : ① by using Group MC Selection Priority Value, the moving actions for each Group MC that has

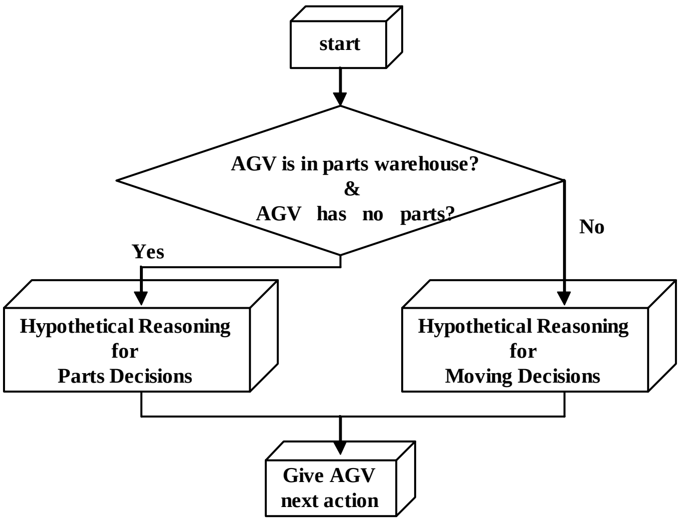

Fig4. IDASH algorithm

Fig.4 shows the chart of an IDASH algorithm. IDASH has two kinds of parallel reasoning : 1) Hypothetical Reasoning for Moving Decisions that decides the moving destination of an AGV and 2) Hypothetical Reasoning for Parts Decisions that decides input parts. The reasoning backtracking can be made by a checking contradiction occurrence and a hypotheses depth.

Hypothetical Reasoning for Moving Decisions considers the practicable next moving destinations of an AGV as competitive hypotheses C-hypotheses-move, proceeds in its reasoning by dividing each hypothesis among the competitive hypotheses C-hypotheses-move into a true hypothesis and false hypotheses and finally decides the AGV moving destinations. Although a conventional hypothetical reasoning optionally divides hypotheses into a true hypothesis and false hypotheses, Hypothetical Reasoning for Moving Decisions makes

the same manufacturing processes are given a priority ranking and are listed according to the ranking : ② by using Parts Selection Priority Value and Products Warehouse Selection Priority, the moving actions for Parts Warehouse and Products Warehouse are given the priority ranking and are listed according to the ranking : ③ by using Job Variance Value, the selection ranking for each MC among a Group MC are ranked and listed according to the ranking. For example, let's consider the case that ${}_gMC_1$～${}_gMC_3$ has one MC for each, ${}_gMC_4$ has three MCs, MC_{4-1}～MC_{4-3}. When ${}_gMC_2$, ${}_gMC_4$, ${}_gMC_3$ and ${}_gMC_1$ in turn are generated in process ①, as shown in **Fig.5** and each of Parts Warehouse Selection Priority Value and Products Warehouse Selection Priority value is calculated as 2 and 6 in process ②, the competitive hypotheses elements from the ranking 1 to the ranking 6 are decided as shown in **Fig. 6**. Because ${}_gMC_4$ has four MCs, the priority selection for the three is carried out in process ③. In the case where the priority ranking for the three MCs is decided as MC_{4-2} ,MC_{4-1} and MC_{4-3}, $_gMC_4$ is replaced with the ranking list. As a result, the final priority ranking for competitive hypotheses elements is decided as shown in **Fig. 7**.

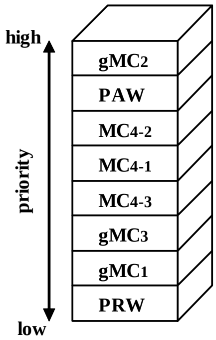

Fig.7 Example 3

Hypothetical Reasoning for Parts Decisions is the reasoning that decides which part an AGV takes when the AGV arrives at the bay of the Parts Warehouse. Because of the reasoning, it is not necessary to have a prior parts input scheduling system.

4. APPLICATION EXAMPLES

The IDASH proposed in Section 3 is applied to the operations of a decentralized autonomous FMS. As there is no actual FMS production system, nine kinds of decentralized autonomous FMSs are constructed in a computer and some numerical experiments are carried out. The nine FMSs are the production systems whose number of parts subject to manufacturing, MCs, Group MCs and AGVs are different, as shown in **Table 1**. That is, <**Type 1**> parts number 3, Group MC number 3, MC number for each Group MC 1 and AGV number 3, <**Type 2**> parts number 3, Group MC number 3, MC number for each Group MC 1,2,1 and AGV number 3, <**Type 3**> parts number 3, Group MC number 3, MC number for each Group MC 2 and AGV number 3, <**Type 4**> parts number 6, Group MC number 6, MC number for each Group MC 1 and AGV number 5, <**Type 5**> parts number 6, Group MC number 6, MC number for each Group MC 2 and AGV number 5, <**Type 6**> parts number 6, Group MC number 6, MC number for each Group MC 3 and AGV number 5, <**Type 7**> parts number 9, Group MC number 8, MC number for each Group MC 1 and AGV number 5, <**Type 8**> parts number 9, Group MC number 8, MC number for each Group MC 2 and AGV number 5 and <**Type 9**> parts number 9, Group MC number 8, MC number for each Group MC 3 and AGV number 5. The factory layout of Type9 is shown in **Fig.1**. Other Types' layouts are the ones that MCs disappear according to MCs number. The manufacturing time for each part is different. For example, in a case where Type 1, the manufacturing time of parts P_1,P_2 and P_3 are established as **Table 2**. The target production ratios for each of the parts are also different as follows. They are : $P_1:P_2:P_3$ =5:6:2 from Type 1 to Type 3 ; $P_1:P_2:P_3:P_4:P_5:P_6$=5:6:3:3:2:1from Type 4 to Type 6 ; $P_1:P_2:P_3:P_4:P_5:P_6:P_7:P_8:P_9$ = 5:6:3:3:2:1:4:5:2 from Type 7 to Type 9.

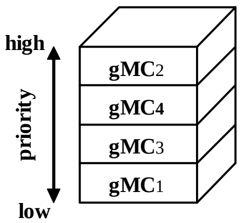

Fig.5 Example 1

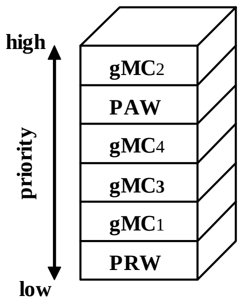

Fig.6 Example 2

Allowing for unpredicted troubles that happen where an actual FMS operating, the numerical experiments adopt four operating conditions : <**Condition 1**> there are not

Table 1 FMS variation

Styles	Parts kinds	gMC(MC)	AGV
1	3	3(1,1,1)	3
2	3	3(1,2,1)	3
3	3	3(2,2,2)	3
4	6	6(1,1,1,1,1,1)	5
5	6	6(2,2,2,2,2,2)	5
6	6	6(3,3,3,3,3,3)	5
7	9	8(1,1,1,1,1,1,1,1)	5
8	9	8(2,2,2,2,2,2,2,2)	5
9	9	8(3,3,3,3,3,3,3,3)	5

any unpredicted troubles : <**Condition 2**> each AGV randomly breaksdown three times a day (24 hours) and its breakdown time is five minutes : <**Condition 3**> parts manufacturing time at each MC is randomly extended 10 % : <**Condition 4**> both unpredicted troubles of Condition 2 and Condition 3 happen. In Condition 2, Condition 3 and Condition 4, ten kinds of happening time for manufacturing time extensions and breakdowns are established as unpredicted troubles' random conditions by adopting ten random series. As a result, Type 1 executed one numerical experiment under Condition 1 and executed ten numerical experiments under each other Condition. A numerical experiment time 24 hours is adopted and n of foreseeable actions range (Foresee[n]) in hypothetical reasoning is established as 3.

One result of the numerical experiments is shown in **Table 3**. **Table 3** indicates the production outputs for each of the four Conditions in Type 5. As a comparison, the numerical experiment of the case that n of foreseeable actions range (Foresee[n]) is 1 was carried out. Judging from the result, the outputs of the case n=3 were bigger than that of the case n=1 under every Condition. In other Types, the same results were obtained. ***Fig.8*** shows the output ratio for each of the parts of Type 5. All four Conditions could get the ratio very close to the target production ratio, $P_1:P_2:P_3:P_4:P_5:P_6=5:6:3:3:2:1$ even though a conventional prior parts input scheduling system was not used. In other Types, the same results were also obtained. For example, the production ratio of Condition 4 in Type 9 is 5.049: 6.028:3.049:3.049: 2.042: 1.000:4.049:5.092:2.049 and its target ratio is $P_1:P_2:P_3:P_4:P_5:P_6:P_7:P_8:P_9 = 5:6:3:3:2:1:4:5:2$.

In consequence, it was ascertained that the decentralized autonomous FMS using IDASH can keep a target production ratio even if unpredicted troubles happen.

Table 2 Examples of machining time

Part	P_1	P_2	P_3
Machining Time (seconds	gMC_1 180	gMC_2 120	gMC_3 180
	gMC_2 120	gMC_1 60	gMC_2 150
	gMC_3 120		

5. CONCLUSIONS

This research described the intelligent method to decide an AGV action plan to operate a decentralized autonomous FMS and developed IDASH to anticipate the FMS operating situations happening in the near future by using information from each agent and forecasting several steps ahead of AGV's practicable next actions. IDASH consists of a hypothetical reasoning that regards practicable AGV next actions as competitive hypotheses and a discrete simulator [10]-[12] that simulates the future alternative possibilities. Because of the decision, AGV next moving destinations and which part is transferred next are decided and both a prior AGV moving plan and a prior parts input schedule are unnecessary. The numerical experiments were executed by applying the developed IDASH for a decentralized autonomous FMS that exists on a computer. As a result, it was ascertained that the FMS can have the product ratio very close to the target production ratio even when a prior parts input schedule is not used. Compared with the result of the case that looked just one step ahead as a foreseeable action range, it was also ascertained that the developed reasoning method to foresee several steps ahead could get the better outputs.

The research started as a basic research to decide the AGV actions plan of a decentralized autonomous FMS with the idea to look several steps ahead. Although there are still some problems left, such as how many steps to foresee is optimal and how closer to the target production ratio is achieved, it was ascertained that the idea to foresee the future in order to control the productions of a decentralized autonomous FMS is an efficient methods by the research results.

Table 3 Simulation outputs results

A \ B	Condition1	Condition2	Condition3	Condition4
1		573 (550)	562 (551)	566 (538)
2		572 (550)	556 (552)	543 (545)
3		576 (558)	556 (550)	564 (537)
4		574 (560)	554 (546)	560 (552)
5		580 (557)	560 (547)	558 (543)
6		575 (555)	568 (545)	568 (544)
7		576 (550)	561 (555)	559 (546)
8		574 (558)	565 (550)	556 (556)
9		565 (553)	566 (545)	559 (546)
10		573 (558)	563 (555)	553 (541)
Average	578 (559)	573.8 (554.9)	561.1 (549.6)	558.6 (544.8)

A : **Random Numbers** B : **Conditions**

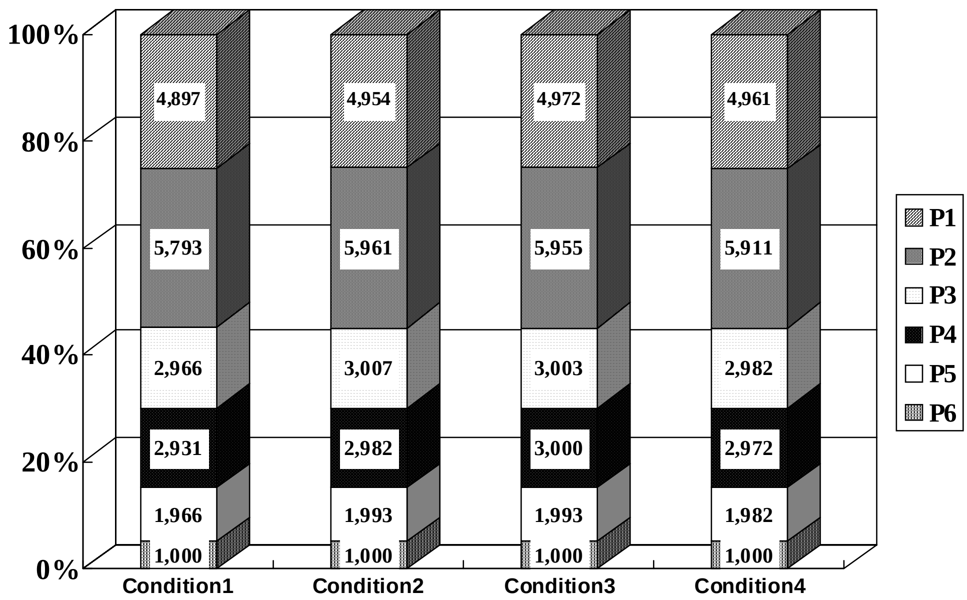

Fig.8 Production ratio of Type 5

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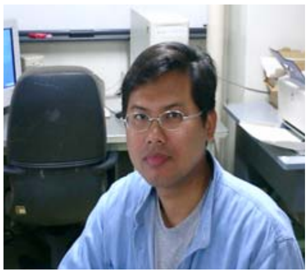

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