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A Dynamic Reconfiguration and Resolution Method Based on Multi-Agent System

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***Abstract*—Manufacturing activity has become highly competitive. Moreover, the management activity of the manufacturing system becomes increasingly complex. This is due to the technological development which includes new tools and machinery production methods. In our research, we propose a multi-agent intelligent system for automatic reconfiguration and control operating modes of automated manufacturing system. This system reacts as quickly as possible to the vagaries of production and offer mode of operation followed by manufacturing system. A new scheduling is provided for a set of machines and products to be manufactured by verifying a reachability property on communicating automata model.**

***Keywords*—manufacturing system, dynamic reconfiguration, failures, multi-agent system, scheduling,**

I. Introduction

Increasing productivity by reducing costs is a major goal in every business. Production systems are characterized by their dynamics and foresight. The tasks are often, complex and are subject to time constraints and requirements [1]. Thus, manufacturing system (MS) provides new targets [2]. Our goal is to provide a distributed reconfiguration approach offering coping skills and self-organization using multi-agent systems (MAS). The advantage of MAS is to distribute the problems of self-organized groups to local management. Promoting responsiveness and emergent behavior can facilitate the implementation of MS reconfiguration. Indeed, the main purpose of MAS is to collaborate and to cooperate a number of agents to solve the reconfiguration problem. We propose to introduce, in the agents, evolutionary techniques to enable them to evolve over time and determine a better solution satisfying a number of criteria. In a disturbed environment, our problem can be seen as a problem of reconfiguration and re-ordering which aims to better meet pre-determined by an initial scheduling plan in the face of production hazards. We achieve this goal by cooperative solving approach that interact all entities comprising our system. Multi-agent systems can coordinate the behavior of intelligent agents interacting and communicating in a company to perform tasks or solve problems [3] [4]. It therefore seems well suited to model and design an intelligent system [5] to reconfigure an automated production system. We will opt for a distributed supervised architecture which constitutes a compromise between distributed and supervised approaches. Each agent is represented by an Integrated Automatic Station for Reconfiguration (IASR). We consider a manufacturing system composed of several work center (many IASR). We applied our approach on simulated system composed of three machines. The results show that it is better to work with a reconfiguration than to repair and restart production.

This paper is composed of three sections. In the next one, we will propose our reconfiguration approach. The third, deals our multi-agent system methodology. In the last one, we resume our experimentation and results. Finally, we will conclude by a discussion.

II. Reconfiguration Approach

During the operational phase of manufacturing system [5], operating hazards are many and varied (fig.1). They are characterized as unplanned events that disrupt the operation thereby jeopardizing the objective of production. There are two types of hazards including internal hazards and external hazards:

- Internal hazards: Such concerns the hazards of the material part of the control system (computer failure, the communication network ...), the vagaries of the software part of the control system (specification error, coding error ...) and vagaries of the game operative (malfunction of a production resource ...).
- External hazards: These kind regard changes in customer demand (change of product specification, reduced delivery time ...), the vagaries of the characteristics of the raw material (prohibited size, hardness of improper material ...) and hazards environmental MS (general power failure ...).

In our work, we will focus on the hazards of the operative part. Our proposal is to address the problem of reconfiguring by its decomposition into two problems: the first is placed at the control center. A sequence of changing patterns of work resources is generated automatically, to pass the current state of manufacturing system to a goal state. The second sub-problem is the determination of the state and objective evaluation of different alternatives to failure.

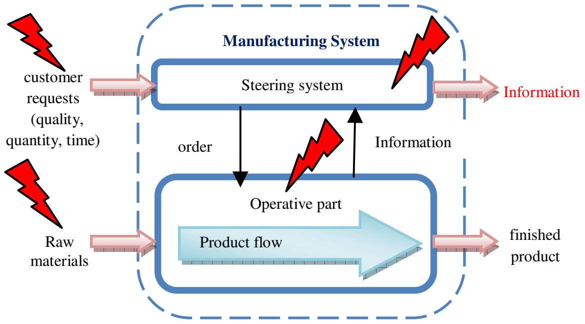

Fig. 1 Origins of operating hazards

The model of operating modes to establish manufacturing system must be defined according to the needs of conduct against disturbances. In fig. 2, we show that the cycle between shutdown and normal operation (for example) is ideal, as it corresponds to a production without incident under the management of the manufacturing system.

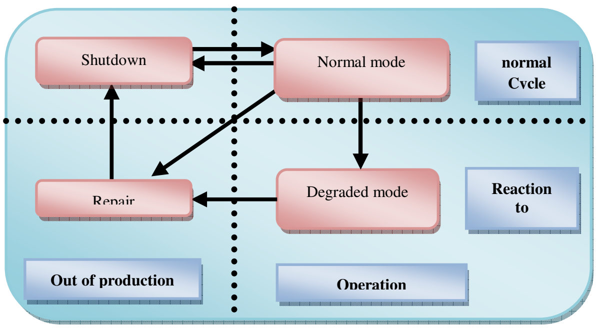

Fig. 2 Generation of the operating modes of interest for the reconfiguration

The set of states characterizing a resource (production machinery, transportation ...) can be modeled by an oriented state graph G (figure 3). Changing the operating modes of an entity is to evolve a state operating mode e_i to state e_j operating mode. This reconfiguration will be called "potential reconfiguration". The global model reconfiguration is the set of entities reconfigured models in the manufacturing system taking into account the constraints between them. A model of reconfiguring a MS is characterized by a set of the entities system states. The transition from one model to another implies changing of entities system states. In order to obtain a set of models that achieves the objectives set reconfiguration, the consolidated entities must be mutually compatible. A model is characterized by a set of states: Model N = (e_1... e_i ... e_n) where n is the number of system entity [6].

All models reconfiguration can be described by a graph where each node and each model features a bow features an indicator or set of indicators that allow passage from one node to another. These indicators are signals that highlight the operating system. The ideal case would eliminate any decision problem is a signal indicative of defects which would be one in the absence of failure and zero when there down. Indicators that we used in our study are physical indicators. We generated a set of indicators namely:

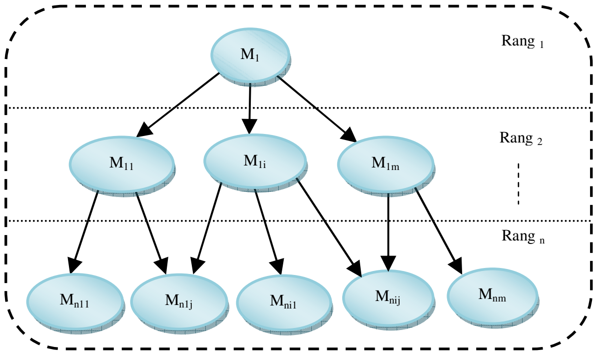

Fig. 3 Graph models

- An indicator of the time cycle: We calculate the minimum time cycle to be stored and if the time cycle exceeds this value at current production then there is an anomaly.
- An indicator of the vitality of the system
- An indicator that measures the operating time of an operation on a machine
- An indicator of the frequency of passage of parts of the machine and in order to decide the model that evolves the system (transient operation, nominal, degraded ...).

At the command, the state graph, modeling the operating modes is of a MS entity, is seen as an operating program (OP). For each state is associated with a program module that can be run alone. Each module can send and/or receive a message from another module of OP or another entity system (two robots which exchange messages during an assembly operation for example). It can also receive a report from a sensor (position of the workpiece, for example). In either case the module may be subject to blockage. Reconfiguration at "command" is therefore the deadlocks to synchronization points. For example, where a robot must climb respectively, a red door on the red body and a blue door on the blue body. In case of blocking of a body in the chain, it is advisable to unload the robot to the door associated with this body to solve the blocking problem.

III. MAS-BASED RECONFIGURATION MODEL

We consider a manufacturing system composed of several work center (many agents). Each agent consists of one or more resources. We will opt for a distributed supervised architecture which constitutes a compromise between distributed and supervised approaches. In this architecture, we distinguish between a Supervisor Agent (SA) and several other agents Resource Agent (RA). Each agent is dedicated to a specific work center. In order to exploit the resources of a computer network, rather than overloading the same machine, we have adopted the approach of physical distribution agents. Agents communicate by sending messages. Thus, we took the concept of message exchange in order to develop a platform for communicating quickly and efficiently [6].

Distributed resolution of a problem by several agents, consists of four phases. In the first phase, a master agent ("Agent M") decomposes the problem (the main task) into several sub-problems (fig.4). The second phase involves the allocation of sub-problems to agents. Each agent tries to solve the sub-problem in a third phase. Solving sub-problems may require sub-decompositions and new distribution of tasks to agents. The last phase allows obtaining a final result by integrating different partial results corresponding to different sub-problems. This result is obtained by an integrator officer ("Agent I"). The agent I and agent M are identical. It is the supervisor agent.

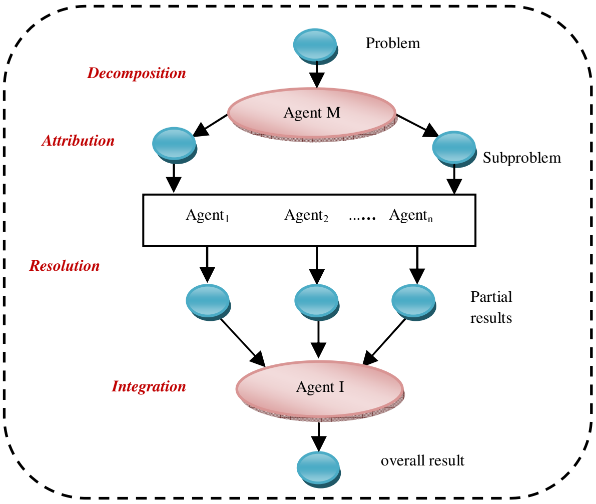

Fig. 4 Resolution of distributed problem

In this work, we use the agents which collaborate with each other to guarantee the intelligence of resources that utilized multi-agent system as the software of control unit. Therefore, jobs for reconfiguration in manufacturing shops can achieve automation and optimization. The basic structure of improved contract model consists of Resource Agent (RA) and Supervisor Agent (SA). RA controls the operating model of the corresponding machine and transmits the information to the SA. Furthermore, it is responsible for receiving and processing production tasks entering into the shops (fig. 5). According to the rules of the agreement, RA lays out a concrete processing planning, and then submits it to the SA. We illustrate the communication between MA and SA in the following figure.

SA is responsible of candidate production planning simulation. Also, it is the core of reconfiguration system. It is mainly role consists of evaluating partial reconfiguration model received from the others agents. SA transmits information to RA changing the operating modes. In figure 6, we illustrate the communication between SA and other agents.

We assume the fully automated manufacturing system. The case of semi-automated manufacturing system (in which the human operator is considered a full-fledged agent) is not covered here. However, we admit that human operators involved in the operation of manufacturing system.

We use the MAS-based intelligent scheduling systems, which collaborate with each other to guarantee the intelligence of machines that utilized MAS as the software of control unit.

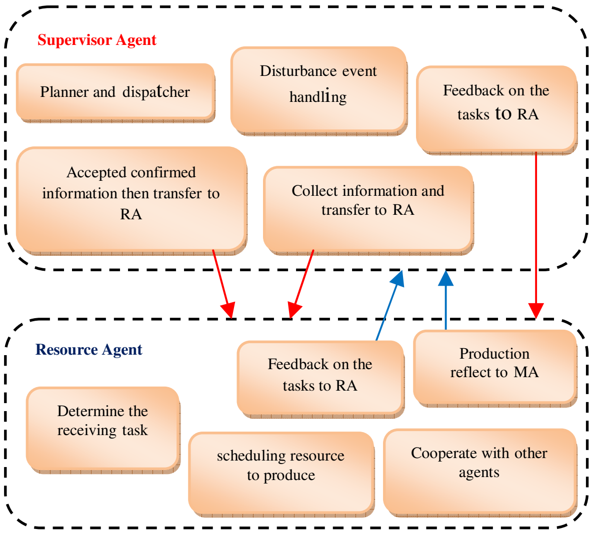

Fig. 5 Resource Agent and supervisor Agent internal schematic

Therefore, jobs for rescheduling in manufacturing shops can achieve the automation and optimization. The Integrated Automatic Station for Reconfiguration IASR is the model of the agent. It will be explained in the following section.

IV. INTEGRATED AUTOMATIC STATION FOR RECONFIGURATION

Integrated Automatic Station for Reconfiguration (IASR) can be associated with one or more workstations, to a line or a manufacturing cell [6]. Its functions are the local management of one or more resources (production machinery, means of transport, food, etc.), Incorporating control functions, real-time management and man-machine dialogue, communication between IASR and databases relating to tasks and working methods, as well as the management of information relating to: workflow, IASR operation, process control, information exchange and management of parts, tools, programs manufacturing and the entry and exit of the products of the manufacturing system. It comprises a decision-making system, an information system, a system interface, a control system and a communication system.

In an automated distributed system reconfiguration production, the IARS control sequences of tasks assigned to each resource. Thus, each resource is associated with its own IARS. The IARS negotiate among them to determine which operations will be performed by the resources they reconfigure. They ensure that these resources are allocated operations. In addition, they are responsible of availability of the elements necessary for the realization of such operations. The IARS consider the data characterizing the flexibility of the manufacturing process by the failure. They involve operations allocated to the resources they reconfigure the appropriate manufacturing procedures. This association includes the time from the production program and a description of the procedure in the production phase.

The fig. 6, shows our chosen architecture where we distinguish the agent supervisor and several other agents, each devoted to a work center, each consisting of its own resources (machines, stock, parts, conveyors...). Also, we show the real-time multi-agent architecture. The IARS consider the data characterizing the flexibility of the manufacturing process by the failure. These data are the following:

- The reconfiguration time: this time, noted T_{RC}, is important for MS reactivity. It includes the possible passage of a normal mode of operation to a degraded mode, or between two degraded modes.
- Alternative operating modes: the existence of alternative modes associated with the resource k is the degraded mode adopted by it in case of failure. Operations assigned to that resource may be performed in a degraded mode, $o_{i,j,kd}$. A degradation rate specific to the resource is introduced ($o< \alpha_k<1$). It is manifested by an increase in the manufacturing time and it is assumed to be independent of the operation.
- Alternative operations: derived from the MS flexibility. Tasks can be assigned to the other resources that determined in the Scoping k, often in a different operation time. Alternative transactions are defined by the feasibility of assigning a task to another resource if the first is not available (replacing $o_{i,j,k}$ by $o_{i,j,l}$ for the same i and j). This involves a reconfiguration of resources from the forecast plan. An α degradation rate can be established for the global MS, depending on the alternative configuration of the resources adopted. Before executing the calculation steps, we take into account the state of resources and the production sequence by the information received from the SA. In this context, we use notation characterizing the monitoring parameters and disturbances caused by a failure.

For our production reconfiguration problem, the developed agents are intended to determine a better solution satisfying a larger or smaller number of criteria (fig. 6).

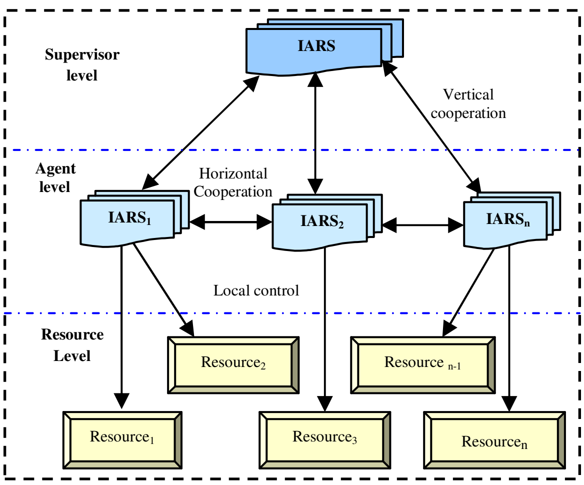

Fig. 6 Reconfiguration model by SMA

However, a model resolution is implemented to the levels of agents, refers to a collaborative and cooperative process by interacting these evolving over time or to solve a disturbed situation in the case of unexpected advent event.

In most cases, a disturbance detected at the second level of decision making, that is to say, the agent level, will be treated to the best in nearly the highest level that involves resources, under the supervision of an officer of the first level that is to say, the supervisor agent.

Our multi-agent system is designed for the reconfiguration of the manufacturing system activities. Indeed, the system is distributed both physically (for production of distribution on several IARS work centers) that operatively (it is constituted by a set of cognitive agents) which cooperate to perform scheduling functions and reconfiguration. The objective of the proposed methodology is to provide a reconfiguration aid procedure relying primarily on alternative search configuration taking into account the actual state of MS and to satisfy production orders. This methodology performs an evaluation of these alternatives, in order to select the most appropriate. Finally, it provides a representation of the solution in the form of tasks allocation.

RA requires the application of a criterion for evaluating the performance of several alternative actions. The achievement of production targets must be translated as indicators, so the SA analyze the state of the MS and judge the consequences of the actions. The decision variables to be adopted by this agent for assessing the MS performance are time, cost, productivity, quality or flexibility of the system. The most common performance indicators are the total manufacturing time and resource utilization. To solve the real-time reconfiguration problem, the most suitable performance criterion is the total time of manufacture. Thus, the comparison of different configuration alternatives will allow SA to focus on the solution that minimizes production time.

We assume, in what follows, the occurrence of a failure at the time t_A and the accomplished what the output is equivalent to Q. The repair involves MS unproductive between t_A and t_B, with a resumption of the normal rate of production and the end of production that is to say $T_{rp2} = T_{rp1}$ (T_{rp}: time of repair). If at the time t_A is determined reaction of the degraded mode switching while the manufacturing period exceeds the margin given to the manufacture that is to say $T_{fd2}> T_{PN} + T_M$ (where T_{fd}: time of operating degraded mode; T_{PN}: time of normal production). If a failure of resource R occurred at time T_{fd}, then this resource goes into degraded mode after a time t_{rc}. Other resources continue until they are allocated a disturbed operation. The duration of each operation disrupted the resource R, whose start date is after t_{df} is increased by a factor of $1/\alpha_R$ with α: own degradation rate of the resource R and $0 <\alpha <1$. This rate is manifested by an increase in the manufacturing time and is independent of the operation.

By keeping all operations of the forecast scheduling (tasks on the same resources), we realize the operations disrupted in the established order, in degraded mode for the resource R and normal for resources k ≠ R.

The start date of disturbed operations (i, j, k), ∀k, will be shifted. It will be situated at the earliest, when the previous task (i,j-1) will be over and the resource R is available. Calculating the total processing time t_{fd} for this alternative is like adding T_{FN} expected duration, the reconfiguration time T_{RC}, and the increment of the length of degraded operations, $\sum T(i,j,xd) - \sum T(i,j,x)$. The total time of manufacturing the gradient mode option in failed resource is:

$$T_{fd} = T_{PN} + T_{RC} + \sum_{i,j}\left(\frac{1}{\alpha R} - 1\right)T(i,j,x)$$

$$T_{RP} = T_{PN} + T_{R}$$

Operation (i, j, R) = task i of product j executed on the machine R.

Subsequently, the results of the two options “repair” and “operate in a degraded mode” are compared for their total duration of manufacture, respectively t_{rp} and t_{fd}. Following adoption of the criterion of time to evaluate alternatives, we retain the one with the shortest length:

$$T_{solution} = \min \{t_{rp}, t_{fd}\}.$$

To validate the solution, it is necessary to check if the margin of time granted to manufacturing is respected:

$$T_{solution} \leq T_{PN} + T_{M}.$$

If the value is consistent with this constraint, so we consider this alternative as the solution to be applied by the reconfiguration of the SAP.

V. IMPLEMENTATION STRATEGIES AND RESULTS

The system studied is composed of three machines, numbered from 1 to 3. In this system, three products, composed of sequences of tasks are to make a forecast sent by scheduling production management. In the following table, we present the durations of operations and MS's flexible parameters and monitoring data of the system status, received in real time. The table shows, also, the manufacturing time of each designated operation (i, j, k), considering alternative operations. The ∞ symbol means the alternative non-existence. Flexibility of the data is assumed to be independent operations. At each machine k, we consider a single value for the estimated average repair time T_R, T_{RC} reconfiguration time and α degradation rates. The T_{RC} time applies when the resource k is used for a new configuration. It is assumed that the time units are arbitrary.

TABLE I. OPERATIONS DURATION AND FLEXIBILITIES IN THE SYSTEM SETTINGS

Product i	Task j	Resource R_1	Resource R_2	Resource R_3
1	1	∞	20	18
	2	17	∞	13
	3	18	16	19
2	1	16	14	15
	2	∞	20	22
	3	9	6	6
	4	17	∞	20
	5	∞	18	25
3	1	20	23	∞
	2	8	13	15
	3	12	20	17
	4	24	22	18
repair T_R		12	13	11
Reconfiguration t_{rc}		2	1	2
Degradation α		0.75	0.68	0.8

The production order production management is shown in fig. 7.

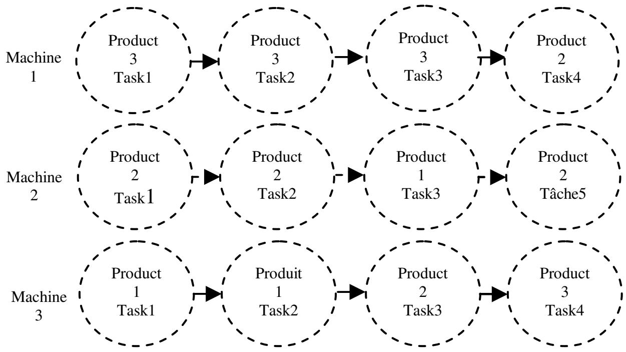

Fig. 7 Production order for normal operation of the SAP

The estimate is considered optimal scheduling, since the total manufacturing time cannot be less than the duration of the operations T_{PN} = 75 time units. The considered margin is T_M = 14. Monitoring the manufacturing system reports, in real time to failure of the machine1, when the current time is 28. The estimate of the repair time is T_R = 12. The T_{RC} said time is considered for reconfiguration and is void options in degraded mode option.

The approach determines, first, resources disrupted by the failure. On the first machine M1, the operations start date is greater than 28, that is to say, (3,3,1) and (2,4.1) are disrupted. As corrupted operations constrain order by propagation of the failure, it is determined that steps (2,5,2) on the second machine M2 and (3,4,3) on the third machine M3 are also disturbed.

This option forces the first M1 machine in degraded mode following the failure. In this example, we assume that the degraded mode transition time is zero is to say T_{RC} = 0. Degraded operations (3,3,1d) and (2 4,1d) run keeping the same order, with increasing durations at 16 and 22.7 time units, respectively, due to degradation 1/α=1.33. The start of the operation (3,4,3) is offset T (3,3,1d)-T (3,3,1) = 4 and that of step (2,5,2), of T(3,3,1d)-T(3,3,1)+T(2,4,1d) -T (2,4,1) = 4 + 5.7 = 9.7. The total processing time is:

$$T_{RP} = T_{PN} + T_{R} = 75 + 12 = 87$$

$$T_{fd} = T_{PN} + T_{RC} + \sum_{i,j}((1/\alpha) - 1)T(i,j,x) = 84.7$$

Both options direct comply margin $T_{PN} + T_M = 89$. However, the decision taken at the end of this stage gives the advantage to the solution which adopts the degraded mode machines since $T_{fd} < Trp$.

In the second calculation step we evaluate two types of options. Reconfiguration strategy includes rescheduling, discarding the first option in a failed resource or considering the second option repair and subsequent reintegration in manufacturing.

In this option, we solve a problem of allocation of tasks whose objective is the minimization of the T_{RSR} manufacturing period. The operations to organize in time are all operations disrupted by the failure. Thus, the additional constraint is the unavailability of the failed resource. In this case, a coupling exists between the resources and the security constraints are important. Repair activities of the failed resource are then programmed after manufacturing.

VI. CONCLUSION

To better understand the operation of automated production, we made a study of manufacturing system namely its features, components, etc. We quickly encountered problems during its operation. To this end, we propose an intelligent system for the reconfiguration of manufacturing system. It is a system that exploits the knowledge of experts, operators and other agents involved in the system to operate independently at both the detection and localization of faults at the level of reconfiguration. This is the main advantage of our approach which can operate automatically interact with the process.

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