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A negotiation scenario using an agent-based modeling approach to deal with dynamic scheduling

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Abstract In order to ensure an overall efficient production performance, the industrial experiences and research activities have demonstrated the interest of hybrid control systems, which couple a predictive scheduling with a distributed reactive control. In this context, it is commonly accepted that using the multi-agent systems (MAS) paradigm enhances the reactivity to treat disturbances and improves the decision making process of a shop floor. Each agent could have different capability (evolution, learning etc.) and the whole system, based on the agent interaction, leads emerging behaviors to dynamically adapt the production schedule.

This paper is aimed to develop and simulate a negotiation scenario to deal with disturbed manufacturing processes. The scenario was implemented on the basis of TRACILOGIS test-bed platform. The negotiation protocol consists in setting the best sequential priority based on some performance indicators. This protocol is compared with a purely reactive production mode.

Keywords Multi-Agent Systems, Negotiation protocol, Distributed reactive control

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1 Introduction

Nowadays, manufacturing industries are facing to many challenges to deal with the increase of the variability on all supply chain processes [1] and to propose a well-designed production process to produce a right product at the right time to customers in accordance with the specified schedule and specifications. As part of this, these industries are continuously seeking for new control systems that enable them to react to unpredictable events. In order to ensure this reactivity to these unpredicted events and provide an overall efficient production performance, the industrial experiences and research activities have demonstrated the interest of hybrid control system that couple a predictive centralized mode with a distributed reactive mode based on the reactivity of Cyber Physical System (CPS). For instance, when schedules acquire a reputation for rapid invalidity because of frequent changes, using dynamic rescheduling methods to conquer such disturbances has become crucial. To realize this surmount, intelligent optimization protocols and algorithms should be used to define different variables and all agents within the environment have to continuously negotiate among each other to reach at converged and optimal offer.

In this paper, a negotiation scenario among product and resource agents cooperating to set best sequential priority-based production process has been presented. A MATLAB simulation on the basis of TRACILOGIS test-bed platform was used to compare reactive and negotiating production heuristics. The rest of the paper is organized as follow. Section two elaborates the justification & related works. After this, section three demonstrates the negotiation heuristic comparing with the pure reactive one. Prior to end, section four depicts and analyses the comparative results of reactive production and negotiating production processes. Finally, section five concludes and forwards its future remark mainly relating to the role of agent consensus for optimizing the manufacturing system of a shop floor.

2 Background and related works

Previous studies have revealed that multi-agent based control systems treat changes and disturbances observed within a shop floor. An agent is an autonomous entity that can be viewed as perceiving its environment through sensors and acting upon that environment through actuators [2] [3]. Naturally, agents in all but the most trivial

of non-deterministic environments must be prepared for the possibility of failure. Due to this non-deterministic nature, Wooldridge [3] has raised two questions that could always come when one needs to implement cooperative agents:

- The design: how one can build agents that are capable of independence & autonomy to successfully carry out their tasks?
- The sociability: how one can build agents that are capable of cooperating with other agents?

In answering these queries, an agent has to coordinate with other agents in several different ways. A system that consists a group of agents that can potentially collaborate with each other is multi-agent system (MAS) with capability to perceive, reason, communicate together to solve problems that are beyond their individual competences [3] [4].

In MAS, the mere presence of multiple agents makes the environment appear dynamic from the point of view of each agent, with the control system they follow; typically distributed control [5]. As a result, to create an environment that provides an infrastructure specifying communication and interaction protocols of agents, Weiss G [6] has pointed out the knowability, predictability, reactivity, and sociability of agents as basic characteristics of multi-agent environment. To continue by fulfilling these characteristics, the cooperation and negotiation of agents would always take appropriate attention as it brings amplified benefits. For instance, Dimopoulos & Moraitis [7] has stated that individual agents can generate and execute their plans independently. However, as they operate in the same environment, conflicts may arise and as a result they need to coordinate their course of action in order to avoid harmful interactions. Zambrano et al. [8] & Wooldridge [3] has also stated that, negotiation among agents is foreseen to host a robust-predictive-reactive scheduling and also to tackle myopia. A chain reaction based on product's perception, could give a sense of forecasting to minimize the impact of disturbances and will allow products to take into account other products' sequences. With this, a certain estimation of system efficiency and performance could be possibly made, giving to industrialist a certain degree of sureness in their system behavior.

In another way Amgoud et al. [9] has illustrated the investigations of different agent negotiation approaches including game-theoretic approaches [10], heuristic-based approaches [11], and argumentation-based approaches [12]. They emphasize the importance of exchanging information and explanations between negotiating agents in order to mutually influence their behaviors. Moreover, Amgoud et al. [9] have proposed a formal protocol handling negotiation dialogues between many agents ($n \geq 2$) and the protocol is supposed to be run as many times as there are non-discussed offers.

3 TRACILOGIS test-bed platform based agents' negotiation

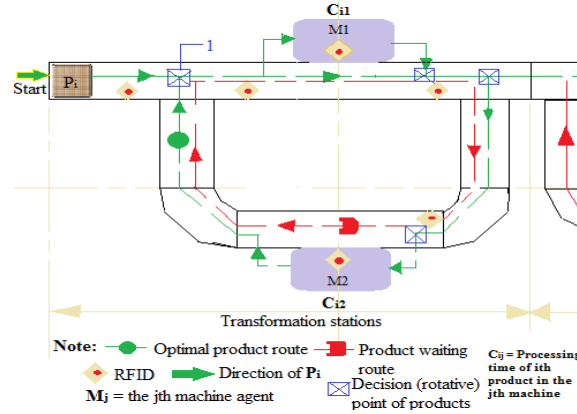
If unexpected event that has significant impact on a master production schedule has occurred, negotiating rescheduling & control is expected right after the interruption to save this master schedule. To seize such event, different intelligent approaches have been enumerated in previous studies even though different challenges are still regarding the manufacturing execution system of a shop floor. For instance, Oliver C et al. [cf1] have outlined three scientific challenges and enabling to estimate future performances & designing pertinent switching mechanisms are the first two challenges delineated. The big concern at this juncture is how to design an efficient mechanism to define the best decision by all control agents in order to behave in a sense that the whole system stays globally optimized.

The proposed scenario is voluntary simpler; three product types P_1 , P_2 , & P_3 are considered. For each of them ten intelligent products are launched on the basis of TRACILOGIS test-bed platform. The physical system is composed by two resources (M_1 and M_2) with their cyber part (resource agents and product agents). Each product agent tries to follow a standard routing sheet shown in Fig. 1 based on the run time given in Table 1.

In the routing sheet shown in Table 1 and Fig. 1, P_1 for example, passes on M_1 for its first processing (O_1), moves to M_2 for its second processing (O_2), and again return to M_1 for its third processing (O_3) with its completion time C_{ij} (where 'i' is the i^{th} product agent and 'j' is the j^{th} resource agent) and then completes its route. While product routes without optimal operational sequence, it will lead to high set-up time. Hence, the route has made to pursue reactive and negotiating heuristics using MATLAB simulation run in the media input of

Table 1 Run time and due date of three product types

Products	Run time on each machine			Due date	Remark
P ₁	M ₁ (3)	M ₂ (1)	M ₁ (4)	10	Completes its routes
P ₂	M ₁ (11)	M ₂ (3)	-	18	Completes its routes
P ₃	M ₁ (8)	-	-	7	Completes its routes

**Fig. 1** Media input of the TRACILOGIS platform

the TRACILOGIS platform so as to pinpoint the best priority based sequential production process.

3.1 The proposed critical ratio based negotiation model

In the negotiation heuristic, all agents are made to cooperate by computing and analyzing intention of products and capacity of resources. The intention of each product agent ‘*i*’ is to arrive and process in each resource agent ‘*m*’ and each product broadcast its intention in particular to each resource that it is approaching based on its starting time, run time and finish time; “Eq. 1”.

$$v_{i(m)} = [a_i \ r_i \ f_i] \quad (1)$$

Where v_{im} is intention of product ‘*i*’ in each resource ‘*m*’, a_i , r_i , f_i , respectively are the starting time, run time, & finish time of product ‘*i*’ in each resource ‘*m*’. Therefore, from Table 1,

$$v_{1(1)} = [0 \ 3 \ 3], \ v_{1(2)} = [3 \ 1 \ 4], \ \text{and} \ v_{1(3)} = [4 \ 4 \ 8]$$

$$v_{2(1)} = [3 \ 11 \ 14], \ v_{2(2)} = [14 \ 3 \ 17]$$

$$v_{3(1)} = [14 \ 8 \ 22]$$

Each product ‘*i*’ computes its intention and sends to other products and to the resource so that its intention will be understandable by all agents and executable on the resource. After each product sends its intention, resources are expected to being used in order to utilize

their run time (i.e., to reduce the setup time and to support the competitive priority of cost) based on utilization model given in “Eq. 2”

$$Utilization = \frac{\text{Average processing time}}{\text{Maximum processing capacity}} \quad (2)$$

To achieve this utilizability, resource agents request each product based on their critical ratio order with an intention to process a product with smallest critical ratio first. Hence, each resource has to calculate the critical ratio (CR_i) of product ‘ i ’ based on the model:

$$CR_i = \frac{\text{Due date} - \text{current date}}{\text{Total shop time remaining}} \quad (3)$$

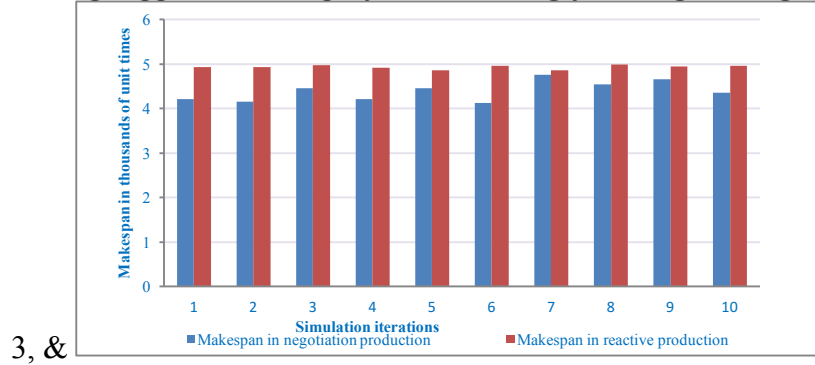
Where total shop time remaining is the setup, processing, routing, and expected queuing times of all remaining operations, including the operation being scheduled.

Finally, depending on the objective of maximizing the resource's run time, resource gives priority to the product that best meets the due date, Table 1. Consequently, after a product recalculates its intention and sends to all products, the other products, in turn, evaluate the intention set by product ‘ i ’ and they will accept it if it doesn’t affect their predetermined critical ratio or ask product ‘ i ’ to revisit its intention. For instance, when P_1 and P_3 meet in decision point number ‘1’ of Fig. 1 while P_1 is routing to M_1 for its third operation and P_3 commencing its route, P_3 ’s intention is to precede P_1 . Hence, P_3 will quarry P_1 to wait wherever it is so that P_3 will first process in M_1 . If not, P_3 will route a loop even though its critical ratio is less than the critical ratio of P_1 in M_1 . Likewise, while products are prioritizing themselves based on their intention, they have to be validated by resources as product’s intention may lead to idleness of resources, which in turn increases the setup time. Thus, resources recalculate their setup time every intention of products and review the critical ratio based product priority.

4 Simulation experiment results

As stated earlier, making several critical ratio based negotiation simulation run helps to converge to a better optimization. In this case, fifty MATLAB simulation runs (its output is presented in **Erreur ! Nous n’avons pas trouvé la source du renvoi.**) have been executed for each production heuristic by considering the resource utilization rate, product lateness (the tardiness), and the global makespan. Initially, the reactive production was simulated taking into account the “change the product intention” principle such that agents simply re-

act to what has happened in their routes. While products do not allow sending their correct intention, resources become inefficient and are led to high setup time when the products are tardy and as a result the global makespan increases linearly. Once the result of this reactive production has obtained, the routing sheet has been shifted to negotiating production heuristic where “update the intention and routing” approach is employed. Accordingly, the figures Fig. 2, Fig.



3, &

Fig. 4 compares and contrast these two production approaches and generally depicts that the pure reactive production mode is almost rectilinear and that of negotiating is nearly alternating to show the negotiation is seeking to satisfy the intentions of product agents.

Fig. 2 compares the simulation results considering the lateness of products. In the negotiating production mode, agents have able to reduce the lateness to a minimum of 10,000 unit times in one of their simulation run but in reactive production; their minimum lateness has resulted to be 23, 600 unit times. This shows that in the former approach, products arrive resources 13,600 unit times prior than in the second production heuristic. Meanwhile, the product lateness in the routing sheet has reduced, on average, by 28.67% as a result of the environment created for negotiation rather than for reactive mode. Similarly, the utilization rate of resource (M_1) while the routing sheet follows negotiating production is better than reactive approach, Fig. 3. For example, on average, when the routing sheet employs the negotiation approach, it has utilized the resource (M_1) 9.51% better than the reactive production approach.

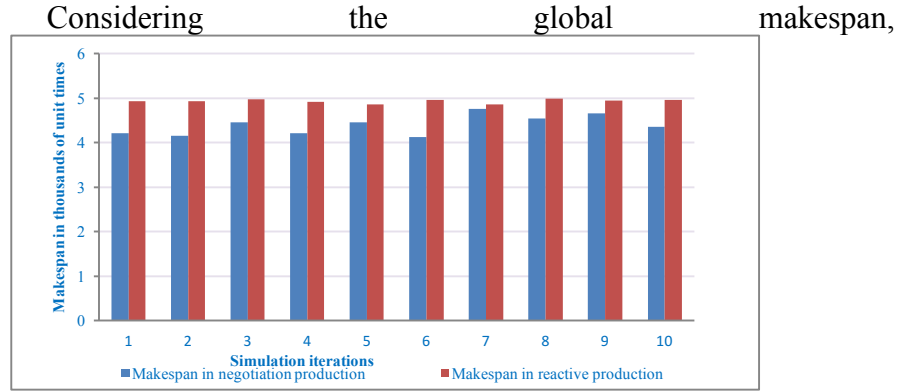


Fig. 4 clearly presents that in the reactive approach, once agents have set their sequential route, they almost continue to follow this route instead of setting another optimal route that helps them minimize their makespan. But in the case of negotiating production, agents update their preset route to minimize their makespan at least by 1.89% of the reactive approach.

Finally, this simulation experiment results indicate that the role of intelligent multi-agents system is increasing from time to time in initiating and supporting the decision making process of manufacturing industries. To achieve this, agents have to continuously negotiate among themselves and reach a final consensus in order to converge to a common offer.

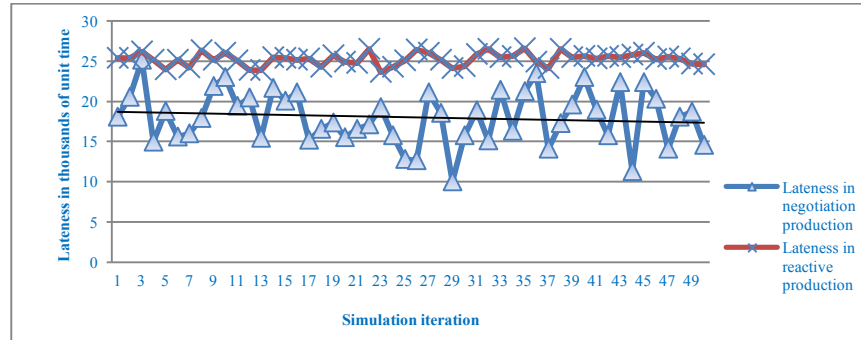


Fig. 2 Product lateness of the two production processes

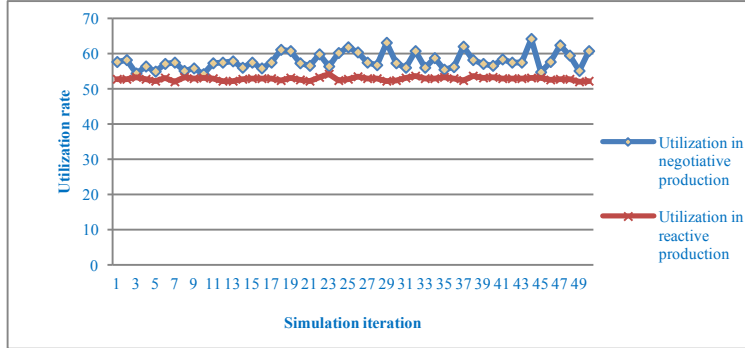


Fig. 3 The utilization rate analysis

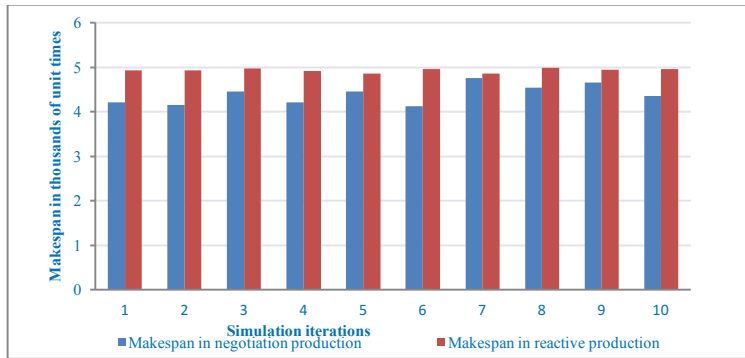


Fig. 4 The makespan analysis

This consensus, in dynamic system, is reaching to agreement regarding a certain quantity of interest that depends on the state of all agents [13]. However, even though many related researches are executing continuous effort, there are long history consensus challenges since the start of consensus to set a common goal by each entity/agent which have its own priority of goals and level of understanding of its environment.

5 Conclusion and future works

This paper has developed a negotiation scenario to simulate product's routing sheet based on the media input of the TRACIOLOGIS test-bed platform and compare its result with reactive sub scenario. The simulated results show that negotiation among resource and product agents have brought good improvement over the reactive circumstance. For example, the product lateness in the routing sheet

has reduced, on average, by 28.67% as a result of the environment created for negotiation rather than for reactive mode. Similarly, the utilization rate of resources (M_1) while the routing sheet employs negotiation heuristic is 9.51% better than the reactive production approach. These values present that the negotiation heuristic has brought sizable improvement in the routing sheet considering the resource utilization, product tardiness, and global makespan as comparative performance indicators.

As continuation of this work, a consensus-based approach will be investigated with an objective to allow some entities (products and/or machines) converging towards a predefined state using the well-known consensus control theory. The predefined state will be computed such that the performances are improved in a distributed way.

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