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FEASIBILITY EVALUATION OF MULTI-SITE SCHEDULING BY DISTRIBUTED SIMULATION OF WORKSHOPS

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Abstract: In this article, a distributed simulation tool for the feasibility evaluation of multi-site scheduling is proposed. The application areas concern supply chains or networks of cooperating and distributed workshops. The distributed simulation of workshops, called virtual workshops, generates various problems of causality and of tasks execution coordination. These problems are addressed in the proposed distributed architecture by the use of HLA protocol guaranteeing the synchronization and the chronology of events. An application to a simple case of supply chain organizing the flow between three workshops shows the effectiveness of the distributed simulation tool. *Copyright © 2006 IFAC*

Keywords: scheduling evaluation, distributed simulation.

1. INTRODUCTION

The Supply Chain (SC) consists of specialized, cooperating and geographically distributed manufacturing units, and poses the problem of its performance evaluation. The principal stakes of SC are organization and management of the production distribution (Stadtler, 2000). The complexity of these multi-site organizations is studied with specialized tools of production activity control such as ERP (Enterprise Resource Planning) or APS (Advanced Planning System) (Stadtler and Kilger, 2000; Meyr *et al.*, 2000). However, these tools are based on aggregated models of real production systems for the generation of production plans used by partners. The calculated plans cannot be suitable for real situation because of discrepancies between aggregated models and real production sites. To cure this drawback, the evaluation of plans is necessary before the dispatching in workshops. By this way, the feasibility is evaluated and if necessary ensured by the SC reconfiguration.

Various methods were proposed to evaluate the plan feasibility of the distributed workshops. In (Lee *et al.*, 2002), the analytical resolution rests on a set of mathematical equations representing the SC model considered. However, incomplete modelling of the dynamic characteristics does not provide acceptable solutions for the analyzed system. As described in (Luder *et al.*, 2004; Gupta *et al.*, 2002; Kubota *et al.*, 1999), simulation allows the SC evaluation by regarding it as a centralized company. Nevertheless, during the modelling phase, difficulties related to the significant number of entities to be modelled and to the detail level wished by companies, represent the first limits of this approach. Other drawbacks are related to the quantity of events to be simulated, the computing power, the reuse of the simulation models and the intellectual property protection. Finally, the modelling of all SC sites remains possible but simulation done with one processor is not always achievable. A fine evaluation of multi-plan feasibility is difficult to obtain when being based on

an aggregated model. For the SC, the feasibility is not reduced to the sum of the evaluations for each site. Taking into account these limits, the evaluation of the multi-site scheduling feasibility requires the definition of distributed simulation architecture.

Several works were undertaken on the distributed simulation of large scale production systems. A first asset in favour of the decentralization is linked to the information protection of each site which can choose to mask certain data at the time of distributed simulation. The distributed models are locally built, maintained and joined for evaluation (Mertins *et al.*, 2005). Moreover, the total performance of the simulation time is improved thanks to distribution (Turner *et al.*, 2000). HLA (High Level Architecture) protocol was proposed by the DMSO (Defense Modelling and Simulation Office) to synchronize simulators within a large simulation. HLA facilitates the interoperability and the reuse of simulations to reduce modelling and simulation costs and provides the means for large simulations using geographically distributed components (Standards, 2000). HLA implements algorithms for synchronization and respect of the chronology for simulated events and in particular those defined in (Chandy and Misra, 1978). HLA enables to synchronize a federation, *i.e.* a set of federates sharing a common model object, the FOM (Federation Object Model), containing all information relating to the simulation execution. A federate is a federation component including a simulator to which an operator, a machine or a complete workshop can be associated. The RTI (Run-time Infrastructure) constitutes a data-processing implementation of the HLA interface specifications and ensures the communications between federates of the same federation by offering the HLA services for the synchronization and the management of the chronology events.

In this article, the definition of the architecture model is presented in Section 2. In Section 3, the principles of distributed simulation are described studying the principal software classes. The coordination and synchronization mechanisms of messages and information are detailed. In Section 4, an application to a simple case of a multi-site SC model organizing a flow between three distributed workshops is used to illustrate modelling steps. Finally, the evaluation results of the multi-site scheduling feasibility are discussed.

2. F-R-PAC MODEL

The PAC model (Production Activity Control) conceptually represents a system for controlling and following-up a workshop. The MO (Manufacturing Orders) are scheduled and distributed

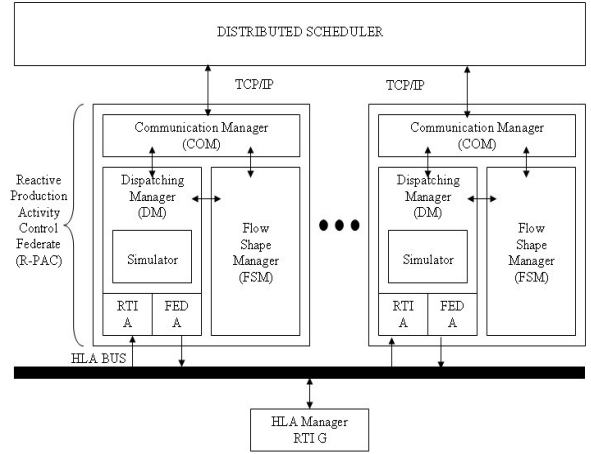


Fig. 1. F-R-PAC federation.

within the workshop. The follow-up makes it possible the count of the events to establish a state of the production and of the workshop. In (Archimede *et al.*, 2003), a MS-R-PAC (Multi-site Reactive PAC) architecture was firstly proposed for geographically distributed workshops simulation. MS-R-PAC coordinates the control of several virtual workshops using a distributed scheduling carried out thanks to a protocol close to Contract Net (Smith, 1980). The virtual workshop is the data-processing representation of a real workshop. However, synchronization problems can appear in the MS-R-PAC model according to the number of events to be simulated. The causality principle and the respect of the chronology of the events issued of each site cannot be guaranteed when the simulators have different processor speeds. In order to answer these requirements, a new model F-R-PAC (Federation of R-PAC), associating as federate as there are sites, was defined. In figure 1, a F-R-PAC federation is depicted. The sites can indifferently represent workshops, machines, operators or transportations. A distributed scheduler calculates the multi-site planning and sends it to the R-PAC federate using TCP/IP protocol. The distributed simulation consists of a HLA bus and a set of R-PAC enabling the execution of any kind of multi-site scheduling in virtual workshops. Federate synchronization is ensured by the HLA protocol.

2.1 R-PAC federate

In figure 1, the R-PAC federate consists of three managers and one encapsulated simulator. The FSM (Flow Shape Manager) carries out the follow-up of the production and enables the detection of events linked to the start or the end of operations resulting from virtual workshop. The COM (COMMunication Manager) ensures the connection between scheduler and DM (Dispatching Manager) or FSM. The DM, whose algo-

rithm was detailed in (Enjalbert *et al.*, 2004), controls the plan execution and the task dispatching in the virtual workshop. This architecture enables to easily take into account any modification of the corporate network; any change in real workshop requires an adaptation of the corresponding virtual workshop. RTI A and FED A are two Ambassadors integrated into the DM, *i.e.* entities providing the interface with HLA.

2.2 Federate synchronization

The F-R-PAC behavior requires the management of two kinds of synchronization: inter-federate and intra-federate synchronizations. The first one, managed by HLA, rests on a publication/subscription mechanism. During simulation, R-PAC federates cooperate and react to events which are conveyed on the network using time stamped messages. These time stamped messages ensure a regulated and constrained behavior for all federates. Intra-federate synchronization between the DM and the controlled simulator is based on the assignation points to which the simulator must go to be synchronized by the DM algorithm. The difficulty rests in these two synchronization mechanisms coexistence. The DM must ensure that an assignation point is not too distant to guarantee synchronization of the simulator. In figure 2 the effectiveness of the time management and the causality rule implementation is illustrated. In order to guarantee the good execution of the plan the DM determine the nearest event date according to information received from the simulator and information drawn from its own scheduling. The next assignation to a desired date is fixed by the DM according to local information. This date can be a planned operation or a beginning or ending transportation, or a date corresponding to a waited and delayed event. Then, the federate requires the RTI authorization to advance the simulator to this date (NER: Next Event Request). If the RTI considers that until this date no external event will appear to disturb the federate, then it authorizes the time advance (TAG: Time Advance Grant) of the simulator. On the contrary, if the RTI refuses the desired assignation date advance, a new assignation point on a lower date corresponding to the next external event concerning the federate is proposed. Until the assigned date was reached, several stops and resumes can be necessary. The DM updates the scheduling, transmits time stamped messages on its state to the RTI, and starts a new cycle by proposing a new assignation date. In figure 2, the first synchronization is done at date u expressed in time unit [t.u.]. A CDE (Current Date Event) is sent by the simulator to the DM, corresponding to an appointed assignation date. The federate

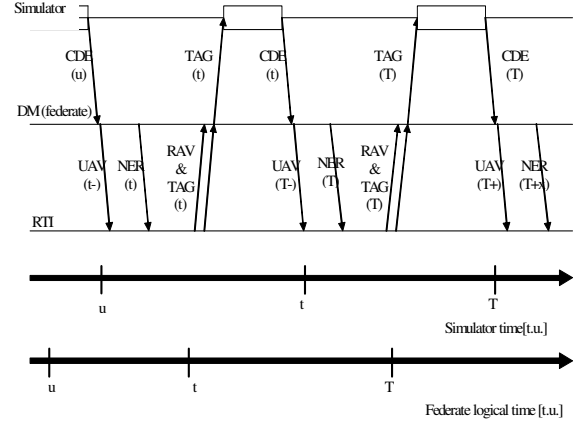


Fig. 2. Communications within a R-PAC federate.

transmits to the RTI messages concerning the state of objects locally simulated, (UAV: Update Attribute Value). Then, a new time advance towards the next assignation desired date is asked. The time advance request must drive the simulator to date t . The RTI makes sure beforehand no event will be able to interfere before the appointed date t for the federate. When the authorization is granted (TAG) and after having received messages concerning the state of the objects simulated by other federates (RAV: Reflect Attribute Value), the DM transmits information to the controlled simulator which can advance at date t . The mechanism is renewed until the complete simulation of all planned events.

3. F-R-PAC IMPLEMENTATION

In figure 3, a UML class diagram details the principal functions of the distributed simulation in F-R-PAC architecture. There are five principal classes. CSimulator models the DM and encapsulates the controlled simulator. CFlowShopManager carries out the follow-up of the production operations through flow-shape functions. COrdoAmbassador is the class which manages the connection with scheduling. CShopFederate enables the federate R-PAC to reach HLA mechanisms. CWorkshop represents database feeding the various classes.

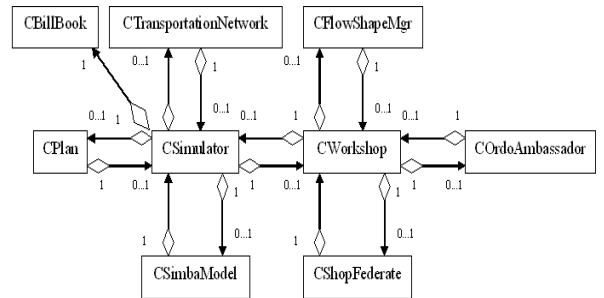


Fig. 3. UML class diagram of F-R-PAC.

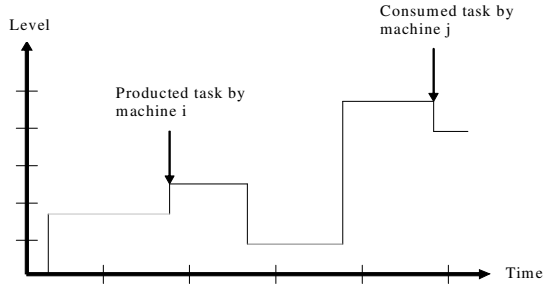


Fig. 4. Flow-shape function between two machines i and j .

3.1 Dispatching Manager

The DM controls the MO execution in the virtual workshop. CSimulator is related to classes allowing the recovery of information on the simulator behavior (CPlan, CBillBook, the DM scheduling and CTransportationNetwork, to facilitate transportations). The CSimbaModel class implements the simulator encapsulation. In this study, the chosen workshop simulator is SIMBA, an event-driven simulation software of Lanner Group. CSimulator ensures the control of the plan execution in the virtual workshop.

3.2 Flow Shape Manager

The FSM is implemented in the CFlowShapeManager class and provides mechanisms for checking, at each event occurrence, if the running plan execution is correct. A planned flow-shape function for the workshop is generated according to scheduling initially predicted and available in CWorkshop. During simulation, the time stamped data concerning the task execution are processed and a comparison is carried out in order to detect the discrepancies. Figure 4 illustrates a flow-shape function generated from the occurrences of beginning and ending of operation dates. The level represents the sum of the tasks whose dispatching is envisaged in the workshop. A level increase expresses that the total load of the workshop is growing whereas level zero means no task is planned. In practice, the production plan always differs from the effective plan because schedule modelling is based on a simplification of reality. The differences between the predicted and real profiles are analyzed for each event occurrence in order to evaluate the plan performances. The flow-shape functions of the same workshop are aggregated according to a mechanism described in (Archimède *et al.*, 1993) to reduce detection times.

Table 1. Routings

MO	Activity	Duration
MO1	Turning	36 t.u.
	Milling	33 t.u.
	Fettling	48 t.u.
	Drilling	48 t.u.
	Fettling	48 t.u.
MO2	Assembling	30 t.u.
	Turning	33 t.u.
	Milling	36 t.u.
	Fettling	28 t.u.
	Turning	18 t.u.
	Assembling	24 t.u.
	Painting	33 t.u.
MO3	Assembling	26 t.u.
	Turning	30 t.u.
	Drilling	36 t.u.
	Turning	24 t.u.
	Painting	30 t.u.
	Assembling	24 t.u.
	Painting	42 t.u.
	Fettling	22 t.u.

3.3 Communication Manager

The COM manager implements a communication layer between the distributed simulation and the distributed scheduling. The COM is described in the COrdoAmbassador class and enables to send to the scheduler information on production or transportation detected disturbances. Moreover, COM listens at scheduler to receive a new scheduling at any moment. The virtual workshops communicate independently of the COM via HLA bus thanks to the CShopFederate class including all HLA information necessary to the federation execution. CWorkshop class recovers all simulation information and stores them in its databases. CWorkshop requires information on initial scheduling by its connection with COrdoAmbassador. The time stamped messages are available for the CShopFederate in HLA formalism. In the same way, a database can be accessed by the DM via the CSimulator class in order to supply the simulator with data. Finally, CWorkshop is linked with CFlowShapeManager to give information on the predicted scheduling to build flow-shape functions. CWorkshop makes available simulation information necessary to the federate synchronization.

4. APPLICATION TO A SIMPLE CASE

A simple application illustrating the case of a corporate network cooperating for manufacturing a coffee table is detailed herein. This ovoid table consists of 4 feet, and of higher and lower plates. The 3 MOs necessary to carry out its manufacturing, MO1, MO2 and MO3, are offered at the possible suppliers. Associated routings and durations of each activity are summarized in Table 1. Three sites of production located at Toulouse, Paris and

Table 2. Machines and activities

Location	Machine	Activity
Toulouse	M1	Milling
	M2	Drilling
	M3	Fettling
Paris	M1	Turning
	M2	Turning
Lyon	M1	Assembling
	M2	Painting

Table 3.
Inter-site transportation durations.

From/To	Toulouse	Paris	Lyon
Toulouse	-	24 t.u.	30 t.u.
Paris	24 t.u.	-	18 t.u.
Lyon	30 t.u.	18 t.u.	-

Lyon are selected as partners for this manufacturing project. The site of Toulouse provides basic preparation of the feet as well as plates. The site of Paris prepares turning activities. The site of Lyon is in charge of assembling and painting. Associated machines and activities are described in Table 2. Inter-site transportation durations are defined in Table 3 while intra-site transportation durations are 2 t.u. between each machine. For this manufacturing case, a distributed scheduling was carried out using the software R@mses (Re@ctive Multi-agent System for Scheduling). During this period, road works are in progress on axes connecting the sites and traffic is limited. An arbitrary direction of traffic is then imposed. The course of delivery joins successively the sites of Toulouse, Lyon and Paris before to be back in Toulouse. Initially, only one truck able to transport only one part per way at the same time is considered. Thereafter, when several trucks are available, as soon as an operation requires a transportation, a request is sent to the trucks. The first available one accomplishes transportation. In order to evaluate the feasibility of this multi-site scheduling, several workshop configurations according to transportation capacities are studied. Simulation was initially carried out with one, two and finally three trucks to determine the better configuration of distributed workshops able to take into account the described constraints linked to traffic. In Figure 5, the flow-shapes resulting from scheduling and simulations are represented. The aggregated flow-shape functions scheduled for the sites (a) Toulouse, (b) Paris, and (c) Lyon are used as input data for simulation. The first simulation was done with one transportation resource. Results are represented in Figure 5 by flow-shapes of the sites (d) Toulouse, (e) Paris, and (f) Lyon. After several simulations, finally the case of three trucks is presented for the sites (g) Toulouse, (h) Paris, and (i) Lyon. For the site of Toulouse (a), (d), and (g), until to 85 t.u., the three flow-shapes are similar because no MO is dispatched and no part is coming from Paris. At

time 85 t.u., the level of (d) increases because new tasks are planned but not carried out. The site is waiting for the deliveries from Paris. The delivery delays increase and the flow-shape (d) is stretched. The load level of the workshop awaited by (a) at time 120 t.u. is reached only around time 270 t.u. for (d). Simulation is complete at date 840 t.u. for (d) against 305 t.u. as initially predicted for (a). In time 85 t.u., the second and third trucks supply quickly enough the site (g) avoiding a load increase. The level awaited by (a) at time 130 t.u. is reached only at date 180 t.u. for (g) because three trucks resource is not sufficient to carry out all transportation at the same time. When a great number of MO are located at the beginning of routings, the cumulative delays are without any consequences as shown in (b), (e), and (h). After initialization, the three flow-shapes are identical until date 115 t.u.. For (e), the level decreases at time 170 t.u. whereas for (h) this decrease begins only at time 145 t.u.. In the case of a single transportation, the flow-shape for (e) ends at date 330 t.u. against 165 t.u. for (b) as initially predicted. The MOs of Lyon are located at the end of routings. The predicted operations are ended at time 350 t.u. for (c), at time 440 t.u. for (i), and at time 440 t.u. for (f).

As soon as inter-site transportations are required, the truck availability, its geographical localization and the traffic direction are the main constraints not taken into account in the multi-site scheduling. The use of only one truck to supply the various sites introduces a delivery delay. In this manufacturing project, the scheduling quality depends on the transportation organization. The two trucks transportation case was simulated but the resulting improvement is not significant in comparison to the three trucks case. Moreover intra-site transportation have no direct influence on multi-site MO transportation strategy (see pikes of 2 or 4 t.u. in Figure 5.a, c, d, f, g & i) because inter-site transportations generate more important delay. The tool for distributed simulation of virtual workshops enables to evaluate the feasibility of multi-site scheduling and to adapt the resources in order to correspond as well as possible to the predicted plan. In this manufacturing project, three inter-site trucks and one intra-site transportation lead to the best result.

5. CONCLUSION

A tool for distributed simulation able to guarantee the synchronization and the causality of production operations for a distributed workshop network was presented. The simulation tool deals with any kind of distributed scheduling by preserving the independence of each partner. The

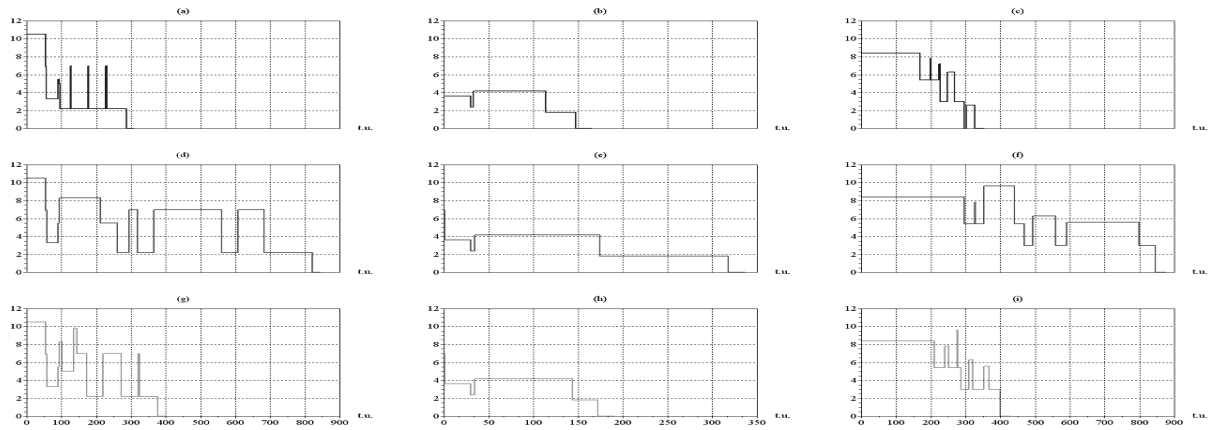


Fig. 5. Aggregated flow-shape predicted for (a) Toulouse, (b) Paris, and (c) Lyon, followed with one transportation for (d) Toulouse, (e) Paris, and (f) Lyon, and followed with three transportations for (g) Toulouse, (h) Paris, and (i) Lyon.

dimensioning of transportation resources can be evaluated when a manufacturing project is dispatched. By this way, the feasibility evaluation of multi-site scheduling enables the adaptation of the supply chain configuration or the improvement of the plan. Next objectives will concern the use of transportation resources without constraint and the definition of variable size of transportation containers.

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