Decentralised Resource Allocation Planning through Negotiation*

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Abstract

This paper presents a multi-agent model for resource allocation planning in a manufacturing environment. This model considers the temporal and synchronism aspects involved in the allocation process. The main contributions of this work are: (i) the definition of a formal strategy for resource allocation supported through a multi-agent system that would be able to reduce the complexity of the model considering real-time events that potentially affect the allocation, (ii) the definition of a hierarchical multi-agent architecture with capacity to support this strategy.

Keywords

Multi-Agent Systems, Planning, Allocation Resource, Manufacturing Systems

1 INTRODUCTION

A production system in a manufacturing environment may be characterised by its products, material consumed, components or sub-assemblies used in the products,

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the production operations and the resources allocated to these operations. The production process occurs according with a production route which is composed by specifics production operations for each final product. The production resources are essentially the machines, other needed equipment and the available labor.

We consider that the complexity in the decision-making of the production planning process is concentrated in the search for an ideal level of resources utilisation. One of the main components of the complexity is the frequent disturbance occurring in the shop floor. These changes occur due to new requirements, modifications of the previous requirements, production malfunctions and others disturbances. To manage these changes, the production planning process must consider the deadlines defined for each production event, as well the local resources constraints and the global constraints of the whole production system.

The conventional production systems use centralised, global and sequential planning models [Parunak 96]. Searching the optimisation, the decisions involved in the planning process are centralised and the results assigned to the execution entities. This approach makes the optimisation susceptible to a combinatorial explosion due to the number of interactive entities that must be considered. Any variation that could affect the planning of one execution entity will make the global plan inconsistent, forcing a new global planning execution.

This paper central issue is to decentralise the resources allocation decisions providing a reactive role to the concerned production entities. We propose a distributed planning process, in which every involved entity is able to realise resources auto-allocation to fulfil the production requirements considering the temporal constraints. To achieve this goal in this paper is propose a multi-agent paradigm to deal with the resource allocation process.

2 THE MULTI-AGENT MODEL

Our approach is CIMOSA compliant [Kosanke 92] [Vernadat 94] [Zelm 95]. The agents here defined are associated with the CIMOSA classes. Five agents types have being defined: the *Human Agents* (HA) - external agents representing the users involved in the interaction, the *Domain Process Agent* (DPA), the *Business Process Agents* (BPA), the *Enterprise Activity Agents* (EAA) and the *Functional Entity Agents* (FEA) (Figure 1).

Figure 1 - Agents relationship

Considering the CIMOSA, from a conceptual point of view, a Domain Process (DP) is functionally decomposed into Business Processes (BP) and Enterprise Activities (EA). In its turn, a business process represents an aggregation of enterprise activities. Both of them could be used in different domain processes. The enterprise activities involve one or more functional operations that are executed by the functional entities. Functional entities represent the production resources. A Domain Process decomposition is exemplified at Figure 2.

Figure 2 - Domain process DP1 decomposition

The Domain Processes are directly triggered by the production events. Each Domain Process has one or more production plans. A production plan represents a production route - composed by business processes and enterprise activities - which can be applied in order to fulfil a production event. The logical sequence of business processes and enterprise activities within a production plan is defined by a set of Procedural Rules.

The resource allocation process is dynamically performed departing from the local resource allocation made by the agents. This allocation is performed based in the restrictions received from the upper levels. The agent's interaction is obtained using an extension of the contract net algorithm [Davis 88] and market-oriented programming [Welmann 95]. There are two stages in the resource allocation process: temporal constraint definition and bidding and contracting process. The first stage defines a pruning mechanism that selects the agents able to participate of the bidding process. The second stage specify a selection process that identifies which agents will be contracted to execute the production plan.

3 ANNOUNCEMENT ELABORATION

The announcement elaboration process starts when the DPA receives a production event. The DPA identifies the corresponding domain process and select the production plans adequate to this one. A production plan represents one of the possible production routes that can be applied to accomplish the domain process. The DPA sends announcements to BPAs and EAAs that compose each production plan requiring bids. These agents send announcements to leaves agents - a BPA send an announcement to the EAAs and the EAAs to the FEAs. The BPA and EAA bids are elaborated based on the FEAs bids.

The announcements are elaborated based in general and temporal constraints. The human agent according to the production process characteristics, including activities sequence, event priority, quality level, etc defines the general constraints. In order to generate the temporal constraints we defined a *temporal planning strategy* based in planning nets.

This temporal planning strategy deals with each requirement as an independent project. For each project, we build a PERT network. Using the PERT network, it is possible to identify the relationships between the project activities - business process and enterprise activity - that compose the domain process production plan. The project activities need functional entities to be executed. Each activity must be planned considering its estimated execution time and the availability of the necessary functional entities. The whole planning must be done in such a way as to respect the production event deadline.

In a project, some activities are considered critical. Such activities are in the critical path. In a PERT network, the sum of the execution times of the activities that form the critical path define the total time to be spent to perform the project. Consequently, any delay in one of these activities determines a delay in the project conclusion. The planning to satisfy a production request must start by the critical path activities.

In order to improve the global planing we use the principles defined at OPT philosophy [Goldratt 80]. The main principles for our work are: (i) the time lost at a bottleneck resource is the time lost for the entire production, (ii) the time saved at a non-bottleneck resource is meaningless for the total production time, and (iii) the bottlenecks determine both total system throughput and inventory.

In the OPT technique a bottleneck resource is any resource whose capacity is equal to or less than the demand. In this work, the resources are represented by functional entities. Due to the characteristics of our propositions, it is necessary to review this concept. A bottleneck resource is defined as a *capacity constrained resource*, a kind of resource, which as a consequence of possible variations in production mix, could disrupt product flow if not scheduled carefully. Therefore, it is important to consider the possibility to add another similar functional entity to distribute the demand in an equilibrate way. Besides that, it is important to safeguard the functional entity that have the larger demand because it could be a bottleneck resource or would become one.

To identify the critical activity that will use the most capacity constrained functional entity, is used a variable called *functional entity occupation level*. The functional entity occupation level is a value that defines the services demand degree for a functional entity.

The functional entity occupation level must be defined considering the temporal interval required by the announcement, the occupation level after the temporal interval required by the announcement and the historical occupation level. The two last information propitiate an evaluation about the probability of the functional entity to receive new announcements.

Considering this premises, the agent responsible for the critical activity that use the most capacity constrained functional entity must be the first one to be programmed. It is only after this agent will be programmed that the agent responsible for the next-to-last critical activity can be programmed, and so on.

It is possible to create virtual slack time for the critical path activities. To create this slack time it is necessary to consider that the time between the project start and its end is greater then the sum of the execution times of the activities that form the critical path.

Consider for example a production order of 300 units sent to the domain process DP1 (Figure 2). This production order represents a production event that requires an action from DPA. The DPA identifies which plans - more than one may be available - is adequate to satisfy this domain process. To simplify the explanation it is supposed that there is just one plan satisfactory for DP1.

After to receive the time estimate from the BPAs and EAAs involved, the DPA builds the PERT Network. A possible PERT Network for the domain process DP1 is showed at Figure 3. In this case, the BP1, BP3 and EA2 form the critical path for DP1. Consider that the production order was issued at time zero with a deadline of 55 time units. It is possible to verify in the PERT network that the necessary time to finish the production order is 34 time units - considering that all the critical path activities will be executed in sequence and without retards. If the production conclusion is required at 55 time units then exists a slack time of 21 time units. This slack time should be used by the critical activities. The schedule of the critical activities is represented in Figure 4.

Figure 3 - PERT Network for DP1

Figure 4 - Preliminary Schedule

To identify the most capacity constrained functional entity the DPA send an announcement requiring the functional entity occupations level to the bottom agents. This announcement must be propagated through the BPAs and EAAs involved until the FEAs responsible for the functional entities qualified to execute the required enterprise activities. These agents must calculate the occupation level considering the time interval available to the execution of the correspondent enterprise activity including the slack times.

4 BIDDING PROCESS

The bidding process starts with the most capacity constrained functional entity. Consider, for example, that the BP3 uses the most capacity constrained functional entity. Hence, the agent responsible (BPA3) for BP3 must be the first to present the bid. In fact, once the BP3 represents a business process, it is necessary that the EAAs responsible for the enterprise activities that compose it prepare their bids in order to BPA3 prepare its own bid. In sequence, the EAAs must require the bids from FEAs responsible for each functional entity that can be candidate to execute the necessary functional operations.

Its important to note that most of one functional entity may have capacity to execute the same functional operation and that may exist more than one instance of each one. All functional entity and its instances could have a bid presented. Each EAA involved in a bidding process must choose the bid which better satisfies the constraints presented into its announcement and offers the smallest price.

The price composition is based on the occupation level and set-up cost. We use a market-based programming approach in order to implement the contracting agents' decision-making process. In this sense, the value correspondent to the occupation level is defined as a profit to each agent. Of course, the agent always must choose the bid with lower price.

Let us examine the bidding process to the example based in BP3. EA9, EA10, EA11 and EA12 (figure 2) compose BP3 and the correspondent PERT network is shown in Figure 5. The critical path is formed by EA9 e EA10. Consider that the most capacity constrained functional entity will be used in EA10. Thus, the bidding process starts with the EAA10, the agent responsible for this enterprise activity. There are two functional entities FE1 - which is the most capacity constrained functional entity - and FE2 qualified to execute the functional operations required by EA10. Both of the functional entities need to form a coalition with a functional entity FE20 in order to fulfil the enterprise activity. Consider still that there are one instance FE1A for FE1, one instance FE2A for FE2 and two instances FE20A and FE20B for FE20. The possible coalitions are FE1A/FE20A, FE1A/FE20B, FE2A/FE20A and FE2A/FE20B.

Figure 5 - Enterprise Activities from BP3

In Figure 6 are shown the particular schedules to each instance of the functional entities when the bidding process starts. For each instance, there is a responsible agent. All the possible coalitions are qualified to present a bid for the announcement. Considering the occupation level to FE1A and FE2A probably the bids presented by the coalitions formed with the second will be smaller than the bids involving the first one. The coalition involving FE1A will be the winner just if the price offered in its bid will be smaller than the coalition with FE2A. This situation could happen in the case where the FEA1 set-up is adequate to EA10 functional operation while the set-up FEA2 is inadequate.

Figure 6 - Functional Entities Schedule

Considering that the bid winner was presented by FE2A/FE20B, a possible final configuration for our example is presented in Figure 7. The critical enterprise activities from BP1 are EA35 and EA31.

Sometimes it should be necessary to a FEA re-schedule its commitments in order to accomplish a new requirement. For this re-scheduling it is important to satisfy the constraints defined in the previous contracts with all the EAAs and the changes must be accepted for its coalition partners.

Figure 7 - Final Schedule to Critical Enterprise Activities

An unfeasibility occurs in the case where it is impossible to the FEA to re-schedule their commitments and no other instance of the functional entity is qualified to present a bid. In this case, the EAA must start a negotiation process with the related EAAs trying to obtain the time interval that could be observed by the FEA. This situation will require the propagation to the respective BPA, if there is one above the EAA in the CIMOSA modelling.

In situations where there are no FEA qualified to present a bid, the bidding process for the production plan must be closed and restarted with the next plan, if there is one. If no plan is confirmed, the Human Agent must be informed.

5 CONTRACTING PROCESS

After receiving the bids from the bottom agents the DPA choose the plan with lower final price - if there is more than one - and starts the contracting process. The contracting process consist on the confirmation of the better bids presented for each FEA. During the contracting process, some FEA coalition may not confirm its bids. It happens due to the fact that the FEAs are constantly sending bids to announcements and committing. Thus, a FEA can have assumed a commitment with another bid that uses total or partially the same time interval. In this case, the FEA coalition will try to present another bid that will fill the announcement constraints.

If it is impossible to this coalition present another bid, the contracting agent must try to contract another coalition candidate, if there is one. When it is impossible to contract one of the necessary FEA to execute an enterprise activity the contracts with the other agents must be cancelled and the negotiation must be restarted with the next plan. If no plan is confirmed, the Human Agent must be informed.

6 DISTURBANCE TREATMENT

A disturbance treatment is required when a disturbance event occurs during the functional operations execution. It is necessary that the FEA coalition reach a solution to avoid delays in their commitments. For this purpose, there are two possibilities:

- Re-scheduling of the commitments affected by disturbance event. In this case, the coalition must negotiate in order to redefine the schedule to the enterprise activities affected by the disturbance event observing the contractual constraints. Probably it will be necessary that the coalition utilise the slack time. It is important to note that each FEA, that compose the coalition, must re-schedule its individual commitments according with the constraints established in the committed contracts. For example, consider a disturbance event occurring in the FE2A. If the problem consumes 4 units of time, the agents responsible for the functional entities FE2A and FE20B must re-schedule the commitment to start at the time 29. On the other hand, if the problem consumes 6 or more time units, the agent responsible for the FE2A must try to re-schedule their next commitments (in this case there is just one) to fulfil the constraints established in the contract.
- If the necessary time to solve the FE2A problem will require more than 10 units of time it will be necessary to re-schedule the EA2. At this moment, the negotiation process transcends the functional entity level and must be performed by the EEAs involved. In this case it is necessary that the EEA2 demand to the FEAs the re-scheduling of theirs commitments in order to satisfy the request from EEA10 increasing the slack time among them.

7 CONCLUSION

This work has presented a multi-agent model for resource allocation in a manufacturing environment. This model considers the temporal aspects and synchronism aspects involved in the allocation process. We describe the agents classes involved and propose planning networks as a strategy to guide the activity scheduling process, in order to ensure the satisfaction of the production event deadline.

In our model the architecture supports the services encapsulation through the hierarchy of agents, in order to preserve their autonomy and capacity to make decisions considering their local plans. The main contribution of this work is the proposition of a formal strategy for resource allocation planning supported through a multi-agent system that would be able to reduce the complexity of the model considering real-time events that potentially affect the allocation. The architecture proposed for the system was developed considering the concepts defined in CIMOSA model. The work presented here represents some results towards the final model. At present we are working in the development of a software environment to validate and refine the architectural details of the model.

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9 BIOGRAPHIES

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