A MEDIATOR-BASED APPROACH FOR DECENTRALISED PRODUCTION PLANNING, SCHEDULING, AND MONITORING

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Abstract: The improvement of business processes along the supply chain has become a focus in industry and research during the past decade. Based on advanced technologies for communication and data structuring this paper describes a software system called the Mediator that provides support for integrating decision-making of several separate actors in decentralized business organizations. The Mediator is designed to offer an adequate level of decision-making integration, taking into account the effort needed for the integration of heterogeneous computer systems by use of the Extended Mark-up Language (XML). The approach is demonstrated for industrial pilot cases in multi-site and supply-chain production.

Keywords: decentralized systems, production planning, Mediator, scheduling, system integration, XML

1. Introduction

Many companies attempt to overcome their hierarchical and centralized production structures and to make their business processes more flexible and efficient. During the past decade considerable effort has been spent on the optimization of business processes within companies which are supported by systems for Enterprise Resource Planning (ERP). Nowadays, the focus is increasingly being shifted to the interaction of multiple sites of enterprises, customers, and suppliers.

Several approaches for distributed and intelligent production systems have been proposed, many of them being based on agent technology. Resources and orders are represented as agents with support of mechanisms for communication and co-operation. Agent-based systems are supposed to realize a high degree of flexibility, agility, scalability, and integration support for heterogeneous actors including software systems and humans (see a survey in Shen and Norrie, 1999). Among these approaches, so-called Mediators are used to co-ordinate actions between different production sites, suppliers, and customers. Often they support the dynamic creation of agent clusters and provide collaborative transactions (see e.g. Maturana and Norrie, 1996).

The approach presented in this paper is based on a single Mediator that is designed to offer an adequate level of decision-making integration taking into account the effort needed for the integration of heterogeneous computer systems. The purpose of the Mediator is not to replace existing systems but rather to extend and integrate their functionality and data. This is supported by use of the Extended Mark-up Language (XML) as data format for messages inside the Mediator and for the data exchange between local systems. This allows for the usage of flexible and adaptable interfaces to existing systems for production planning and scheduling.

2. Decentralized decision-making processes

2.1. *Overview of the business processes*

The business processes considered in this study include order planning, scheduling, and monitoring. The purpose of these processes is to allocate orders to resources, to monitor their production, and, if need

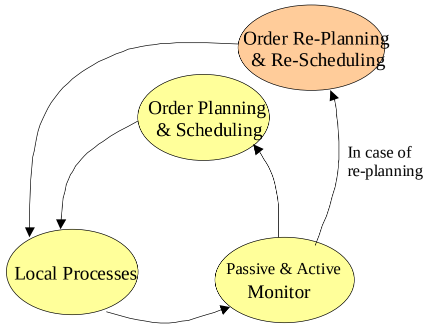

Fig. 1: Plan-Do-Monitor cycle

be, to initiate the re-allocation process. The goals of these processes typically include the fulfillment of requested orders with low lead times and low delivery deviations, efficient utilization of resources, and low inventory.

The order monitoring sub-process is a component of the plan-do-monitor cycle which represents dynamically the activity within a manufacturing company (fig. 1).

In practice, the described business processes appear in several different variations. The complexity of the product affects the characteristics of the processes as well as production strategy, organization, and situation. In the case of standard products and produce-to-stock production type the processes may be quite straightforward. On the other hand, in the case of configurable, engineer-to-order products with multiple production sites the processes can involve a substantial amount of negotiation and iteration.

Regardless of the variations, many real instances of these processes share many common features. In a more general view, the mentioned business processes may be interpreted as decentralized and collaborative planning and plan-monitoring processes among task and resource owners. The common goal of the task and resource owners is to agree on contracts in a way that fulfils their responsibilities and balances their goals. Based on this more general view, it is expected to make it possible to build more widely usable decision-support tools for these processes.

2.2. *Order planning*

The first part of the studied business process is order planning. The order planning process is interleaved with order scheduling and comprises several steps as illustrated in fig. 2. The sales sites have to specify the orders with customers and request responses from the production sites about when and where the orders could be produced. A production order (PrO) can consist of several manufacturing orders (MO) that usually correspond to products. Again, the sales sites have to collect, combine, and evaluate the responses from the production sites. Finally, the sales sites also have to negotiate with the customer and to agree on the contracts.

2.3. *Order scheduling*

In order to support decisions during the order planning process information about availability and capability for all appropriate production sites must be provided. This includes possible start and end dates of orders, based on the current load of the site and on costs and specification of the order (e.g. quantity, product modification, etc.). Therefore, new orders are preliminarily scheduled to the site. The new schedule is the base of the order response. It is evaluated and - if necessary - modified by the resource owner.

Fig. 2 describes the basic scheduling process where a MO delivery planning request is sent to an internal or external production site.

The request contains information about the specification, quantity, and planned costs of the product, about due dates and the priority of the order. The production planner of a manufacturing site sends a request to the local PPC system to get the current schedule. The new order is provisionally scheduled to the system. The planner can select an appropriate algorithm according to the dates, costs, and priority of the order. If the result is sufficient and does not affect other orders in the system a MO response will be sent to sales. In the other case the planner can send a re-scheduling request to the local system, e.g. to increase the capacity (overtimes) or to shift other orders. The task owner evaluates all received responses and decides if they are sufficient to create a customer order response. In this case a MO confirmation message is sent to the resource owner. The preliminary schedule can be accepted, and a schedule update request is sent to the local system.

2.4. *Order monitoring*

The order monitoring is an important business process inside the decentralized decision-making processes and intends to support the user to:

- know about delays in the order processing.
- be informed about temporary incapacity of a supplier (breakdowns or delays).
- re-adjust delivery times.
- find out quality problems during the production, etc.

Based in the monitoring sub-process, it is possible

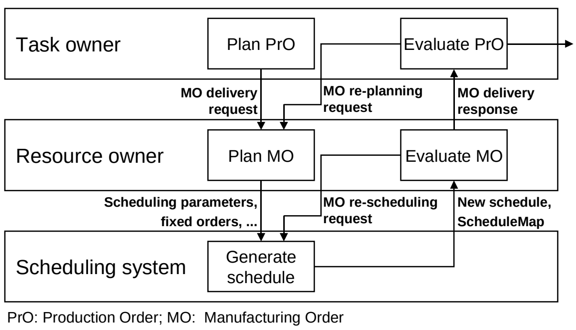

Fig. 2: Order planning and scheduling sub-processes

to make corrective actions in order to optimize the process, to change the specifications of the orders, and to cope with possible disturbances.

It is important to consider two different types of monitoring: passive (request-and-reply) and active (publish-and-subscribe). Passive monitoring is the type of monitoring that does not involve any alarm-event-driven mechanism. The request for passive monitoring comes from the decision-making unit which wants to obtain some specific information, such as the current status of an order or the capacity of a production site.

Active monitoring is related to the alarm- and event-driven systems, concerning parameters of decision-making units. These alarms can be caused both by disturbances on the resources and manufacturing site, which has possibly not been able to execute the allocated orders, and delays in the planned production and delivery dates. In order to fulfil this requirement, the active monitoring sub-process implements an event-driven system, based on notification of the occurrence of alarms subscribed by local decision-making units.

3. Mediator-based approach

3.1. Overview of the approach

The approach in this study to support decentralized decision-making in the described business processes is based on the concept of the Mediator. The Mediator is a specification of a shared server whose role is to provide mechanisms to support collaborative decision-making between task and resource owners. It is essentially a co-ordination broker with decision-support functionality.

In order to fulfil its role, the Mediator provides a selection of decision-support mechanisms. The mechanisms are targeted for various steps of the previously presented generalized business processes. In this study the Mediator provides negotiation, scheduling, rule-based decision support, and monitoring mechanisms. These decision-support mechanisms are based on an underlying XML-based communication solution. The mechanisms are explained in more detail in subsequent chapters.

In order to understand how the Mediator works one needs to know that the Mediator is implemented with a decentralized software architecture as illustrated in fig. 3. This architecture is motivated by scalability and modifiability needs. The architecture is also reflected in the decision-support mechanisms. Although in this study there is only one Mediator, it might be possible to have many of them co-operating with each other. However, this would entail more complex functionality.

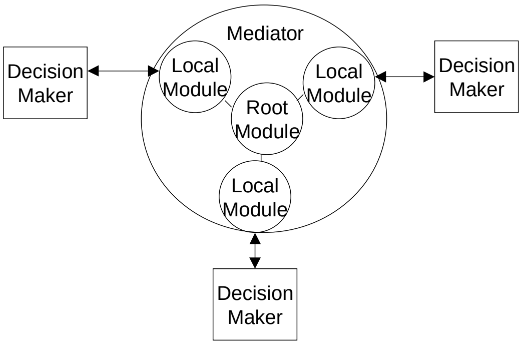

Fig. 3: Decentralized architecture of the Mediator.

The presented approach is based on several developments both in research and technology. The approach builds upon the previous research about negotiation (Davis and Smith 1983), scheduling (Baker 1998), and mediation-based systems (Cutcovsky 1993, Maturana and Norrie 1996). The Mediator of this study combines selected features of these earlier approaches. The novel XML-based integration tools are expected to provide suitable implementation mechanisms particularly for the communication needs of the Mediator.

3.2. Support mechanisms for decentralized negotiation

In order to support the order planning process the Mediator provides a Contract-Net-based negotiation mechanism (Smith 1980, Parunak 1987). This approach is based on the metaphor of an auction. The task owners announce their tasks, and the resource owners reply with bids. Finally, the task owners make their choices between bids.

The negotiation mechanism of the Contract Net has to be extended for usage in real applications. While in the basic Contract Net the resource owners have to accept the tasks as such, in a more flexible approach they can make counter proposals. In general, the resource owners need to adjust the time, cost, and content of the announced tasks. Limits to these adjustments can be set by application-case-dependent negotiation policy. However, one should note that this approach leads to more complicated iterative negotiations, because the task owners have no guarantee to be able to allocate their tasks in one negotiation phase.

The Mediator's role as a negotiation hub offers a possibility to make the negotiation a service for the task and resource owners. The Mediator can hold the data structures and run the processes of negotiations. The Mediator can also select suitable resource owners for the negotiations. In order to do this, the Mediator needs to have access to some data that characterizes the resource owners and to some rules that describe the logic to select them. As a consequence, the Mediator can make the negotiations transparent to the task owners.

The negotiation service of the Mediator becomes particularly useful when combined with other decision-support mechanisms. The scheduling and rule-based decision-making mechanisms described in subsequent chapters can be used to make some of the decisions during the negotiations. Furthermore, the Mediator may act as a monitoring broker.

3.3. *Support mechanisms for decentralized scheduling*

The co-operation of decision-making units in distributed scheduling is supported by the Mediator in interaction with local systems. The scheduler provides mechanisms for a rough finite capacity scheduling. Different scenarios can be simulated and evaluated by a set of pre-defined rules. Each actor in the order planning process can use a scheduling module for different purposes.

On the task owner's side the manufacturing orders of a production order can be planned sequentially, if the manufacturing orders are dependent, or in a parallel way by using forward or backward planning, if they are independent. Here, the evaluation mechanisms of the scheduler are used to compare and combine different order responses.

A resource owner can use the module for preliminary scheduling of new orders. In order to find a nearly optimal schedule different scenarios can be generated and evaluated before the resource owner responds to the task owner's order request.

In the scope of this approach the definition of resources is scaleable. A resource can be a manufacturing site, a department of a site, a supplier, or an external site. Detailed scheduling below this level is done by using local systems when the order is actually allocated to the site.

For a prototype implementation extended priority rules are used in order to be able to meet the requirements for decentralized scheduling. Due to their simplicity priority rules are commonly used in the industrial branch for solving the resource allocation problem. Apart from time-based priority rules (like earliest due date, least slack, or shortest processing time) cost based rules and rules that consider the importance of an order are also used. With the help of cost-based rules costs that are directly related to the order as well as resource-related costs for machines and personnel can be taken into consideration.

Fig. 4 gives an example of decentralized scheduling with support of the Mediator. A task owner can use a sales interface to plan new orders (cf. chapter 2.1). The order specification including due dates or maximum costs is sent to the Mediator. The Mediator selects two sites (A and B) as appropriate production sites and sends an order request. Then, the current rough schedules of the sites are loaded to the Mediator. The local scheduling modules (for site A and B) calculate preliminary schedules which are used to send an order response back to the sales site. The Mediator can process the responses according to pre-defined rules (see chapter 3.4). The scheduler for the sales site is used to evaluate the order responses and to maintain a master schedule for the production order.

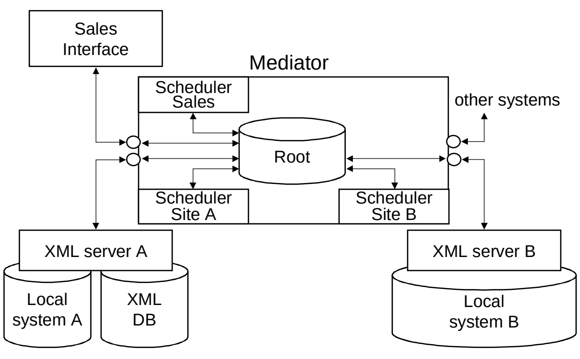

Fig. 4: Use of decentralized schedulers

The production planning and control mechanisms of local systems are not replaced but rather extended and integrated by the Mediator. Basic PPC functionality like process planning or material planning remains to be carried out by local systems. In order to allow for an easy and efficient access to local systems an XML-parser is used for data transfer. Rough level order data can be stored in a separate XML database which is permanently being synchronized with the local system's database. Moreover, XML is the communication standard for internal data exchange between the modules of the Mediator and the scheduler.

3.4. *Other support mechanisms*

Another support mechanism for decentralized decision-making is the use of rules which can be viewed as the automatic logic part of the Mediator functionality.

The use of rules supports the business processes described in the previous chapters: first, in order planning by filtering the resources where orders could be processed; and second, in order monitoring, by selecting the decision-making units that should be notified when an event occurs. Those roles are stored in the Mediator database and can be easily created, modified, or deleted, either by the local decision-making unit or by the Mediator in a learning process. The Mediator has a rule engine, which is started whenever rule handling is needed, and which accesses the rules database and applies it to the current situation.

In this approach Microsoft Excel is used to handle the rules inside the Mediator because Excel formula language is a natural choice for implementing the rule

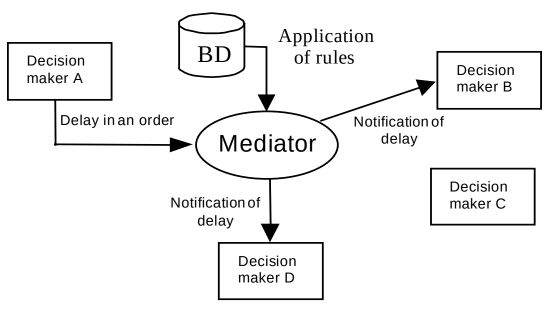

Fig. 5: Application of rules in order monitoring

definition language.

3.5. *Communication needs*

In a distributed environment, the autonomous entities co-operate in order to improve their global manufacturing performance, forming a wide and distributed decision-making and decentralized scheduling system. The definition of a communication system that supports the co-operation and exchange of data between autonomous entities is essential and a key factor to the success of the distributed system. In this environment, the data exchanged between distributed entities can be classified into two main classes: *business data*, which include commercial information, such as order (quantity, status, etc), customer and financial data, and *technical product data*, related to technical data associated with the product, such as geometrical and process data. The need for business data exchange becomes obvious in business and commercial transactions, and the need for technical product data occurs when a client wants to order a new product (which requires negotiation in the product design and definition) or when an entity goal is related to PDM (Product Data Management).

In the definition of the communication needs it is necessary to consider the mode of communication, which can be point-to-point, one-to-many, or broadcast. Other components defined during the communication model design were the protocol, i.e. the communication scheme between decision-making units for each sub-process model, and the vocabulary, i.e. the definition of the contents.

In the case of entities with different communication systems, it is necessary to use a standard communication language that makes transparent communication between distributed entities possible. The well-known communication standard is KQML (Knowledge Query and Manipulation Language) (Ferber, 1999), but other approaches are emerging, such as FIPA (Foundation for Intelligent Physical Agents) (Shen and Norrie, 1999) and ontologies (Ontology research group).

The data exchange format is one of the major problems associated with the distributed co-operation, in which it is necessary to guarantee that a target decision-making unit understands the meaning of data sent by other decision-making units. Normally, for the business data, an EDI (Electronic Data Interchange) format like EDIFACT is used; for technical product data the STEP (Standard for the Exchange of Product model data) protocol is used. However, these standards do not completely solve the data translation problem. In this case, XML is a promising approach that is regarded as the standard for the exchange of data. The XML format allows for tag definition reflecting the structure of the data, which facilitates the data exchange between different sources. The data is converted from the source format to XML in the middle-tier and then transferred to the target entities. The XML allows for designing tailored messages and extensions to the semantics. In this approach, the XML language is used to normalize the data exchange between the distributed decision-making units and the Mediator.

4. Applications of the Mediator-based approach

4.1. *Order planning in a multi-site case*

Some features of the presented approach are being piloted for order planning and monitoring in the case of a multi-site manufacturing company. The pilot case consists of three sales offices and three production sites located in different countries in Scandinavia. The main objective for the company in this pilot project is to enhance the transparency in their order planning and monitoring processes. Some of the products of the company are produced in several factories. In some situations this creates an opportunity of choosing a production site for a specific order or a part of it, based on considerations of efficiency. The redundant capacity in different production sites also offers flexibility for order planning. The objective of the Mediator in this pilot case is to provide a means of taking advantage of these opportunities.

The Mediator is used here as a broker between sales offices and production sites for fairly simple negotiations. The sales sites specify orders and request capacity for them from the Mediator. The Mediator has data about the production capabilities at different production sites. Based on this data the Mediator forwards the capability requests to appropriate production sites. It can also apply filtering rules in order to constrain the set of target production sites. The production sites respond, according to their real-time capacity situation. The Mediator collects the responses and passes them on to the sales site. At this stage the Mediator can apply rules for evaluating the alternatives.

The Mediator-based brokering scheme provides an effective and easy mechanism for transparent order planning in this pilot case. The production capability data that the Mediator uses for brokering is neither very large nor dynamic so that it can be maintained with a reasonable effort. In addition to capability-based brokering, further fine-tuning to the negotiation scheme is done with filtering and bid evaluation rules. The implementation of this pilot is carried out by WM-data Consulting Finland.

4.2. *Order allocation for distributed enterprises*

The order allocation process in the case of a group of manufacturers for bakery equipment is characterized by a heterogeneous IT environment at the production sites and a poor or even no IT support on sales' side. On the customer's site salesmen are planning orders which consist of single machines up to the complete design of a whole bakery where components can be supplied by different companies. In the current order planning process paper checklists are used for product configuration which are then sent by fax or post to the sales department. This process is time-consuming, cost-intensive, and error-prone. With support of the Mediator it is possible to co-ordinate activities between different actors and systems and to determine realistic due dates with fast rough level scheduling. This will reduce effort and errors and increase transparency in the order planning process.

The current production planning system is based on MRP 2 (Manufacturing Resource Planning) with time-consuming schedule calculations and a proprietary database. With support of an XML server it was possible to connect the system via the Internet to the Mediator and to use its decision-making and scheduling mechanisms. Due to the rough finite capacity planning it is supposed to achieve a considerable reduction of time and costs in order planning and to make the planning process more reliable.

The company intends to acquire further production sites that will be involved simultaneously in one customer order. Furthermore, the sales organization will change from regional orientation to product and system orientation. Theses changes increase the need of an efficient co-ordination of multiple heterogeneous actors by the Mediator.

5. Conclusions

In a wide and decentralized production environment, such as it can be found in extended enterprises, supply chains, and multi-site manufacturing, there is a need for mechanisms to support the decentralized decision-making in order to improve their production performance, based on the communication and co-operation facilities.

This paper presents a Mediator-based approach to support decentralized decision-making, focussing on the communication, negotiation, and scheduling processes. The approach provides a set of support mechanisms for decentralized negotiation, decentralized scheduling, and rules. The communication approach uses the XML language to support the decentralized decision-making, which allows for a transparent data exchange between distributed decision-making units and the Mediator.

The described approach is being piloted in two industrial application cases: one (in a multi-site case) focussing on the order planning, and the other focussing on the order allocation in distributed enterprises.

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