Decentralized Production-Synchronization Based On A Multi-Agent-Model

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1. Introduction

The Bremen Institute of Industrial Technology and Applied Work Science at the University of Bremen (BIBA) has developed a system for production-coordination in the shipbuilding industry to support the decentralization of production planning. The system development was topic of the ESPRIT MUSYK project sponsored by the European Commission and of the ITiS-E project, sponsored by the former BMFT (German Ministry for Research and Technology). This application, so called GIGROS, supports long- and middle-term production-planning of complex one-of-a-kind products.

Considering the involved software-systems concurrent manufacturing demands a transition from centralized towards increasingly decentralized models of control and action. Our goal has to be to support decentralized planning entities, each of them being equipped with a GIGROS-system. A main challenge is the co-ordination and synchronization of activities within those complex systems.

To improve the system according to the latest production paradigms, it needs be redesigned towards a multi-agent system architecture. By introducing concepts of distributed artificial intelligence, a cooperation of the modules or of several systems can be achieved to yield solutions for the simultaneous, co-operative and decentralized scheduling and resource planning.

2. A System for Production - Coordination

The special features of customer order processing in the production of complex one-of-a-kind products, e.g. ships, are the product individuality and the required production processes together with their corresponding dependencies.

Due to these characteristics, a separate, all-embracing concept for shipbuilding has evolved. In this concept, the harmonization of production and its activities with respect to time and content is given priority. Customer orders are handled as projects and the simultaneous production processes, their activities and the resource requirements are harmonized with multi-projects in mind. Based on this, a two-layered production coordination and control concept was developed. The concept consists of a decentralized independent planning and control level for autonomous production areas and a centralized planning and coordination level. This integrated concept enables the devolution of decision making to the lowest possible level of operational responsibility. Therefore, the planning activities of autonomous production areas are supported by decentralized shop floor monitoring and control (SMC) systems.

the chosen harmonization approach is made in the order of coordination concepts for one-of-a-kind production.

Due to the characteristics of one-of-a-kind

Harmonization / Harmonization by	horizontal	vertical
constrains		classical approach
feedback		centralised co-ordination
negotiation	decentralised synchronization	co-operativ co-ordination

Figure 1. Co-ordination Concepts for One-of-A-Kind Production

production [Kuhlmann95], a separate, all-embracing concept for the coordination of ship-building has evolved (see Figure 2).

This concept gives priority to the harmonization of production and to its activities with respect to time and content . Customer orders are handled as projects and the simultaneous production processes, their activities and resource requirements are harmonized with multi-projects in mind. Based on this and on the requirements

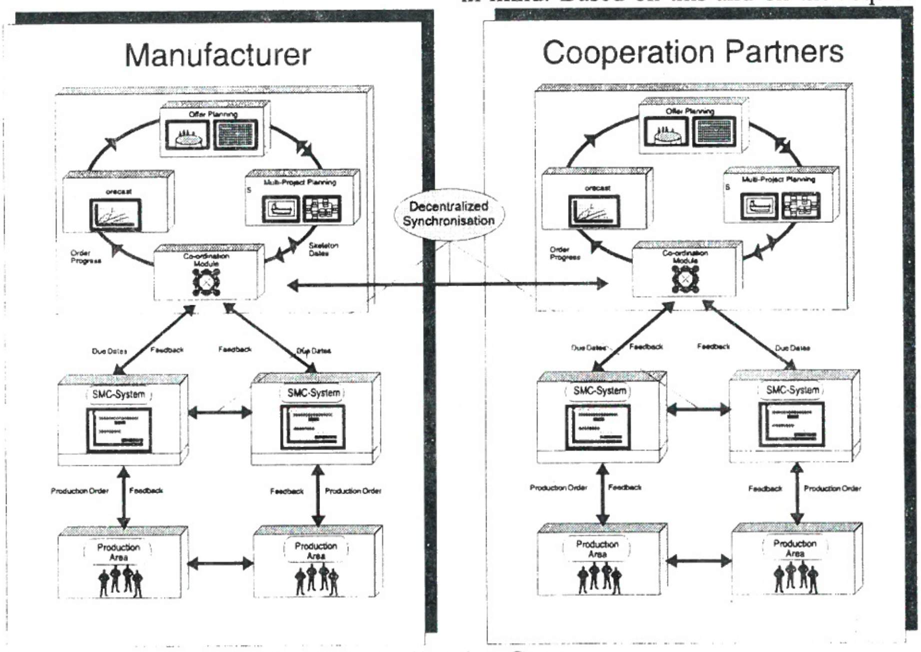

Figure 2. Co-ordination Concept

The vertical integration of the planning levels is realized by the coordination level joining the production area control level via closed control loops. This integration process is supported by a revolving planning concept. That means, planning and control activities will be started not by time intervals but by events. In Figure 1

defined in [MUSYK93], a production co-ordination and control concept was developed. This MUSYK approach developed for one-of-a-kind production makes the starting point for the ITiS-E project. Planning and coordination at the central level covers tendering and long- and middle-term planning of due dates and capacities. The autonomous decentralized production areas are supported by shop floor monitoring and control systems. They produce local planning optima that do not necessarily lead to an overall optimum. The aim of ITiS-E is to fill the gap between these two levels in concept and information technology by the implementation of a decentralized coordination level [ITISE94]. Rough planning, coordination and Production Control underlie the concept design.

2.1 Central Rough Planning Level

The central rough planning level tasks are bid planning, long -term scheduling and capacity planning, multi-project planning, and the customer order monitoring. Planning results of the rough planning level determine the decision scope at the coordination level. The main functions and tasks at rough planning level are outlined in the following according to [Kuhlmann95]:

- Customer-Oriented Scheduling: The central task at the rough planning level is the planning of customer related or specific dates and capacity demands. This involves the planning of all the associated production activities. The main goal is to ensure that the delivery date is met. In order to consider the complex interdependencies between activities, scheduling must be based on hierarchical, dynamic network plans.
- Capacity Planning: To check whether the schedule is realistic about production capacity constraints, the workload capacity needs be balanced. This has to be done by taking the multi -project situation into account. In this context decision is made , amongst others, on how to shift activities, to increase capacity, or consigned component production.
- Customer Order Monitoring and Prognosis: To make sure that set delivery dates are met and to observe the estimated capacity demands, a comparison of the current and planned situations is necessary to be aware of deviations and to estimate future order processing. In this way corrections can be made punctually.

2.2 Decentral Coordination Level

With the introduction of autonomous production areas and the associated distribution of disposition tasks, a demand for additional co-ordination arises, aimed at harmonizing planning activities in these areas. As a result of the decomposition of the planning problem only local optimization can be guaranteed; in order to optimize the entire system the results have to be transferred at the coordination level. The main tasks of the coordination level are:

- Subdivision of due dates given by the rough planning with respect to the autonomy of decentral production areas (Hierarchical Network Planning)
- Development of actual work order programs for decentral production areas (Modified Throughput Diagram)
- Equalization of capacity and work-load (Placing of Cooperative Orders, Shifting of Due Dates)
- Production spatial resource planning (SPR) over a middle- and short-term range (Interactive Graphical SPR with time constraints)
- The management of disturbances (Part Tracing, Pin Board) and
- The support of vertical (between central level and decentral production area) and horizontal (between decentral production areas) coordination (conferences)
- Communication between decentral production areas and with external cooperating partners.

2.3 Production Control Level

The main tasks at the production control level are sequence planning in the given buffers, the release, monitoring and control of manufacturing orders. There are no planning activities at this level that go beyond a production area. The production program for the control level is established by the coordination level and the production status information is returned. There will be a communication mainly between control and coordination levels, between production areas at control level only in case of foreseeable and unforeseeable unsolved due dates. Tools to support the control level — shop floor monitoring and control systems (SMC) — have to cover various requirements of a lot of production areas. These requirements will differ to the extent to which the type of production in each area will differ.

To support such a concept, as the today competitiveness asks for, the GIGROS system was developed. It can be seen as a collection of several independent software modules operating on the same database. The development of the centralized and cooperative coordination modules is over and the system is being implemented at a shipyard in Germany with the organizational structure shown in Figure 3.

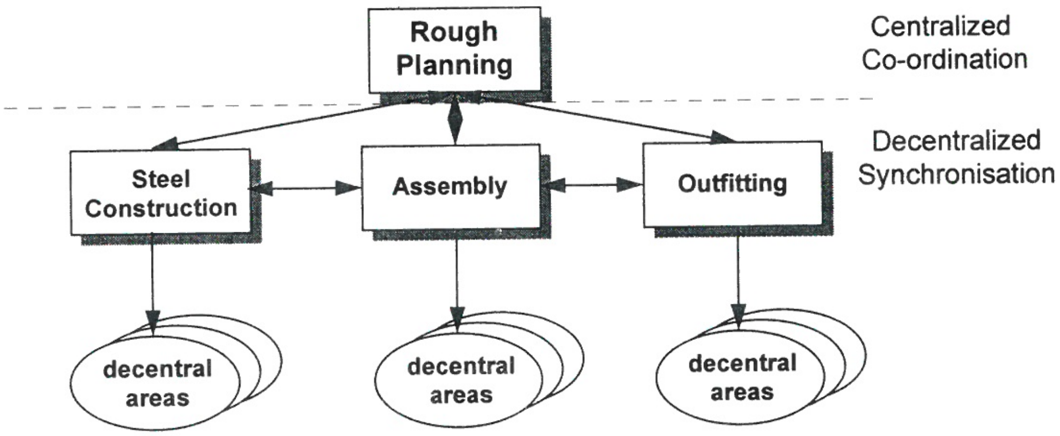

Figure 3. The Organisational Structure

2.4 Centralized Coordination Module

The analysis of the production planning and control process reveals the gap between the centralized multi-project planning and the control of autonomous production areas. A first approach to integrating different planning areas and to harmonizing the planning decisions is to implement a centralized coordination module.

A main requirement for the module is "the concentration on essential aspects" which means that to plan each job of a production order separately at the coordination level will not do. Consequently, the centralized coordination plans and controls, the so -called "blocks" e.g. jobs of an order belonging to a specific production area are aggregated. [Kuhlmann94]

As a matter of fact, the Centralized Co-ordination does not plan each resource mentioned in the process plan, but only the resource "production area", since production areas have a disposition autonomy fixed and exact dates are not available. The production areas acting like internal suppliers and their goods are well defined "Partial Products". A Partial Product is an assembly (or parts for an assembly) which is produced in one specific production area by performing blocks. Following the approach of manufacturing cells, the decentralized production areas are responsible for their Partial Products as regards due date, quality, and costs. [Kuhlmann95]

2.5 Cooperative Coordination Module

In the situations in which production areas cannot guarantee their due dates, i.e. in the case of plan deviations or unrealistic dates, a dialogue of the involved planning experts should take place. The aim of this module is not only to support such a cooperative harmonization strategy, but also to reduce expenditures on such coordination meetings by means of a CSCW-system. [Kuhlmann93]

The module itself enables the presentation of the current production plans of different planning units and the simulation of planning alternatives by the participants during a meeting. That means that the module can share the existing applications used for production management. During a session the involved planning experts can instantiate their respective applications as a server. The other participants get the application as a client window on their screens. In order to achieve shared applications the module uses a sharing framework which enables distributed interaction without any modification of the applications and with easy integration of new applications. [Kuhlmann95]

2.6 Decentralized Synchronization

Due to the increasing complexity inherent to the decision making process in a distributed production, extra effort has to be spent on the coordination of the activities between autonomous production sites involved in short-term cooperations. In order to achieve a harmonization of the activities between autonomous production areas based on negotiation, a third building block, the decentralized synchronization was introduced. Our approach to overcoming the information and coordination problems arising in a distributed production is to model the constituent parts as agents, each responsible for one or more activities, and each interacting with other agents in planning and carrying out their responsibilities. Such an approach is well suited to face and solve large and complex problems, characterized by physically distributed reasoning, knowledge and data management.The remainder of this Section describes the motivation for the development of that additional feature.

The responsible planner applies a planning-tool to solve planning-problems for a distinct set of activities. The project decomposition into activities is made by the project-manager during the rough-planning-phase. The activities are performed by workshops or external partners. The overall goal of all involved parties is to perform the production-process in a time-frame specified in the rough-planning-phase. But the stability of the schedule is changing over time. During the rough planning the schedule is relatively stable and a coordinator is able to create a schedule for the whole project. But in the course of time the stability gets feeble. Rough-planned activities are specified in detail by the responsible planners in the workshops and others are already performed so that the former planned dates are no longer valid. Another aspect is related with feedbacks from the workshop causing a continuous change of the schedule.

Local rescheduling can cause many problems, e.g. resource-lacks or violated time-frames. To solve these problems planners can apply a set of methods in order to harmonize the activities between the involved autonomous production areas:

- shifting activities within their computed time-buffer
- adding overtime to the resource
- substitution of resources with alternatives
- shortening of the activity-duration through the assignment of extra resources
- lengthening of the activity-duration through the withdrawal of resources

To manually apply these methods the planner has to have a certain degree of experience and the whole process will take some time. To simplify problem-solving, the GIGROS-system should offer an automatic application of these methods. If all these methods do not fit, the planner has to harmonize further actions with the other involved planners responsible for the successing or predecessing activities. The aspects mentioned before point to a demand for an additional building block for production synchronization. We call this building block an intelligent planning assistant. To actively support the decision making process the following functionality is required:

- Problem detection
- Suggestions for local problem-solving
- Cooperative elaboration of the problem- solving scenarios in cooperation with other assistants
- Suggestions to the user on how to solve the problem cooperatively

As a first step we have developed an appropriate agent architecture. The agents comprise the functionality to detect problems and to solve them cooperatively.

3. A System-Architecture Based On A Multi-Agent-Model

To allow an automatic synchronization of the activities among autonomous production areas, a third layer was introduced to achieve a horizontal integration of the production planning and control. Distributed artificial intelligence offers several approaches capable of improving the production-coordination-system. We decided to extend and redesign our GIGROS-system based on a multi-agent system approach.

The goal is to equip each production area with an agent capable to analyze the capacity demand and availability. In case of an overload or an insufficient capacity load this agent applies a set of strategies to solve his problem. If the problem cannot be solved locally, the agent will co-operate with his partners, i.e. the agents responsible for other production areas.

The base-functionality of the agent, implemented in the *Body*, represents the functionality and problem-solving-expertise of the module. The *Head* contains the knowledge about its own basic functionality, inter-agent communication facilities, and about functionalities and capabilities of other agents. It operates as a mediator between the base-functionality and the actual problems to solve. The *Communicator* enables the agent to cooperate with other agents. It has knowledge about the addresses of other agents and about how to access appropriate communication channels.

4. A Concept for Synchronization of Activities

Decentralized planning entities form a set of locally-controlled, asynchronous and concurrent processes interacting with an unpredictable environment. The decisions of the constitutes are based on local, imperfect, delayed, and conflicting information. Waldspurger et al [Wald92] refer to this collection of interacting processes as computational ecosystems. Miller and Drexler [Miller88] stated that the fundamental parallels between the problems of social and computational organization are strong enough to motivate the wholesale of importation of economic models and metaphors in the computational domain. Cooperative interactions among entities with diverse knowledge, skills, and goals can be effectively promoted on markets. In the Enterprise-system Malone [Malone88] proposes a task sharing among workstations based on such a metaphor of a market: processors send out „calls for bids" on tasks to be done and other partners respond with bids. The task is sent to the best bidder and cancel messages are sent to the other bidders. In this case „best bidder" means an agent offering a bid with the smallest estimated completion time.

An approach to bidding and awarding in distributed systems based on a negotiation-metaphor, the Contract Net Protocol (CNP), was first made by Smith and Davies [Smith88]. Such a net consists of a set of nodes that negotiate with one another through a set of messages. This approach is well -suited for our case because the agents have the same functionality and are able to make similar contributions. In a negotiation process an agent can find out the best cooperation partner.

In terms of the Contract Net Protocol the originator of a problem-solving-process acts as a manager performing the task announcement. At first the manager tries to solve the problem locally and then he evaluates possible solutions. If there are no solutions available he has to send an announcement to other agents asking for help. Due to the possibility of identifying the agents responsible for the precessing and successing activities the audience is restricted in order to avoid communication overhead. [Parunak87]

The potential contractors evaluate this request for bids. On finishing the evaluation, the potential contractor sends either a bid or a refusal back to the manager. A bid has to contain the price the agents wants to charge the manager in case of a contract. Due to the pricing mechanism a manager is able to compare the bids with his own evaluation and to choose the best offer. If one of the potential contractors offers a cheaper solution the manager chooses this contractor and sends the award. Such a pricing mechanism increases the flexibility by eliminating the need for complicating the system with artificial priorities.

Agents cooperate to achieve an overall goal. Usually this goal is to increase the effectiveness by minimizing costs, and to maximize the profit of the company. Due to this assumption agents have sometimes to accept local losses in order to optimize the overall performance. High price for performing a task means a local loss for the responsible assistant. But when this agent gets the award he will accept it. This approach ensures that the overall goal, the transaction of the whole project in the predefined time-frame, is not violated.

The determination of suitable prices has to take into account the following aspects:

- overtime premium
- alternative resources have different hourly rates
- costs for overtime
- change of production hours or piece work wages
- costs for additional communication

Parunak [Parunak87] pointed out that negotiation mechanisms were only worthwhile in systems subject to change. In the rough-planning phase the simple distribution of the global knowledge defined by the coordinator, i.e. the time-frames for the activities to perform, is sufficient. After that the schedule becomes more and more volatile. Negotiation offers a reasonable way to achieve a reasonable performance using the local knowledge of the agents.

An additional source for intensive communication is the fact that during the planning of a new project more or less all agents will detect capacity problems at the same time. The question is: who will start the problem solving and negotiation ? To avoid confusion an arbitrator-agent was introduced. If detecting a problem an agent will send a request for problem solving to the arbitrator. During a given time the arbitrator collects these requests and decides which agent will be allowed to start first. A strategy to make this decision would be to find out which one of the agents is responsible for the activity with the earliest start date.

5. Conclusion

The agent-architecture and communication protocols were developed for a first prototype. On applying the CommonKADS method we specified the application and problem solving knowledge of the future agents. The application knowledge was divided into domain, inference and task knowledge.

In general, communication can be realized by applying two approaches, i.e. shared memory (blackboard) and message passing [Albay93]. Due to the fact that our agents know exactly their partners, we chose the message passing approach. The communication protocol was based on KQML [Finin94] and implemented by applying a CORBA implementation.

If compared to any kind of manual production harmonization the multi-agent approach shows a significant benefit. The system has a reasonable performance, i.e. it takes two minutes to insert ten new production orders and to harmonize their capacity loads. A production order comprises approx. 20 activities, each of them requiring some resources. The activities are carried out by different production areas. In this test case three different planning agents, each responsible for an autonomous production area, were involved. However, due to the communication overhead, it is obvious that the performance corresponds to the number of involved agents.

Actually problem -solving, i.e. production harmonization, is made fully automatically. This is not appropriate for an implementation in a real life production environment because decisions are made by planners and the system should support the decision making process. To provide large assistance the system will be extended in order to make suggestions on how problems can be solved cooperatively. The user will be let to choose the best solution.

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