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A system architecture for holonic manufacturing planning and control (EtoPlan)

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Abstract

In this paper, we present the system architecture of a flexible manufacturing planning and control system, named EtoPlan. The concept is based on the holonic control approach of building multiple and temporary hierarchies (holarchies). This paper describes the system architecture for flexible planning and control of activities and (groups of) Resources in a manufacture-to-order environment. The system architecture consists of generic control modules that can be applied on different hierarchical levels and for different kinds of manufacturing activities. The main function of the Resource Controller is the Determine Applicability function. © 2002 Published by Elsevier Science Ltd.

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1. Introduction

In today's manufacturing industry, customers' influence is becoming more and more important in the planning and production processes. The still increasing influence results in huge complexity on the shop floor and a high variety of manufactured products. Various researchers in the field of manufacturing planning and control have recognized this, which led to research projects like bionic manufacturing control [1], fractal companies [2] and holonic manufacturing systems [3]. In this paper, the system architecture of a holonic manufacturing planning and control system, named EtoPlan [4], is presented. The concept is designed for this environment. A manufacture-to-order environment refers to either a make-to-order, or an engineer-to-order environment, or a combination of both. Manufacture-to-order environments are characterized by uncertainties in the information. These uncertainties are a result of randomness on the shop floor and the incompleteness of information due to not fully developed product specifications. For instance, processing times are not yet known in complete detail when macro process planning decisions are taken. In order to be able to cope with the uncertainties, a manufacturing planning and control concept, which is able to deal with dynamic production and planning situations, is required.

The first part of this paper briefly discusses the EtoPlan concept. The basics are discussed and the interactions between the different entities are recognized. The second part of this paper deals with the design of the holonic system architecture. In this part, the functional design of the control modules is defined. The exact function of all control entities is determined in order to be able to allocate the different authorizations or decision competences. The design of the system architecture results in a control concept that makes concurrent engineering and integration of engineering and planning processes possible.

2. The concept

The EtoPlan concept is based on an Information Management concept [5] for handling all the information-processing activities within the company. Uniform information structures for Resources, Orders and Products have been developed to integrate the execution of the various engineering and production planning processes.

The Order Information Structure deals with all the activities concerning the manufacturing process. This means that besides production activities on the shop

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floor, both the planning activities (technological and logistic) and the supporting activities are dealt with by the EtoPlan concept. Supporting activities can, for instance, be maintenance activities, tool assembly activities or cleaning activities. Like the Order Information Structure that deals with the activities, the information about (groups of) Resources is managed by the Resource Information Structure.

2.1. Temporary hierarchies of applicable resources

The concept aims to recognize the probable occurrence of planning problems as early as possible. Several aggregation levels in the planning process are applied to reach the tactical goals while, at the same time, dealing with short-term control issues [6]. This approach should prevent the undesired situation of too much replanning work by avoiding too much detail in the earlier planning phases. After all, the production environment is too dynamic to directly plan newly entered orders in a detailed manner. Besides, detailed information often is not even available in the early planning stages.

The procedure of building temporary hierarchies is as follows. In a manufacture-to-order environment, a client order enters the company and initiates engineering activities, which result in various suborders that are subsequently planned and/or executed by the company. In this way, a hierarchical order structure is built up. In order to deal with a large variety of orders, these temporary hierarchies are built by dynamically grouping Resources that are matched to the hierarchical order structures. The Resources are temporarily grouped according to the requirements of individual activities to be planned. For each activity, a unique group of applicable Resources (an Applicability Group) is drawn up. A Resource is considered to be 'applicable' for executing a given activity if it is as follows:

- the Resource is capable of meeting the already known technological requirements in the roughly defined process plans for executing the activity, and
- the Resource is considered to be available during a period of time that is roughly planned for executing the activity.

An AG is defined as the group containing all the Resources that are 'applicable' to execute a given activity. Depending on the complexity of the product or production process, the number of aggregation levels in the hierarchy will differ. An example of an AG and its Child-AGs is depicted in Fig. 1 and 2.

The method of building multiple and temporary hierarchies of AGs imply that Resources are a member of multiple AGs. Therefore, it is of utmost importance to define the interaction between the control modules of the Resources (Resource Controllers) and the AGs (AG

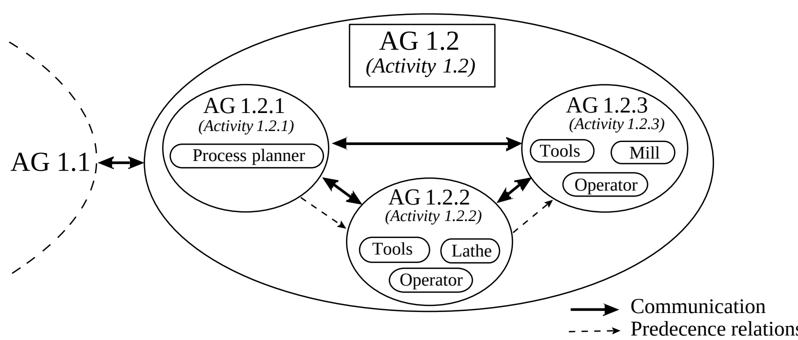

Fig. 1. A part of a hierarchy of AGs [4].

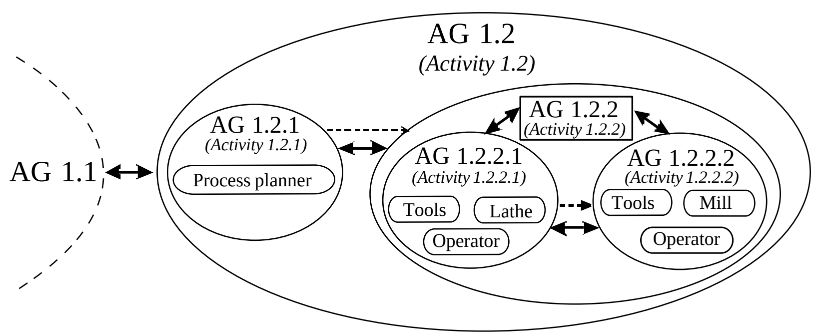

Fig. 2. A hierarchy of AGs with an extra aggregation level.

Controllers) properly. Control modules can interact with each other in several ways. These are the following:

- vertical interaction, child–parent relations between AG Controllers,
- horizontal interaction, interaction between AG Controllers with the same parent-order,
- bottom-up interaction via the Resource Controllers.

The latter case is discussed in Section 3.2. In order to prevent an overload of control communication—which may happen if AG Controllers interact with too many other AG Controllers in the system—it is necessary to define the ways of interaction between AG Controllers with different Parent-AGs. In the next section, only the first two cases are discussed.

2.2. Communication in the EtoPlan concept

In this section, horizontal and vertical communication in the EtoPlan concept are discussed. The first situation is illustrated in Fig. 1. AG 1.2 has created three Child-AGs; AG 1.2.1, AG 1.2.2 and AG 1.2.3. AG 1.2.1 is a process-planning group, which plans the activities for the workstations, AG 1.2.2 and AG 1.2.3. The three Peer-AGs communicate directly with each other. This is an example of all Child-AGs communicating in a horizontal way. As said before, a large extent of horizontal interaction may cause an overload of information flows.

If an additional aggregation level is added in the hierarchy, communication between the process planning AG and the other two is made via AG 1.2.2. This additional aggregation level centralizes the decision competence, which in this case reduces the information flows.

Still vertical communication may be required. Therefore, an adequate principle of communication must be applied to regulate the amount of communication between different control modules. In the next section, we suggest a principle of communication, which is based on minimizing the need for exchange of information.

2.3. The principle of communication

Communication between the control modules has to be defined properly in order to avoid an overload of communication flows. This can be done with the use of the communication axiom proposed by Kals et al. [7]. This axiom aims at minimizing the need for communication. In other words, only communication which is strictly needed has to established. In manufacturing systems, there are several constraints to be met in the communication between different entities. Local interpretation may drastically reduce the need for communication. Global goals are often laid up from higher levels, whereas local interpretations are often the result of horizontal information flows on a local scale. Therefore, vertical communication can be combined with horizontal communication. In this paper, we suggest the application of this principle of communication to control the communication flows between different control modules, yet still allowing a combination of vertical and horizontal communication.

3. The design

The design of the system architecture for the EtoPlan concept consists of two main control modules: the AG Controller and the Resource Controller. Fig. 3 shows the position of the AG and Resource Controllers in the framework of the control structure. The AG and Resource Controllers are further described in Sections 3.1 and 3.2, respectively.

3.1. The AG Controller

The design of the AG Controller is based on the generic control building block as presented by Arentsen [8]. The building block is characterized by a functional division between on-line and off-line control and a division between feedback and feed-forward information handling (see Fig. 4). The four sub-functions in the AG Controller are Planning, Diagnostics, Dispatching and Monitoring.

The two functions in the off-line part of the controller are Planning and Diagnostics. On-line means that the considered time horizon coincides with the time horizon considered by the Planning and Diagnostics functions (off-line) of the lower level AG Controller. This means that the Dispatching function only dispatches those tasks in the workplan that can already be planned by the lower level AG Controller. The planning of all the tasks in the workplan that are to be executed later on still remains the task of the off-line Planning function of the

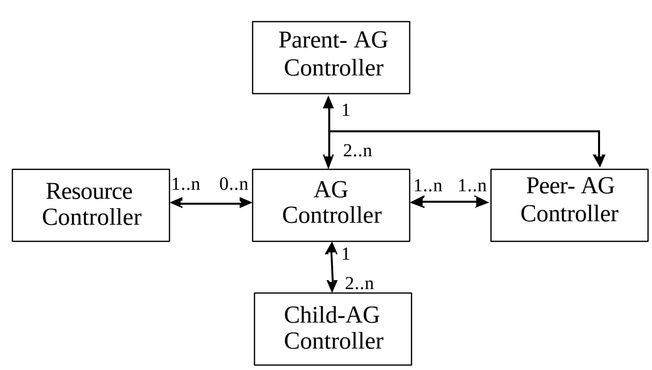

Fig. 3. The framework of the AG and Resource Controllers in the EtoPlan concept.

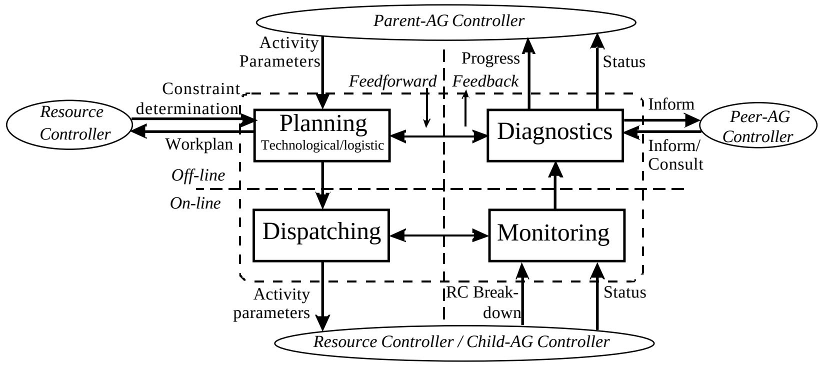

Fig. 4. Functional architecture of the AG Controller [9].

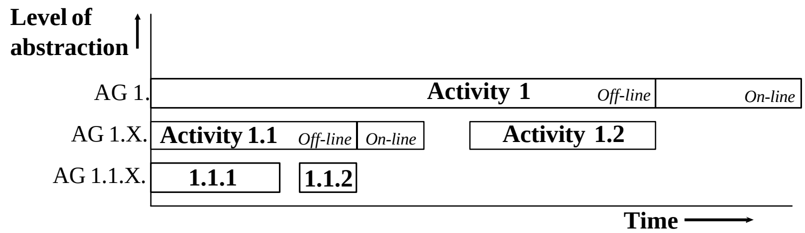

Fig. 5. Hierarchical order structure with planning horizons for three abstraction levels.

AG Controller. On the other hand, no planning activities can be applied for the tasks that have already been dispatched to a lower level AG; the lower-level AG Controller will execute them. In Fig. 5 the representation of a schedule with a decreasing time horizon is depicted.

The Planning function of the AG Controller consists of two sub-functions: technological planning and logistic planning. Technological planning deals with drawing up the product design and the process plans. The logistic Planning task of the AG Controller configures the Child-AGs and performs the in-time planning of these Child-AGs. The planning of the activities will become more detailed on the lower aggregation levels. The planning task is performed on the basis of the activity parameters received from its Parent-AG, the information from the Resource Controllers and the feedback information from the Diagnostics function.

A part of Logistic Planning of an AG Controller is the allocation of the Resources (Child-AGs) to the sub-activities. The procedure is as follows. A workplan is generated by the AG Controller and sent to the Resource Controller. On the basis of this workplan, the Resource Controller can determine whether it is possible to execute the activity. The Resource Controller can approve the workplan, reject it, or it can propose a change in the time constraints. The AG Controller will subsequently plan the activity in more detail on the basis of the mentioned feedback information from the Resource Controller(s) (see also Sections 3.2 and 3.3).

The configuration of a new Child-AG is an important task of the Planning function. This task does not solely consist of selecting the available and applicable Resources, but of determining whether an additional aggregation level in the hierarchy is needed as well (see Fig. 2). In fact, configuring a new AG corresponds with the planning of activities on Resources.

The Planning function solves problems in the case of a planning conflict. A new plan is sent to the Resource Controller when the problem is solved. It may be possible that the AG Controller has to consult Parent-AGs to solve the problem. It may also be possible that a solution inflicts a subsequent activity (controlled by a Peer-AG). In this case, the Peer-AG has to be informed about the consequences of the changed plan. The decision to inform or consult a Peer-AG is made by the AG Controller with the use of the aforementioned principle of communication axiom.

An alternative solution has to be found if no feasible plan for a given activity is possible within the current constraints (e.g. due to Resource unavailability). In that case, the Planning function of a higher level AG has to create the solution for the conflict.

The Diagnostics function is provided with information from Monitoring and Planning. Its main tasks are to interpret this information and determine its consequences. With this interpretation the Diagnostics function can decide which other control modules are to be informed. The three parties possible are:

- the Planning function,
- the (Parent-) AG of which the entity is a member (horizontal communication), and
- a Peer-AG (vertical communication).

Depending on the consequences, the Diagnostics function has to choose. For instance, if a problem does not affect the plans of other AGs or Resources, then Diagnostics may only have to inform the Planning function in the same controller. If a problem has larger consequences, which may inflict other activities, then Peer/Parent-AGs may have to be consulted. The decision which denotes the controller to be informed is an important task of the Diagnostics function. The use of the principle of communication, mentioned in Section 2.2, can be applied in the same way as explained in Section 2.3.

To be able to maintain control over the manufacturing process, information about the status of an activity is essential. This information is gathered by the Monitoring function. The status reports, which are sent from the Child-AG and Resource Controllers, represent this information to the Monitoring function. The Monitoring function rearranges the information and sends it to the Dispatching function and the Diagnostics function. On the basis of this information, the Dispatching function can change the dispatching of the activity parameters to the Child-AG Controllers or the Resource Controllers. If the impact of the disturbances reported to the Monitoring function is too big, then the off-line function of the AG Controller (Diagnostics and Planning) must handle the problem (as described above).

3.2. The resource controller

In this section, the four functions in the Resource Controller are discussed. In Fig. 5 the layout of the Resource Controller is depicted. As mentioned before, a Resource can be part of multiple AGs. This implies that different AGs can plan activities on a Resource. The fact that a Resource is a member of multiple AGs makes it difficult if not impossible for a Resource to plan these activities by itself. The AG plans the activity. The task of the Resource is to determine whether it (still) is a member of an AG. This is done by the Determine Applicability function. With the workplan sent to the Resource Controller by the AG, the Resource Controller determines the applicability by sending back the constraints. If the constraints do not match the requirements of the AG a Resource is not applicable. As mentioned in Section 2.1, applicability will be determined by technological and logistic constraints. Requirements (technological or logistical)—as a result of the concurrency of the manufacturing process—become more specific as the amount of information increases.

The presence of a Diagnostics function is required, because the status, which is reported by the Monitoring function, must be interpreted. The interpretations of status reports can, for instance, consist of a Resource failure or a mean-time-to-repair report. This can be important information for the Parent-AG. The Diagnostics function communicates with the on-line part of the AG, in particular the Monitoring function of the AG Controller. If a problem affects the planning, the

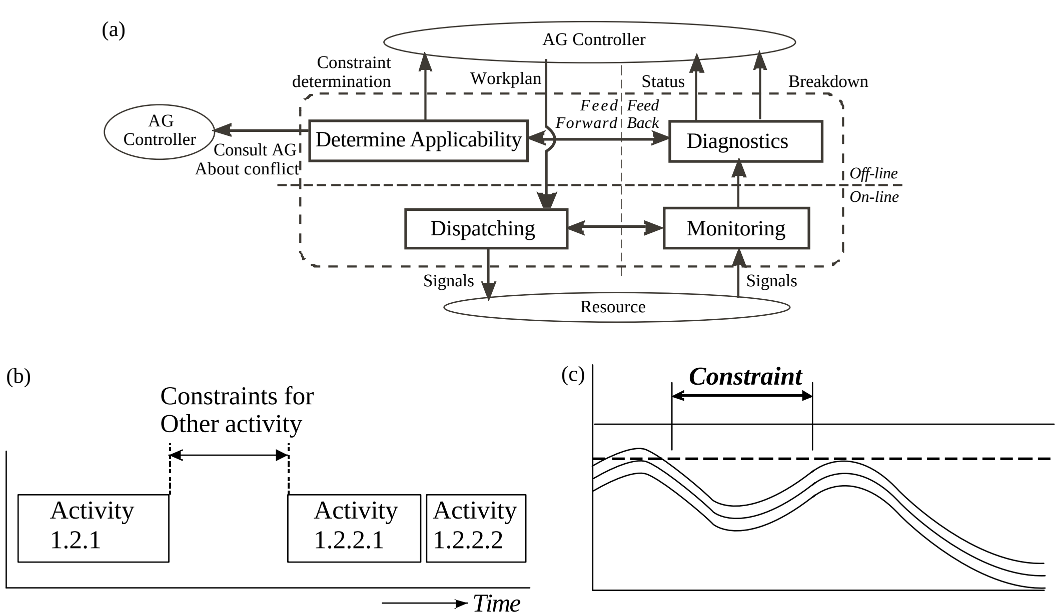

Fig. 6. (a) The Resource Controller [9], (b) a schedule for a Resource, and (c) a Resource loading profile.

Diagnostics function has to report this to the Determine Applicability function as well, since it may be possible that the Resource is not applicable anymore.

3.3. An example of logistic planning

In this section, an example is given of the procedure of checking the logistic applicability. As mentioned before, a Resource can be a member of multiple AGs. To determine this membership the Resource Controller is equipped with the Determine Applicability function. This function determines the applicability constraints. Logistic constraints can be represented in a schedule or a loading profile.

For instance, consider the operator from Fig. 2. In this example, the operator is a member of another AG as well. The schedule for this Resource (the operator) can be displayed as depicted in Fig. 6. More information is generated as the planning process progresses. This additional information can change, in most cases, by narrowing the time interval in which the AG wants to execute the (other) activity. If the constraints, provided by the Resource Controller (operator), do not match with the time interval (workplace if technological parameters are also considered, see Fig. 6) of the AG, then the Resource becomes inapplicable for the other activity. In some cases, even replanning of other activities may be required. This can be the case if, for instance, a high priority activity has to be executed.

This can also be done with Resource loading profiles, yet these profiles will be used to determine the logistic applicability in the long term. This constraint and applicability determination can also be executed for determining the technological applicability.

4. Concluding remarks and future research

In the manufacture-to-order environment, production plans can only be drawn up and executed successfully with the use of a planning and control concept that provides, on the one hand, predictability and stability and, on the other hand, flexibility and fault tolerance. The system architecture presented in this paper provides a functional structure for a computer application, which enables the planners to cope with logistic and technological planning problems on multiple levels of aggregation. In the proposed system architecture, the interaction between the AG Controller and the Resource Controller is defined. The communication between these control modules can be optimized with the use of the principle of minimizing the need for communication presented in Section 2.3. The suggested architecture provides—as part of the discussed manufacturing planning and control concept—a sound base for extending the prototype implementation [10]. In the future, this research project will focus on methods to deal with uncertainty in manufacturing planning. We will focus on mathematical methods to generate robust plans for capacity planning.

References

[1] N. Okino, Bionic manufacturing systems. In: J. Peklenik, editor. CIRP flexible manufacturing systems past–present–future, 1993. p.73–95.

[2] H.J. Warencke, Die Fraktale Fabrik, Revolution der Unternehmenskutltur. Springer, Berlin, 1992. ISBN 3-540-55200-6.

[3] L. Bongearts, J. Wyns, J. Detand, H. van Brussel, P. Valkenears. Identification of manufacturing holons. Proceedings of the European Workshop for Agent-Oriented Systems in Manufacturing, Berlin, 1996.

[4] M.M.T. Giebels. EtoPlan a concept for concurrent manufacturing planning and control. Ph. D. thesis, University of Twente, Enschede, 2000. ISBN 90-365-14533.

[5] D. Lutters, E. ten Brinke, A.H. Streppel, H.J.J. Kals. Design and manufacturing processes based on information management. Proceedings of the 15th International Conference on Production Research. Limerick, 1999. p. 1375–78. ISBN 1-874653-56-9.

[6] R. Washington. Abstraction planning in real time. Ph. D. thesis, Department of computer science, Stanford University, 1994.

[7] H.J.J. Kals, D. Lutters. The role of information management in intelligent manufacturing. Proceedings of the CIRP International Conference on Intelligent Computation in Manufacturing Engineering, Capri, 1998. p. 21–8.

[8] A.L. Arentsen. Ageneric architecture for factory activity control. Ph. D. thesis, University of Twente, Enschede, 1995. ISBN 90-9008660-9.

[9] G. Wullink. Towards decision support in a manufacture-to-order environment. M. Sc. thesis, University of Twente, Enschede, 2000.

[10] M.M.T. Giebels, H.J.J. Kals, W.H.M. Zijm. Implementation of an engineer-to-order manufacturing planning system (EtoPlan). Proceedings of the Ninth International Conference on Flexible Automation and Intelligent Manufacturing, FAIM'99. Tilburg University, Tilburg, 1999.