Improved logistics performance through the use of locked flexibility potentials

K. Windt[1], O. Jeken[1], F. Arbabzadah[1]

[1] Jacobs University Bremen gGmbH, Campus Ring 1, 28759 Bremen, Germany

Abstract

Further enhancement of the logistics targets achievement can be attained through development and use of so far locked flexibility potentials. Product structures with many variants allow for additional flexibility potentials due to the fact, that one component can become a part in one of many different final products variants for different customers. The challenge of this approach is to enable products to decide autonomously about their production processes. Hence, this paper will introduce a concept of an autonomous product and analyze the methodical requirements for decentralized decision-making. Based on these requirements the paper will present a method for autonomous components to generate decision alternatives concerning their life cycle during the manufacturing process.

Keywords:

Manufacturing, Control, Autonomous products

1 INTRODUCTION

Nowadays production planning and control systems are already able to cope well with tradeoffs between the different logistics targets: low work-in-process, high capacity utilization, short lead time, and high due date reliability [1]. However, ambitious customer requirements e.g. highly customized products, short delivery times and ever faster changing boundary conditions call for new concepts, which are able to cope with these challenges [2]. One proposed way to enhance the logistics targets achievement further is to increase the level of autonomous control [3]. In order to increase the level of autonomous control it is necessary to enable logistics objects to generate and evaluate different decision alternatives, in order to select and execute the best alternative according to their target system [4]. Within manufacturing systems, one can consider products as intelligently acting objects that decide about their production process by themselves. In order to enable these objects to generate different decision alternatives the level of flexibility within manufacturing systems needs to be increased. Manufacturing flexibility serves as a provider for decision alternatives as it offers several options to perform a manufacturing process.

The paper is structured in the following way. Following the introduction, section 2 will introduce the meaning of manufacturing flexibility in the context of autonomous control. Section 3 will introduce the concept of an autonomous product and analyze the methodical requirements for decision-making. Based on this fundamental understanding of autonomous control section 4 will present a method for autonomous products to generate decision alternatives during the manufacturing process.

2 MANUFACTURING FLEXIBILITY AS AN ENABLER FOR AUTONOMOUS CONTROL

2.1 Manufacturing flexibility

Even though manufacturing flexibility is a much explored topic no consistent definition can be found in literature (see for example [5]). Furthermore, there are different attempts to classify the various types or dimensions of manufacturing flexibility (see for example [6], [7], [8]). A newly discovered type of manufacturing flexibility named allocation flexibility was defined and classified in [9]. The discovery of this new type of manufacturing flexibility demanded for an assessment of already described types of manufacturing flexibility and resulted in a new framework of manufacturing flexibility types. Based on the fundamental elements of a manufacturing system i.e. orders, resources, and products the different types of manufacturing flexibility were structured and classified. Table 1 shows the catalogue of manufacturing flexibility types. Resulting from the different flexibility types, degrees of freedom can be formulated to operationalize manufacturing flexibility. Based on the degrees of freedom provided in the catalog multiple decision alternatives can be generated in order to increase the level of autonomous control.

Level	Element	Flexibility Type	Degree of Freedom
Logical	Order	Allocation flexibility	convertible orders
Physical	Resource	Machine flexibility	different operations
		Material handling flexibility	multiple system paths
		Volume flexibility	workload variation
	Product	Operation flexibility	different processing plans

Table 1: Catalog for manufacturing flexibility types [9].

2.2 Autonomous control

To unlock flexibility potentials in the manufacturing process is a precondition for a successful implementation of autonomous control strategies. Within the Collaborative Research Centre 637 "Autonomous Cooperating Logistic Processes: A Paradigm Shift and its Limitations" in Bremen, Germany, autonomous control methods are investigated with the aim of developing logistics potentials resulting in a higher achievement of the logistic objectives. For logistics systems, autonomous control is defined as "… the ability of logistics objects to process information, to render and to execute decisions on their own." [4]. Based on this definition the following requirements are formulated: The object needs to have the technological capability for a unique identification and to communicate with its environment. Furthermore, it has to have the methodical capability to use the complete flexibility potential for decisions making. A current approach to fulfill the technological requirements is to implement RFID tags in the cast process of a product [10]. This paper will address the methodical requirements, namely decision making of autonomous products.

3 AUTONOMOUS PRODUCT DECISIONS MAKING

3.1 Concept of an autonomous product

In the context of a typical job-shop manufacturing scenario the concept of an autonomous product means, that a product has the capability to route itself through the production process. Hence, it has to be able to decide by itself:

- about the next production process step,
- according to which product variant,
- on which machine it gets manufactured, and
- for which customer order it gets manufactured.

These decision alternatives are especially available for product structures with many variants, as one component of a product can become part of different final products variants for different customers. Which final product variant is favorable depends on current demand and production situation.

Based on the upper mentioned framework for manufacturing flexibility types and the resulting degrees of freedom in manufacturing systems a so-called product variant corridor can be determined. The product variant corridor provides each single item at any time with the current combination of product variant and customer order.

3.2 Methodical requirements for decision making

The process of decision making is generally divided in five sub processes: (i) problem description, (ii) definition of target system, (iii) generation of decision alternatives, (iv) evaluation of decision alternatives according to target system, and (v) execution of the decision alternative with the best target contribution [11]. In case of autonomous decision-making in manufacturing, the problem in question is to decide about the next production process step. As earlier mentioned this step includes not only the production step according to the targeted product variant itself, but also available resources (machines) and current demand (customer orders).

While some of the in the introduction already mentioned targets support each other (targets low work-in-process and short lead-time), others are contradictory (work-in-process, high capacity utilization). For a target system the different targets have to be weighted. A weighting of the different targets can to be derived from the strategic positioning of a company (for example differentiation vs. costs according to Porters generic strategies [12]). The process of decision alternative generation plays a crucial role in the context of autonomous control, as the autonomous product has to gather the required information from its environment. In order to generate decision alternatives the product has to know the different possible production processes and the resulting final product variants. Furthermore, it has to know the accessible machines for the different available production steps.

For the evaluation of the different decision alternatives, the product has to be able to collect information about the current situation at the available machines (e.g. machine breakdowns, work-in-process level in front of machine). In order to avoid on stock production and to react to market dynamics, the product has to know the current demand situation as well.

In order to execute the selected decision alternative the product has to communicate the decision to the material flow system, which then organizes the necessary processes.

4 PRODUCT VARIANT CORRIDOR IDENTIFICATION

In order to set up the product variant corridor a feature graph has been developed to display all decision alternatives of a part or component for each manufacturing step. Furthermore, since the result of the production process is not predetermined anymore, it is necessary to detect possible outcomes (variants) for a product during its production process in real-time. To do so, an algorithm has been developed which determines possible final products instantaneously for each production step. Hence, the product variant corridor represents the range of possible production decisions alternatives and matches them with final possible product variants and actual customer orders. This loose allocation of to be manufactured products and confirmed customer orders unlocks additional flexibility. Before explaining the feature graph and the product matching, the required terminology will be introduced briefly. To differentiate between characteristics of a product and capabilities of different machines, the terms feature and operation are defined. A feature is a property that is added to a product (painting, mounting a device, etc.). Different operations on different machines can lead to the same feature, therefore the relation of operations to feature is n:1. Features can have different specification (i.e. feature paint has the specifications red, blue etc.). Machines can perform different operations, which ultimately lead to a feature. An order represents the external demand. It specifies product variant and due date for the production, but is allowed to change these. A product is a partially ordered set of features. Some of the features can be added in an interchangeable order. Differing elements in the set of features lead to different products. A product variant is a set of features where some features have slightly different specifications compared to the set of features of another product. For example, the feature paint can have different specifications (colors). Thus, products with an identical feature structure but different characteristics in some features are said to be variants.

4.1 Feature graph

To implement the product variant corridor identification method a feature graph is created to model the different ways of obtaining features. As the product has to be able to decide on its own about the next production step, the feature graph is based on a bottom-up product structure. In contrast to typical product structures the feature graph starts with the raw material or the semi-finished part and ends with the final product or the subassembly. Each path through the graph leads to a specific product variant.

Nodes within the feature graph represent features. Through the separation of features and operations, the decision process of the part can be applied to different factory layouts, as long as the required features can be obtained on the machines. The part moves based on the graph through the available machines.

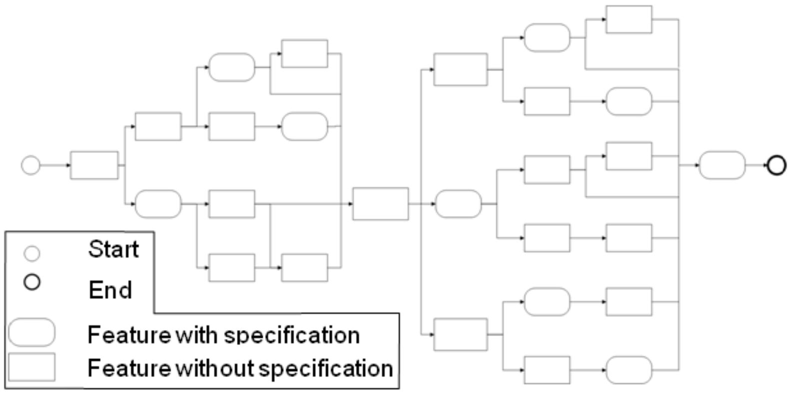

Figure 1: Feature graph for autonomous product decision-making.

4.2 Product matching

Notation

In order to determine the possible outcomes from the product's production status, a notation has been developed that enables matching products with predefined product descriptions. The aim of this notation is to represent as many sequences of features that belong to the same product as possible. Assuming that a product is created by addition of several features, it is possible that a group of consecutive features can be added in an arbitrary order. Either one notes down all the possible sequences with the permutations of these features, or one reduces the number of sequences by representing the permutations as a class of permutations. If the permutations are represented as a class, one single string contains all possible sequences that lead to the same product.

Each process has an associated feature number. This feature number is a unique identifier for the feature that is obtained through this process. Different processes can produce the same feature and the same process can lead to different features.

The feature number is supplemented by a feature specification. The specification determines which product variant will be produced. Features that do not have different variations do not have any further specifications.

A sequence of feature numbers separated by commas represents the order at which the features are added to a product. A product within the production process has a sequential list of features that have been added to it, which represents its current production status. This list of currently added features can be compared to complete product descriptions in order to identify the possible outcomes.

However, in case of a changed order at which the features are added to a product, the mere matching of sequences fails. Therefore, it is necessary to develop a method that identifies products correctly, based on their sequential list of features. The permutations can be reduced to their permutation classes, hence the sequences 1,2 and 2,1 can be represented by [1,2] which denotes the set of all permutations of the elements in the brackets.

For that purpose the following notation for product matching strings has been developed. The key element of this notation are commutator brackets [ ]. The features within these brackets can be applied in the order of any of their possible permutations. Thus instead of matching the product status with all possible permutations of the matching string, one only has to identify whether the order in which the features were added to the product, matches the product description with a permutation. As the number of permutations increases in a factorial manner, the number of possible matching sequences quickly becomes very large, however this notation reduces the number of matching strings significantly. In order to utilize this notation the following product matching algorithm is used.

Algorithm

In order to identify possible production outcomes, the algorithm compares the product's production status feature list with a list of predefined product description strings. Initially the product can become every final product variant and thus matches all product variant descriptions. Every time a new feature is added, only the product matching strings corresponding to the list of possible products on the product in production is used for comparison. Furthermore, not the entire sequence on the part is compared, but the elements at the last positions in feature list of the product and the feature in the corresponding position within the product matching string. The product matching string is represented as a nested array.

When a feature is added to a product, the matching algorithm compares all matching strings for the products listed as possible products on the product in production. For each matching string, the algorithm has an indexing array, which returns the array position needed to be accessed in order to find out whether the feature added to the product is at the right position. In the example illustrated in Table 2 the fourth element has the index 3, thus the algorithm will now access the third element (column) in the data structure. This column has two entries. The algorithm will then compare these two entries with the recently added feature and in case there is a match, the list of possible product outcomes on the product is stays the same. However, if the algorithm finds a mismatch this product is deleted from the list of possible product outcomes. That way the algorithm excludes more and more possible product outcomes, the further the production processes has progressed.

matching string	data structure						access indices							
1,2,[3,4],5,[6,7],8	1	2	3	5	6	8	1	2	3	3	4	5	5	6
			4		7									

Table 2: Product matching string with corresponding data structure and indexing.

5 CONCLUSION

In order to implement methods of autonomous control in manufacturing processes the level of flexibility has to be increased. Based on a framework for different types of manufacturing flexibility a method has been developed to use the full logistics potential. The method comprises a feature graph that represents the decision alternatives of an autonomous product and a product matching method that allows linking products with customer orders. By doing so, the paper has shown one step of implementing autonomous control in manufacturing.

6 OUTLOOK

In order to develop an autonomous control method for assessing the product variant corridor alternatives based on technological and logistical criteria a scenario generator will be developed. This simulation framework will be used to do experiments in order to study cause and effect relations between different autonomous control strategies and logistical target achievement. By doing so, it is aspired to develop and to enhance suitable autonomous control methods for different manufacturing scenarios. However, the implementation of autonomous logistics processes in production encompasses also restructuring of common production planning and control methods as processes of the planning level will be shifted to the control level. Implementing autonomous control into production processes requires certain degrees of freedom; therefore, capacity planning and order release cannot be conducted in the conventional way.

A new approach to order release and capacity planning has to be developed, taking into account the implementation of autonomous processes in production planning and control.

7 ACKNOWLEDGMENTS

This research is funded by the German Research Foundation (DFG) as part of the Collaborative Research Centre 637 “Autonomous Cooperating Logistic Processes: A Paradigm Shift and its Limitations” (SFB 637) at Bremen University and at Jacobs University Bremen.

8 REFERENCES

[1] Nyhuis, P., Wiendahl, H.P., 2008, Fundamentals of production logistics: theory, tools and applications, Springer, Berlin, Heidelberg, New York.

[2] Scholz-Reiter, B., Windt, K., Freitag, M., 2004, Autonomous logistic processes: New demands and first approaches, Proc. 37th CIRP International Seminar on Manufacturing Systems, Hungarian Academy of Science, Budapest, Hungary, pp. 357-362.

[3] Scholz-Reiter, B., Görges, M., Philipp, T., 2009, Autonomously controlled production systems - Influence of autonomous control level on logistic performance, CIRP Annals 2009 Manufacturing Technology, 58/1:395-398.

[4] Windt, K., Böse, F., Philipp, T., 2008, Autonomy in Production Logistics - Identification, Characterisation and Application, International Journal of Robotics and CIM, 24/4:572-578.

[5] ElMaraghy, H. A., 2006, Flexible and reconfigurable manufacturing systems paradigms, International Journal of Flexible Manufacturing Systems, 17/4:261-276.

[6] Sethi, A. K. and Sethi, S. P., 1990, Flexibility in manufacturing: a survey, The International Journal of Flexible Manufacturing Systems, 2/4:289-328.

[7] Shewchuk, J. P., Moodie, C. L., 1998, Definition and Classification of Manufacturing Flexibility Types and Measures, International Journal of Flexible Manufacturing Systems, 10/4:325-349.

[8] Koste, L. L., Malhotra, M. K., Sharma, S., 2004, Measuring dimensions of manufacturing flexibility, Journal of Operations Management, 22/2:171-196.

[9] Windt, K., Jeken, O., 2009, Allocation Flexibility - A New Flexibility Type as an Enabler for Autonomous Control in Production Logistics, 42nd CIRP Conference on Manufacturing Systems, Grenoble, France.

[10] Busse, M., Wöstmann, F.-J., Müller, T., Melz, T., Spies, P., 2006, Druckgussteile mit Köpfchen. Eingießen von RFID und Piezos macht Druckgussteile intelligent, Industrie Anzeiger, 13:44-45.

[11] Laux, H., 2007, Entscheidungstheorie, 7th Edition, Springer, Berlin, Heidelberg, New York.

[12] Porter, M.E., 1998, Competitive advantage: creating and sustaining superior performance, Free Press.