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THE OBJECT-ORIENTED PROCESS FLOW MODELLING
OF DISCRETE PRODUCTION SYSTEMSOBIEKTOWO-ZORIENTOWANY MODEL PRZEPIYU
PRODUKCJI DYSKRETNEGO SYSTEMU WYTWARZANIA

Abstract

The main idea of this paper is related to building of models allowing to visualise and examine some aspects of a discrete production system. Those models, which are simplified, artificial representations of real environment, constructed to facilitate off-line study of real objects or complex systems, will allow to test out in advance the impact of planning decisions and therefore avoid making wrong decisions and minimize the disruption to the real process. The idea of process flow model is based on the machining subsystem model, which has been worked out for describing only machining processes. The extension of that model is proposed in this paper. The new process flow model includes a description of materials flow as well (products, tools, tooling etc.), needed for manufacturing raw materials into finished products. Materials flow occurs between consecutive work stations or assembly stations and it concerns transportation, manipulation and warehousing of materials. So it is set a technological subsystem and a materials flow subsystem apart. An object-oriented models for these subsystems has been worked out. Whole production system is described as a set of objects, which consist of attributes. Each object has got a state space. A state space can describe single object, a pair of objects or a chain of objects. Between the objects, which are made up of a couple of objects, some relationships occur. An object state space can change under the influence of an activity sequence. Activities are divided into manufacturing activities model and auxiliary activities model. The second model consists of objects from materials flow subsystem. These objects influence other objects in production system by auxiliary activities realization, which change a state space of them by changing their attributes values. Auxiliary activities allow to make manufacturing activities. Auxiliary activities model is described in this paper.

Keywords: object-oriented modelling, production structure, discrete manufacturing system, discrete production systems

Streszczenie

W artykule przedstawiono koncepcję utworzenia obiektowo-zorientowanego modelu przepływu produkcji, aby możliwa była analiza pewnych kwestii, związanych z realizacją procesów produkcyjnych w dyskretnym systemie wytwarzania. Jako główny cel założono, że praca z modelem ma ułatwić planowanie zdolności produkcyjnych, co w konsekwencji pozwoli uniknąć błędnego podejmowania decyzji dotyczących przyjmowania nieopłacalnych zleceń. Model składa się z dwóch głównych części, gdzie wyróżniono model budowy systemu wytwarzania oraz model działań produkcyjnych.

Słowa kluczowe: obiektowo-zorientowane modelowanie, struktura produkcyjna, dyskretny system wytwarzania

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1. Introduction

Production flow is essential to obtain a finished product. The primary purpose of production business is to achieve the production of high-level product variety. In fact, production flow will become more complicated. However, first, it satisfies customers' demands and second, greater product variety brings in greater profit. Moreover, a profit will be increased if production activities, which result in making product, are appropriately planned [1].

The approach presented in this paper is a proposal to use an object-oriented programming connected with database technology to describe a production flow. An object-oriented process flow as materials flow (production subjects like work pieces, and workshop aids like tools, pallets, tooling, etc.) is made by object-oriented production system. This system represents real production equipment, which performs production activities in sequential manner so that to achieve the primary purpose – to manufacture a product in high-level product variety.

2. A production structure of manufacturing systems

A production flow involves production process in manufacturing system. A production process includes manufacturing processes (machining, assembly, and quality control) as a main part of production process and an auxiliary process (transportation, warehousing, and handling) [2]. According to [4], production equipment (workstations, transport and manipulation devices, warehouses, human resources, etc.) perform some activities on production subjects (raw materials, semi-finished products, parts or components) and workshop aids. All of the issues above form a production structure. A production structure of a manufacturing system makes connections net between production equipment in static meaning (as a system configuration and construction) and in dynamic meaning (processes flow in a system). A production system can be divided into some functional subsystems. These subsystems and their relationships are shown in Fig. 1.

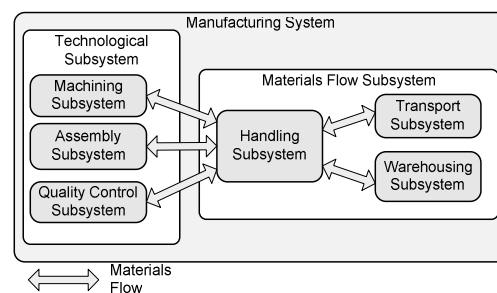


Fig. 1. The general structure of manufacturing systems

Rys. 1. Ogólna struktura produkcyjna systemów wytwarzania

The elements shown in Fig. 1 form a production structure of manufacturing system. The division of manufacturing system into functional subsystems assures full integration of

materials flow. However, additional flow must be considered to impact on a main product flow (a main fabrication). Additional flow should provide a firm product flow, through supplying additional workshop aids. An additional flow assures production equipment reconfiguration in each subsystem so that a main product flow can be carried out. This flow is a part of auxiliary process. The activities, contained in this flow, are called preparation activities. Rest of the activities from auxiliary process, which provide main product flows are called logistic activities.

The information above is needed to make the flow plan. This plan must be created in two ways. First, the flow plan should represent a product process, therefore it is a process plan. It means the time when one product is tracked in production as work-in-process. Every activity, which causes this product flow, must be included in the process plan. Second, each resource should be prepared to perform tasks connected with the product. Thus, resource plan should be scheduled. The resource plan involves technological activities and preparation activities.

However, flow plan preparation requires developing of the process flow model. That model should allow to put down the information about production structure of a manufacturing system. The process flow model would contain a production system description, product data as work-in-process description and production activities description as well.

3. The object-oriented machining subsystem model

The idea of process flow model is based on the machining subsystem model, which has been worked out for describing only machining processes [2]. The machining subsystem, as an object-oriented model, is very complex. It consists of a set of objects that represents technical devices. The objects are of different complexity. Each complex object can also consist of simpler objects. Thus, two kinds of objects can be set apart in a machining subsystem (and in a manufacturing system as well):

- Simple objects. They cannot be divided into objects that are more elementary. They will lose their functionality if they are still divided.
- Complex objects. They consist of simple objects or other complex objects.

A simple object can be defined by attributes list. The attributes describe some features of each object. The object features have been divided into geometrical parameters *AG*, technological parameters *AT* and physical parameters *AF*. These features form a vector of the object state. Complex objects are more complicated. Between objects that create a complex object, occur some bonds. It means that each object (within a complex object) is connected with others but not with every object in complex object. Connected objects remain in relationships each other. They create some hierarchical structure, which presents complex object. Complex object definition requires giving more information than simple object description:

- Objects must be separated from a complex object. Their attributes must be defined separately. Constituent object can also be complex; hence it should be split into simple objects.

- Pairs of simple objects must be distinguished. The bonds between two simple objects in pair must be characterized. Pairs of simple objects should be created after separating constituent objects from a complex object.
- Chains of objects must be defined. The chain of objects focuses several pairs of objects. Chains of objects can describe complex object functionality or variants of its configuration, e.g. various methods of work piece setup.

It may be assumed that any device in a machining subsystem is a set of bonded objects. Each object has got specific task, which performs in a device. Generally, some bonds occur between simple objects. However, one object is not connected with rest of objects in complex object (e.g. three-jaw chuck in a machine tool). It forms a bonds structure only with few objects. This structure describes a chain of bonded objects. Two bonded objects are composed as pair of objects. The bond between two objects in pair can be described as following set:

$$W = \{B, M, P, K, F, I\} \quad (1)$$

where:

B = base bond, M = clamping bond, P = shift bond, K = kinematical bond, F = force bond, I = measurement bond [3]. Furthermore, four groups of attributes describe the pair of objects: IDP – identifiers of objects in pair, WPG – providing mutual geometrical orientation of objects, CZO – describing the contact character of objects, PPK – are parameters of kinematical pair [2].

A vector of the object state describes every simple object of machining subsystem. However, pairs of objects and chains of objects, which represent real production equipment, can consist of many simple objects, hence they make a complex objects. A complex object is described by the objects state space. The objects state space can be changed under the influence of activity, which affects the complex object. The machining subsystem performs mainly manufacturing activities. Systematic manufacturing activities sequence represents a manufacturing process. A manufacturing process dynamically changes over time. Manufacturing activities can be divided into technological activities and supportive activities. Technological activities lead to changes in a vector of the object state. Supportive activities involve object attitude modification. In order to achieve object attitude modification (translation, rotation etc.), at least one constituent pair of objects from a working complex object must have shift bond or kinematical bond. Almost all of manufacturing activities in machining subsystem result in objects attitude modification. However, manufacturing activities differ because of functions, which they do in subsystem. The manufacturing activities can be divided into transformation activity TR , identification activity ID , setup activity OU , shift activity OP [1].

The formal manufacturing activities description (mentioned above) is presented as following operators set:

$$DT = (TR, ID, OU, OP) \quad (2)$$

where TR = transformation operator, ID = identification operator, OU = setup operator, OP = shift operator.

Each defined object determines some technological capabilities of machining subsystem. The machining subsystem capabilities must be recorded every time when at least one of the objects state spaces has been changed. Machining subsystem model configuration follows from manufacturing process assumptions. Thus, some aspects, like work piece setup variant, machining type or even amount of cuts, influence machine tool only, which is represented by complex object in object-oriented model. Describing the whole manufacturing system requires adding objects state spaces description of materials flow subsystem as well as expanding activities description through considering auxiliary activities.

4. The State Space of a Manufacturing System

A manufacturing system is multi-elemental, hierarchical and closed system. It contains objects (production equipment) with high-level of complexity. The objects of manufacturing system and their relationships make the manufacturing structure. The manufacturing system objects represent both production subjects and workshop aids that flow through the system, and production equipment (machine, assembly stand, robot, warehouse, cart, human resource, etc.), whereas objects relationships in manufacturing system make production processes. The object-oriented process flow modelling requires dividing objects into stationary objects, movable objects and free objects [7].

An object-oriented manufacturing system consists of many complex objects, which represents real production equipment. These objects make chains of objects described by their objects state spaces. It means that simple objects are ordered in series. However, extended manufacturing system definition should also allow to define objects as a set of objects on the same level (not only as a chain of objects). Object-oriented manufacturing system model requires describing objects collections. The objects collection can contain simple objects as well as complex objects. It plays a significant role on the layout level (where production equipment is identified relative to reference system of the shopfloor). The object collection occurs in materials flow subsystem as well. Here it appears mainly in production subjects' flow using transport pallets. Objects collection analysis in materials flow subsystem is important, when multi-object flow transforms into single-object flow or the other way round. The above-mentioned issues allow to define the objects collection as a set of objects with organised relationships. The objects (in objects collection) either accomplish specific task or form some structure (organisation) in closed environment.

Fig. 3 illustrates simple objects structure of manufacturing system configuration. Two neighbouring objects are connected with bonds (red connector), hence they form a pair of objects. A row of simple objects, connected by bonds, constitutes a chain of objects. Here, one simple object is directly connected only with two neighbours. Furthermore, a simple object can form more than two pairs of objects. Objects collection must be defined in this situation, because it allows to create parallel pairs of objects. These pairs of objects are described (apart from four groups of attributes mentioned above) by collection attributes (green connector).

The collection attributes inform how many pairs of objects definite collection have. They also determine objects location relative to the basic object within the collection. The basic object connects with more than one object in the same direction, so it occurs in each

parallel pair of objects. Additionally, objects collection stores the information about organizational rules.

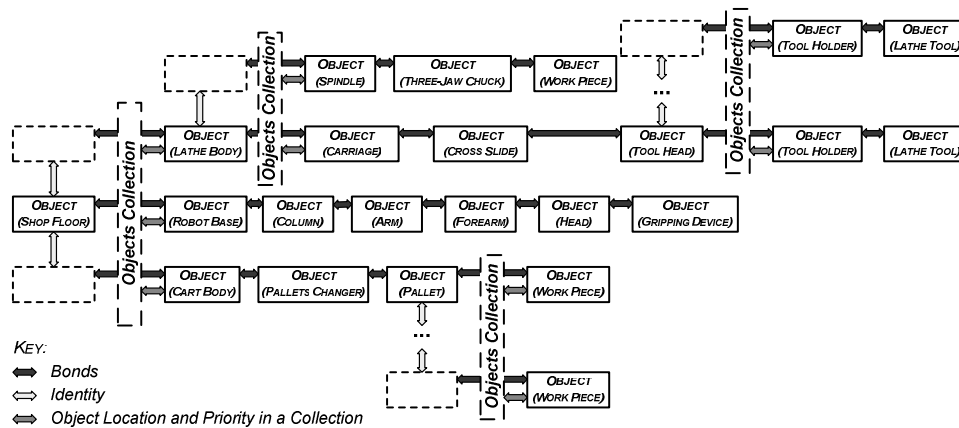


Fig. 3. Simple objects arrangement in manufacturing system

Rys. 3. Konfiguracja obiektów w modelu systemu wytwarzania

The objects collection can be characterized with different type of organizational rules [5]. The objects collection has continuous structure if organizational rule of objects collection cannot be specified for some time interval (e.g. when object is fluid like grease, ink etc.). Otherwise, objects collection has discrete structure (e.g. tool warehouse). Therefore, basic object can create continuous objects collection as well as discrete objects collection. Moreover, four types of discrete objects collections can be distinguished in manufacturing system: chaotic collection, vector collection, queue, and stack [7].

The idea of chains of objects and objects collections provides proper manufacturing system partition. It means that a chain of objects can be divided into shorter sub-chains of objects. It allows to show complex object functionality. Complex objects can relocate in manufacturing system and change their configuration. Objects movement requires developing production activities. The auxiliary activities should be worked out (the manufacturing activities has already been developed) in order to describe process flow in manufacturing system.

5. Production Activities Modelling of Materials Flow Subsystem

The production equipment of materials flow subsystem accomplishes auxiliary activities. Auxiliary activities consist on auxiliary process. The aim of auxiliary process is to enable cooperation between production equipment in technological subsystem in order to supply production subjects and workshop aids into workstations. Auxiliary activities can be defined as systematic sequence of auxiliary process. They can change attributes in vectors of the object state, objects state spaces or even in objects collections. The changes must be made in order to begin specific stages of manufacturing process.

The idea of auxiliary activities modelling is based on the manufacturing activities model. The manufacturing activities model has been developed in order to describe machining subsystem behaviour. The auxiliary activities model should represent every event in materials flow subsystem. Thus, this model should explain, how production subjects and workshop aids flow through production equipment from handling subsystem, transport subsystem and warehousing subsystem. The classification of materials flow production equipment is needed to create auxiliary activities model. The classification has been made mainly on the grounds of the idea of flexible manufacturing systems [4]. Production equipment was analysed paying special attention to materials flow capabilities. The classification contributed to the development of the auxiliary activities model. The formal auxiliary activities description is presented as following operators set:

$$DP = (OP, OU) \quad (3)$$

where OU = setup operator, OP = shift operator.

Every auxiliary activity results in manufacturing system reconfiguration. Thus, every auxiliary activity should be presented as object-oriented model in order to change objects state spaces. Moreover, according to [3], activities model should explicitly classify and describe activities in definite subsystem. The main duty of materials flow subsystem is to manage work-in-process. Therefore, production subjects' transmission between production equipment is essential action. This transmission is described by both setup operator (to intercept or relay materials between two pieces of production equipment) and shift operator (to transport production subjects between some pieces of production equipment). Setup operator and shift operator of auxiliary activities influence objects state spaces. They prepare the technological subsystem objects to permit manufacturing activities performance.

The auxiliary activity as an object-oriented model is described on three detail levels as follows:

- A, which describes auxiliary activity model in materials flow subsystem,
- B, which describes auxiliary activity model realization in materials flow subsystem,
- C, which describes auxiliary activity model parameterization in materials flow subsystem.

These levels should be defined for each auxiliary activities type, which occur in materials flow subsystem. The auxiliary activities types have been worked out based on materials flow resources classification. The classification includes handling subsystem, transport subsystem and warehousing subsystem.

6. Conclusions

The object-oriented manufacturing system was presented as production structure, where objects represent both a production subjects and workshop aids that flow through the system, and production equipment, whereas objects relationships in manufacturing system make production processes. Production subjects or workshop aids constitute simple objects, which are described with a vector of state space. Moreover complex objects represent production equipment as a set of chains of objects, pair of objects or simple objects

connected by some bonds. They are described with objects state spaces. Here was proposed that the object-oriented manufacturing system description should contain objects collection. It allows to create parallel objects which may represent e.g. individual piece of production equipment on the shopfloor. The suggested production process model consists of manufacturing activities and auxiliary activities. These two kinds of activities express behaviour of each object from production equipment in manufacturing system.

The object-oriented manufacturing system model was developed in order to provide real production equipment representation and production flow, which occurs in existing manufacturing system. The simplified, artificial representation of real environment should facilitate off-line study and analysis of real manufacturing systems. The results from model study should be feasible to plan and achieve in real manufacturing. Modern tools of object-oriented programming allow to create that model, which can reflect the majority of production issues. Thus, the next stage of model developing involves database design, which will be able to store great amount of data coming from the object-oriented process flow model as a part of whole production structure representation.

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