Management of Distributed Production for Stochastic Events - Product Model

Marjan JENKO, Peter MITROUCHEV, Daniel BRUN-PICARD

Abstract: A decentralized architecture product model (PM), based on a social approach to production management, is presented. The approach is based on a bionic manufacturing paradigm, where raw materials carry information on possible processing. The PM is introduced into a common experimental platform, developed by the partners of the project on the Synchronous Production among Order-Givers and Subcontractors (SPOGS). The discrete-event type simulation of the distributed production system, amongst order-givers and subcontractors, confirms the potential of the PM. The approach integrates all the elements necessary for the management of production by interaction via Electronic Data Interchange (EDI) among order-givers and subcontractors.

Keywords: flexible manufacturing systems, product model, scheduling algorithm

1 Introduction

1.1 Relation between manufacturing practices and the present work

Static manufacturing scheduling builds on the assumption that the number of jobs, their processing sequence and respective processing times are known a priori. In real time, there are many uncertainties associated with part arrival, processing time and machine availability [1, 2]. It is assumed in most studies that machines in the shop are continuously available [3, 4 and 5]. Machine breakdowns and other stochastic events are frequent enough in real manufacturing systems that they deserve a systematic approach.

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In this context, we consider traditional scheduling optimization, based on combinatorial mathematics, as inefficient since it fails to take into account dynamic aspects, which are prevalent [6]. These disturbances (breakdowns, quality problems, organizational problems, modifications made by the sales department and others) lead to a difference between the actual state of the shop floor and the prearranged schedule [7, 8]. The complex prearranged schedule has to be re-computed in case of a significant stochastic event and the next scheduling optimization can be significantly different from the previous one. Hence, optimization must not deal with hypothetically deterministic production but rather with its stochastic dynamics.

One method of dealing with production stochastics is enhanced structuralization of scheduling into deterministic and stochastic aspects of activities, and into relations amongst them. Long- and medium-term scheduling are of a deterministic nature, since they consider activities as known well enough in advance. That scheduling is performed in the form of Gantt charts.

Short-term scheduling is an activity that is not needed when deterministic long- and medium-term scheduling absolutely translates into successful production. When not so, i.e. when stochastic phenomena in production occur, an emergent response is needed [9]. This implies short-term scheduling, i.e. real-time consideration of combinatorial options in the given situation.

Long- and medium-term scheduling is conceptually different from short-term scheduling. The former are about deterministic operations, while the latter is more about prediction and anticipation. These mechanisms allow for a less formal decision making process. When predicting and anticipating, successive relatively short operations can be linked in time, i.e., they can be treated as a single, non-interruptible work operation. This simplifies the analysis.

The aim of this paper is to develop a short-term scheduling approach among order-givers and subcontractors. A short-term period implies nearly real-time scheduling of the production process. The approach is aimed at further generalizations, as scheduling among parts in production and machines. The approach is based on a social model in which most contributors (including non-humans) to manufacturing contribute to scheduling.

In this context, we took part in the Synchronous Production among Order-Givers and Subcontractors (SPOGS) project, subsidized by the Rhône-Alpes regional council. Its goal was to propose a global solution for manufacturing control, aiming at integration of a production system with the Enterprise and Resource Planning (ERP) system.

The starting point of our work is pre-existing developments of a multi-agent production model targeted at short-term synchronization among order-givers and subcontractors [10, 11]. Our work, within the SPOGS project, is particularly related to integration of properties of product design and product manufacturing. Integration of properties of both types is articulated as a product model (PM). The subject of this paper, i.e. short time scheduling among order-givers and subcontractors, is a vital part of the PM.

Results of this study may be useful to product designers and to designers of production systems. The PM encapsulates information that is needed for a) specification of manufacturing procedures, and b) for management of production processes.

This paper is organized as follows: a general presentation of the SPOGS project is presented after the introduction, i.e. in Section 2. The objectives of the research within the framework of the SPOGS project are presented in Section 3. Section 4 describes the simulation of relations among order-givers and subcontractors, reasoning, the results of the simulation and their validation. In Section 5, the introduction of the PA for scheduling and control of manufacturing systems is addressed. Finally, discussions and conclusions are elaborated in Section 6.

2 General presentation of SPOGS project

Within the SPOGS project, an approach to production, running by management of products-in-production, was developed. Its goal was to propose most adequate production solution in a modern distributed production environment by:
- making analysis of relations and constraints among order-givers and subcontractors,
- studying problem of scheduling, and providing subcontractors with scheduling scenarios for the near-future (almost real-time scheduling),
- sufficiently articulating control in manufacturing for the Electronic Data Interchange (EDI) implementation among order-givers and subcontractors,
- sufficiently articulating information exchange to allow each partner to anticipate work orders to follow.

As a result, the project aimed at developing approaches and a methodological support adapted to the short-term scheduling of production for small and medium enterprise (SME) subcontractors, in synchronization with partner companies and with customers. The impact of new installation, based on the approaches above, was estimated on the economic, operational and organizational level.

2.1 Contribution of the participants

The Economic Institute of Research in Production Development (EIRPD, Grenoble) contributed on the economic aspects, competencies and contractual relations. It was also the project coordinator.

The Grenoble based Science pour la Conception et l'Optimization de la Production (G-SCOP) laboratory approached to the development of geographically spread multi-contributor production scheme, to aspects of autonomy and coherence, to convergence of the decision-making process, to formalization of partners' activities and to the PM.

Laboratory of Digital Systems in Ljubljana contributed to modeling for discrete event type simulations.

Laboratory of Automatics of Grenoble (LAG) contributed to modeling and to evolution of methods for distributed scheduling.

Laboratory of Industrial Automatics (LIA, Lyons) studied and evaluated reliability of production flows among partners, with respect to timing, quality and costs.

Renault Industrial Vehicles (RIV) division (being recently purchased by Volvo) shared its significant experience in coordination with a substantional number of Rhône-Alpes area subcontractors in the field of manufacturing. It expressed its economic and industrial interest for improvement of existing coordination.

2.2 Industrial multi-companies context of the project

The industrial partners that took part in the project were representatives of the metal cutting industry of the Vallée de l'Arve, part of the upper Savoi region. Arve valley is one of the most industrialized valleys in the French Alps. Approximately seventy percent of the French metal cutting industry is located there. These companies employ fourteen thousand workers. Set up on four hundred square kilometers they are specialized in manufacturing of batches of various mechanical components in significant volumes. The companies associated with the project were:
- Renault Industrial Vehicles (RIV) division,
- Pernat, Scionzier, important volume of production with RIV.

With a work force of one hundred fifty, on the sites of Marnaz (3000 m^2) and Scionzier (2400 m^2), is its sales turnover at 16 M€ with a catalogue of 1700 reference parts,
- Briffaz, Marnaz, company of "Mechanics and Metal cutting", is RIV's first contractor for metal cutting,
- Eurotec Manducher, Oyonnax, a plasturgy specialized company.

3 Research objectives within the framework of the SPOGS project

The scientific goal of the project was to propose optimal synchronization methods that do not introduce additional problems into organizations and into the local production management. The goal consisted of:
- proposition of architecture for decentralized decision-making process, while preserving autonomy of the partner-internal decisions to the most extent,
- ensuring independence of small partners, in order to effectively manage their resources, and to protect them against production risks (too heavy work load fluctuations, negative profits, unachievable timing constraints about deliverables).

In such a decentralized context, it is necessary to have synchronization mechanisms that are based directly on the production targets, such as e.g. defined by the supply agreement (a record of obligations to sell and buy quantities of goods over time) between the vendor and the purchaser.

3.1 Consequences of efforts for improved synchronization

Relation among order-giver and subcontractor change according to new substance, which is flexible but effective synchronization. Subcontractors credibility does not depend any more only on quality of the products and on strict respect of the deadlines. It also depends on subcontractors' capacity of reaction to the inevitable dysfunctions that may take place during manufacturing. Thus, we need:
- communication to reactivate production management in case of a production dysfunction, and
- dysfunctions model, in order to anticipate their propagated effects.

A high level of subcontractor autonomy is essential to locally absorb the risks resulting from dysfunctions in the order-giver manufacturing process or simply caused by the fluctuations of orders. Profitability of the companies, able to answer the constraints of a synchronous production, involves adequate contractual conditions that are difficult to define.

Consequence of structuring production for improved synchronization is that the production system becomes *interactive*, characterized by a *synchronous approach*, rather than *reactive, Figure 1*.

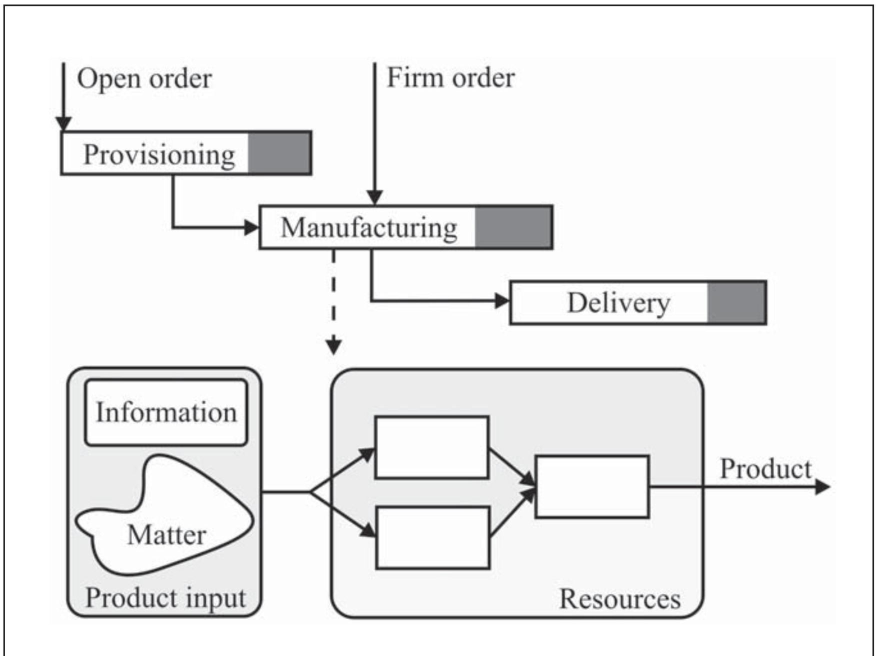

Figure 1. *General representation of activities between order-givers and subcontractors, and corresponding subcontractor activities*

3.2 Industrial state of art synchronization. Supply agreements

Deterministic scheduling depends on assumptions, that [11]:
- products are inert,
- operators are order executors, i.e., they are behaviorally degraded into position of slaves. This is less than optimal per se, since operator intelligence is wasted.
- all depends on the person in charge of planning.

In SPOGS project, open (i.e., estimated) orders and firm orders are generated and transmitted via EDI. [8]. The EDI is a teleprocessing application that provides, according to a standardized format, exchange of computerized documents amongst the computers of commercial partners. Then it allows integration of these documents, as received, validated and accepted, into computer of the recipient and their possible immediate processing. That allows us to split the quantities to be delivered (deliveries per day, for example), and to make these quantities definite only at the last moment (for a few days, even a few hours in advance).

Among the adopted solutions, we expose:
- usage of open (estimated) orders and EDI reduces loss of time and error margins, compared to traditional reactive relation between order-giver and subcontractor,
- just in time production by integrating order-giver firm orders into the production schedule of subcontractor. A time margin may be required,
- reducing this margin for lower risk of gaps in deliveries to the

customer. It is also proposed to soften constraints in the supply agreement,
- giving rights to a subcontractor, that he delivers less then requested quantities in expected time, if he warns the customer early enough.

We propose to open the supply agreement towards subcontractors or groups of subcontractors that are not exposed to the same risks at the same time.

3.3 Reasoning and problematics

The suggested model is based on a model of society [12]. Production needs of a product in production define steps in its production process. A product is considered as an actor, while it is inert in traditional prescriptive approaches to manufacturing, where even operators are decision-wise passive and responsibility for planning is on higher levels. Our approach is based on a model of society in which:
- products are choosing their operators, (autonomy of the actors), and
- products and operators make appointments, (production is guided by the product).

All the actors of this society collaborate with the same aim, to satisfy objectives laid down by the production plan. The decisions are made in coordination with all the concerned actors. Each one acts at the same time at the level of appointments (short time production estimation) and at the reactive level (reassignment of the appointments in case of disturbances). This approach presumes rationality and continuity of activities within the fields of design, management and production, in a spirit of integrated design for production (IDP), taking the decisive role of a human into account. Operator has the capacity of an intelligent actor, and he is a base of autonomy in production.

Coordination rules are distributed uniformly among all actors and are applied simultaneously in real time. The implemented mechanism is based on trust in fair relations between order-givers and subcontractors.

4 Simulation, interpretation, results and validation

Among the industrial partners associated with the project, the companies of the metal cutting sector played a particular role, because they were to be used as models for construction of a platform on which simulations would be carried out. As a result of such planning, the model presented in this study was tested on a platform of metal cutting suppliers for the automotive producer Renault RIV.

Collecting the necessary data required a long-time involvement of researchers with the factories. The first analysis, carried out in-situ, allowed collecting a precise description of material flows among the various activities of production. It also allowed a careful reflection on significance of synchronous-type production and its implications on production management. Then, the analysis could be widened by means of regular participation of a researcher in the installation of new software for production control PRODSTAR [11] on a site of the partner company.

The software gave implementation means for management of technical data, as quality and production control, and for commercial management, as purchasing and sales. Initially, level of production management was limited to a level of planning by a standard reactive practice, annotated in this paper as "reactive oriented product method". Then, a database of the technological platform was constituted, to which the interactive model presented above was applied. The validation of the suggested concepts, which are PM and PA, was performed through simulation that is presented below.

4.1 Evolution. Production reliability (fluent production flow) and flow simulation

After planning optimization of production, we proposed evaluation of reliability for production flows, based on capacities of the subcontractors, by three stages:
- mapping optimization of planning into a planning model,
- simulation of flows by the planning model, and multicriteria assistance for results interpretation,
- design of data processing and data exchange for support of the planning model.

Simulation of production flows assume that random dysfunctions take place and corrective decisions are based on measurements of production reliability and delays, compared to planning. The goal was to provide subcontractors with rules on scheduling that give satisfactory performance in terms of productivity and production reliability.

Production dysfunctions and interactions among partners were modeled as stochastic processes and deterministic reactions to random events.

Significant process variables are:
- arrivals of estimated and firm orders from order-givers, by the EDI infrastructure,
- deliveries of subcontractors,
- potential deliveries of other subcontractors.

Simulation is based on replacement of distributed production system with a mathematical model, consisting of logical relations amongst entities that represent order-givers and subcontractors. This model is mapped into an input to a program, able to generate by simulation the characteristic data on production efficiency. Finally, that data (average values, confidence intervals) were interpreted statistically in order to draw some inferences from it.

The adopted approach to simulation was the approach by the simulation needs, not by capabilities of a particular software suite. Therefore, different software packages were evaluated (WITNESS, Simfactory and ARENA) and ARENA was chosen. The goal was to use the one which would be most useful later on to the subcontractors when they need to make decisions about production.

Simulation of a production system is a discrete-event type of simulation, with inclusion of stochastic phenomena [13].

Production process of the Pernat company, a RIV metal cutting subcontractor, was studied as an example. *Figure 2* below summarizes it. It is about performance measurement. We were most interested in the following performance indices:

– exact delivery days, compared to the planned narrow intervals for deliveries,
– reliability of the production process. At the output, production flow needs to be reliable and uniform,
– amount of repository-connected work. This represents non-productive expenses,
– usage of subcontractor warehousing. Expenses, again, and possible delays.

Simulated scenarios gave confidence intervals for the above listed performance indices. To compare different control strategies, one is often confronted with multicriteria decision making, which is complex enough that it requires development of methodology. We started with simple objects and simple material flows. Then, we were adding decision alternatives. Criteria were developed in the process and they were combined into a smaller number of stronger criteria. The final outcome of repeating loops of simulation, reasoning and adaptation of production behavior was a set of rules that allows optimal solutions for prescribed criteria. Let us note that a human intervention is sometimes necessary to converge to the final optimized solution.

Quantitative criteria were chosen in this study. The criterion of performance was time marks of reference events, compared to the planned intervals. Then, criteria for production reliability, i.e., for a stable production flow on the output, were defined. Let us recall that three main mechanisms exist, when defining a production scenario:

– aggregation of many less significant criteria into fewer more significant criteria,

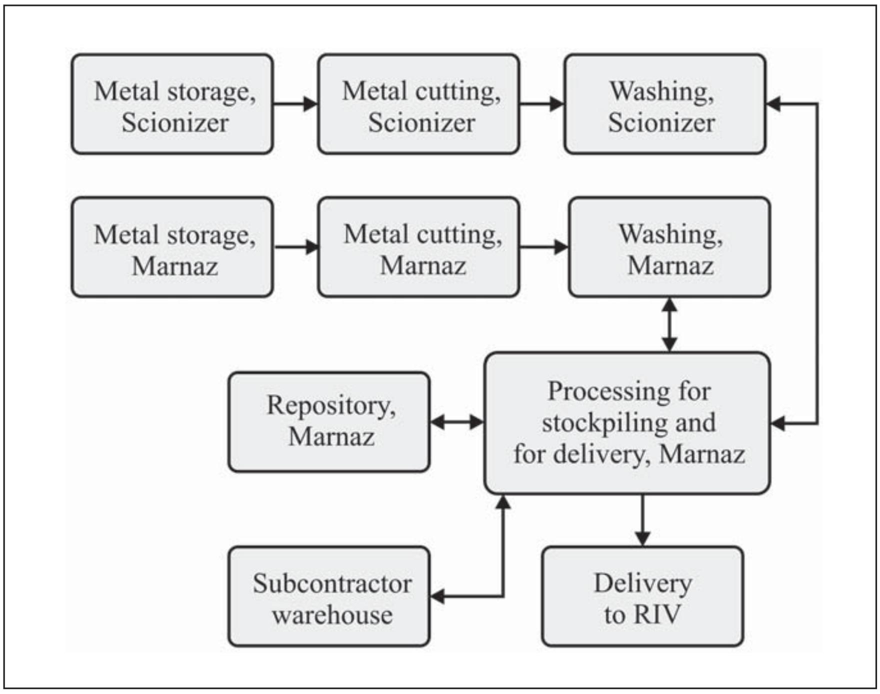

Figure 2. *Diagram of material paths and activities in metal cutting companies*

– exclusion of certain activities in a presence of some other activities (based on classification),
– production flow is defined by interactions.

We took interest in the definition of the performance measurement, related to reliability of material flows between the order-giver and the subcontractor. Reliability and position of the production events, compared to the planned intervals, were criteria that were finally included in the simulation model and being improved by simulations.

Analysis of results required to define several additional criteria of quantitative and qualitative evaluation (delay of a part, amount of stock, costs). It was then possible for the subcontractor to analyze the received requests from order-givers, in order to evaluate his limits and over-costs generated by lack of open orders and by rush orders.

5 Introduction of a PA for scheduling and control of a manufacturing system

The PA relates to production managing, by needs of products that are being produced by the shop floor. In this context a *product* may represent *an elementary component, an assembly of several elementary components or a set of similar components*.

Concept of operation corresponds to material transformation, reshaping, assembly, handling, and transportation of the product. Resources, in

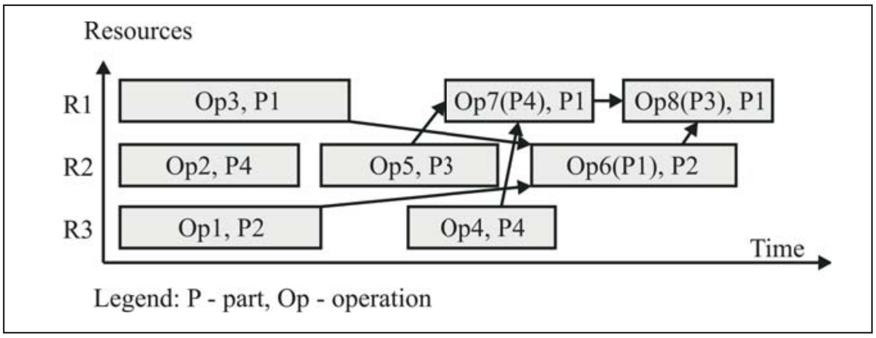

Figure 3. *Gantt chart of production through time, from 4 parts, on 3 resources, by 8 operations, out of which 3 represent a combined operation, i.e., work on a part and assembl*

this context, are human operators and machines that perform operations.

The aim of scheduling is assigning operations to resources for periods of time. Usually, this effort results in formation of a Gantt chart, *Figure 3*.

5.1 Solution range to be examined

To define solution range, let us consider:
– the set **P** of products,
– the set **R** of resources with their tools,
– the set **T** representing times of activities.

Production operations can be formally defined as an element of the ***PRT*** set which is a Cartesian product of 3 sets:

PRT = P x R x T

(set of all possible ordered triples).

Scheduling consists of finding, for each product, an oriented graph in ***PRT***, where each node of the graph represents the exclusive meeting between a resource and a product or its components, for some time, to perform an operation. For an assembly operation, the product groups several components together: this product may already have been processed by other operations and therefore the graph has a tree structure, as on *Figure 4*, where:
– gray rectangles represent operations,
– operation duration is represented by the rectangle height.

Each operation takes place, where a product, its components, if any, and a resource meet each other. Operations are linked according to the sequence of product processing.

5.2 Classical approaches

First steps in design of control for specific manufacturing are planning and scheduling. Combinatorial problem is presented in terms of production flow and of resource allocation. The outcome is typically a Gantt chart (Figure 3), that freezes the operations allocated to each resource, for allocated time periods.

As a result, resources can be theoretically used to their maximum extent, for given constraints of particular production. Such planning and scheduling represents production optimization - resources are optimally exploited. This approach organizes manufacturing operations and is characterized by the answer to three questions that are, in a sequence of importance: Which resource - When - What product (context of 'product': cf. section 5, paragraph 1).

Which resource does the operation? The answer is on Resources axis of the diagram in Figure 4.

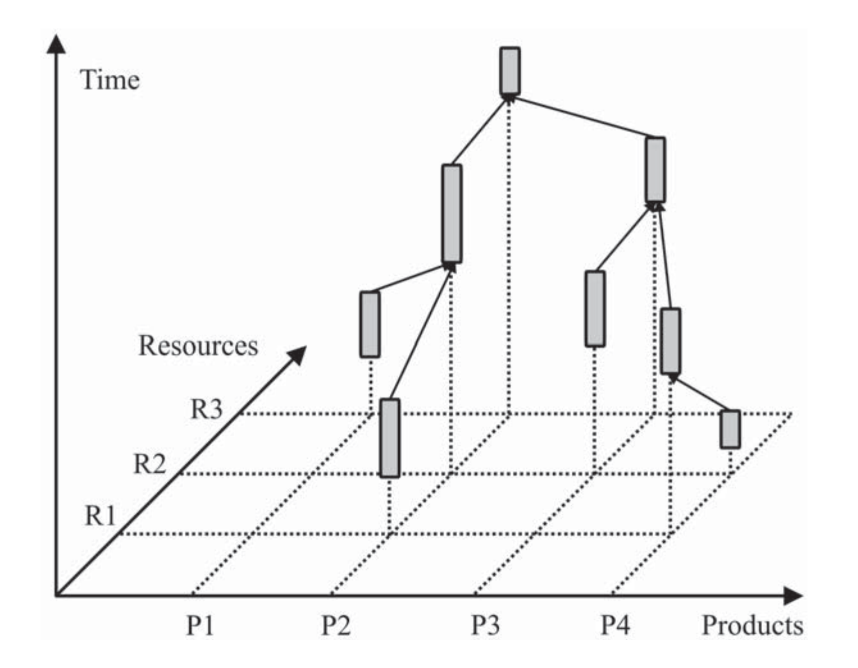

Figure 4. *Production in a PRT set*

When does the operation take place? The answer is on the Time axis of the same diagram.

What product is concerned by the operation? The answer is found in rectangles representing the operations on the diagram.

When scheduling, priority is given to the second question and time is privileged. It seems to be natural to give priority to time when synchronizing the production (i.e., working on establishment of coincidence between end of a previous operation and start of a next operation). However, this coincidence is difficult to obtain for resources that should never be idle and for products that should never wait in an intermediary stock.

Furthermore, the diagram in Figure 3 masks many degrees of freedom**,** represented in Figure 4 as the ***PRT***-set volume, where production flow can go astray in case of disturbances. Increasing demands on quantities, on product customization, on tight schedule are factors, which add to frequency of disturbances and to the need for systematic processing of disturbances.

To respect the prearranged scheduling, time-critical production is planned as batch production with as few interrupts as possible (, which results in less than optimal resource usage), time margins are introduced between operations, and introduction of material buffers helps with organization and reliability of production. These solutions differ from principles of maximum resource utilization and stock reduction. To avoid these solutions, usage of Gantt chart is called into question, but not the reasoning: grouping of operations is performed on several levels, i.e., the most of order is introduced into a manufacturing system to decrease frequency and impacts of unexpected events. Then, resource and operation substitutions are allowed to achieve most effective real-time decisions.

6 Conclusions

In this paper, a PM for manufacturing has been presented. It was implanted in a common experimental platform developed by all the partners of SPOGS Project. The PM integrates all the necessary elements for the piloting of production in interaction with the EDI among order-givers and subcontractors. It is also a support for demonstration and validation of the methods and tools under development.

Next, a PA, which considers three objectives simultaneously: flexibility, reactivity and modularity, was presented. These aspects will be explored further.

In a view of synchronous production among order-givers and subcontractors, the effort in this study was related to the concept of process. As a result, in a near future, we can hope to be able to solve problems of process synchronization and to contribute to optimization. A development of mathematical model can be considered, which will make possible to locate managing points of a production system. Relevant information will be injected into such points. We think that such a model will bring a base to carry out possible improvements in communication, in decision making, and it the actual course of events and procedures of modern distributed manufacturing.

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Upravljanje porazdeljene proizvodnje z upoštevanjem naključnih dogodkov – produktni model

Razširjeni povzetek

Prispevek predstavlja decentralizirano arhitekturo upravljanja proizvodnje, poimenovano produktni model (PM). Zasnovan je na bionski proizvodni paradigmi, pri kateri materiali vsebujejo informacije za potencialno obdelavo. PM je uporabljen v eksperimentalni platformi projekta Sinhrone proizvodnje med matičnim podjetjem in podizvajalci. PM je verificiran z diskretno simulacijo materialnega in komunikacijskega pretoka med entitetami platforme. V predlagano decentralizirano arhitekturo upravljanja so integrirani elementi za sporazumevanje z elektronsko izmenjavo podatkov med matičnim podjetjem in podizvajalci.

Motivacija za prispevek je izboljšanje produktivnosti, kakovosti in zadovoljstva v distribuiranem proizvodnem procesu v avtomobilski industriji. Preučujemo odnose med matičnim podjetjem in podizvajalci in proizvodni proces pri podizvajalcu. Metodi preučevanja sta popis dogodkov in simulacija proizvodnih scenarijev v distribuiranem okolju. Parametri uspešnosti so točnost dobav, zanesljivost in stalnost pretoka izdelkov na izhodu proizvodnje, minimizacija transporta in skladiščenja. Predlagane izboljšave v odnosih med matičnim podjetjem in podizvajalci so doseganje JIT-proizvodnje in dobav podizvajalcev z informacijsko podprtim vpogledom matičnega podjetja v proizvodne procese podizvajalcev, zmanjšanje časovnih rezerv v pogodbah in dogovorih, uvedba možnosti manjših od pogodbenih dobav, ob pravočasnem opozorilu podizvajalca, in vpeljava odprtih naročil z močno informacijsko podporo. Odprto naročilo omogoči podizvajalcu pripravo na začetek proizvodnje že pred dospetjem zahteve po količinah izdelkov in zahtevani časovni dinamiki dobav.

Naključni dogodki v distribuirani proizvodnji z omenjenimi izboljšavami niso zajeti. Bazo za sistematično obravnavo naključnosti v proizvodnem procesu predstavlja PM, ki vsebuje potrebne informacije za izdelavo produkta v distribuiranem okolju. Model temelji na produktnem pristopu, kjer o poteku proizvodnje odločamo v opisanem vrstnem redu: obdelava na katerem stroju, kdaj, kateri obdelovanec. Na osnovi teh vprašanj določimo prostor, v katerem planiramo proizvodnjo. Ta pristop se od planiranja v diagramih Gantt loči po tem, da omogoča prikaz, posredno s tem pa tudi reagiranje na naključne proizvodne dogodke.

Ključne besede: prilagodljivi proizvodni sistemi, produktni model, planiranje, naključnost,

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