– IT System BaaN IV Upgraded to Automotive

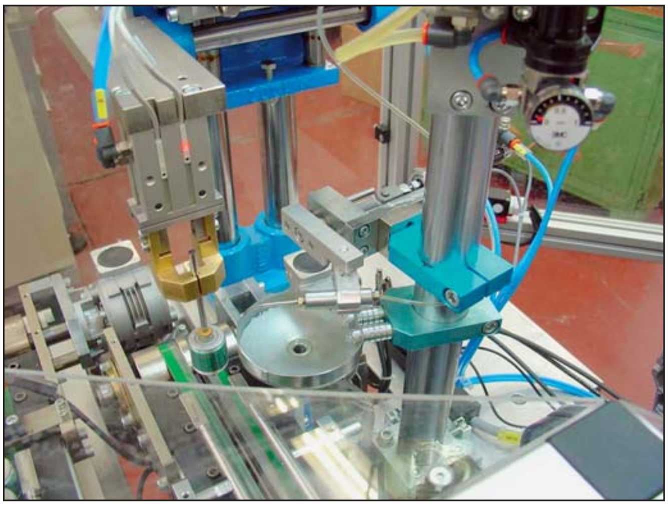
– Certifikat Družini prijazno podjetje.

Podjetje Ydria motors ima vpeljan sistem vodenja kakovosti po standardu ISO 9001:2000. Z njegovo uporabo je zagotovljeno, da so vsi pomembni procesi, njihove meje, njihovo sosledje ter njihovi lastniki točno definirani. Poleg tega so določeni cilji, periode spremljanja njihovega napredovanja in odpravljanja motenj, ki bi lahko ogrozile njihovo doseganje.

V procesu proizvodnje se pri načrtovanju tehnologije izdelave in montaže izvaja analiza možnih napak in njihovih vplivov – FMEA, tako se vnaprej ugotovijo možne napake procesa in pravočasno uvedejo varnostni ukrepi. Ob vsaki uvedbi novega procesa izdelave se izvede presoja, da se ugotovijo odstopanja, ki bi lahko ogrozila raven kakovosti izdelka.

Tako je v toku materiala, od vstopa materiala v podjetje do izdelave končnega izdelka, več nadzornih točk, ki naj zagotovijo visoko raven kakovosti, ki jo zahteva kupec.

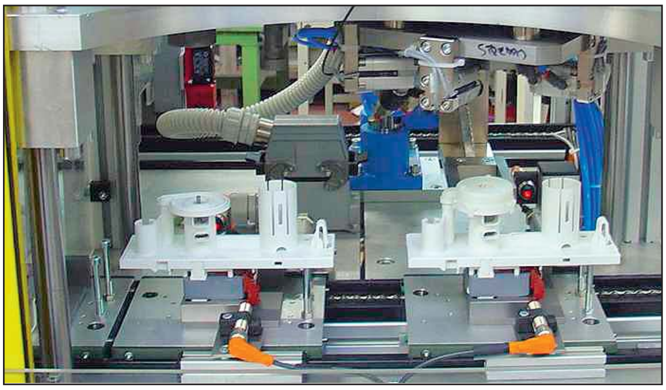
Material se po predpisanem postopku pregleda v vhodni kontroli. Za nekatere materiale in dobavitelje, ki so bili izbrani na osnovi kakovostnih in pravočasnih dobav v zadnjih petih letih, so letos začeli uvajati sistem STS (Ship to stock), kjer se vhodna kontrola ne izvaja. Dobavitelj dostavlja material in podsestave neposredno v skladišče oziroma na montažno linijo.


*Enota za sestavljanje črpalk*

Pri izdelavi podsestavov se v proizvodnji uporabljajo tri vrste kontrole. Prva je pri proženju delovnega naloga, kjer delovodja preveri nastavitve stroja in ustreznost materiala. Operater na stroju v času izdelave spremlja in preverja ustreznost sestavnih delov in ustreznost polproizvodov, vzorec obsega pet odstotkov sestavnih delov. Tretjič se proces kontrolira vsake štiri ure z vzorčenjem, vzorci se preverjajo s predpisano dokumentacijo. Tako se ugotavljajo odstopanja v procesu proizvodnje.

Podoben sistem kontrole uporabljajo tudi v končni montaži. Pri vseh končnih izdelkih se preverijo električni parametri, ki jih je določil kupec. Rezultati kontrole se shranjujejo v bazi podatkov. Vsak izdelek ima lastno sledilno kodo, ki omogoča, da za vsak izdelek na tržišču vedo, kakšne so bile njegove karakteristike med kontrolo v podjetju.

V podjetju se v rednih presledkih izvaja presoja izdelka v laboratoriju, kjer se simulirajo pogoji njegovega delovanja, ki so enaki tistim pri kupcu.


*Detajl iz linije za sestavljanje črpalk*

Napake, ki se pojavljajo na izdelkih v proizvodnji, se zbirajo v posebni bazi podatkov. Skupina za izboljšanje kakovosti jih pregleduje v mesečnih periodah, definira razloge za nastanek in opredeli korektivne ukrepe za glavne vzroke napak in njihovo odpravo.

V podjetju poteka proces stalnih izboljšav na vseh nivojih. Operaterje na napravah spodbujajo, da prijavljajo izboljšave, ki jih uresničujejo v za to organiziranih skupinah. Pri kompleksnejših problemih sestavijo posebne skupine za njihovo reševanje.

***Vizija in kako naprej***

Podjetje se veliko ukvarja s posodabljanjem posameznih sklopov opreme z namenom, da bi izboljšali učinkovitost in storilnost strojev, posebej pomembna je tudi prilagodljivost menjav iz serije v serijo. Velika pozornost je namenjena ergonomiji in avomatizaciji delovnih mest, da je delo manj obremenjujoče in monotono.

Da bi podjetje doseglo pričakovane cilje in rezultate, mora delovati v skladu z vizijo. *Vizija družbe je postavitev centra za proizvodnjo motorjev in ventilatorjev pa tudi njihovih sklopov za belo tehniko za celoten sistem* ***ebm-papst*** *na lokaciji v Podskrajniku.* Podjetje si prizadeva za zadovoljstvo kupcev in lastnikov, za uspešen razvoj družbe in odgovorno ravnanje do družbe in okolice.

*Hvala za pogovor in uspešno na trdem konkurenčnem trgu.*

*Dr. Dragica Noe*

# Control of the FMS by the Product, in Presence of Stochastic Phenomena - Simulation and Results

Marjan JENKO, Peter MITROUCHEV, Daniel BRUN-PICARD

***Abstract:*** This paper deals with a new multi-agent approach to control manufacturing process where agents represent products, assemblies and parts, which results in increased reactivity and flexibility. The approach is based on a bionic manufacturing paradigm, where raw materials carry information on possible processing. The approach results in a decentralized product-approach model with communication based on a social approach to production management. The manufacturing system (MS) is managed by a set of autonomous and intelligent agents just as the activities in a society result from actions of individuals. The discrete-event type simulation of the control system, built from agents of materials, parts and products, confirms the potential of self-scheduling production. An experimental case study is studied by simulation. Agents able to negotiate operations that the materials, parts and products must undergo on the manufacturing workstations are attached to the former. These agents have all the necessary information on production environment, objectives, constraints and rules. They make decisions and they interact. This is how production is managed. The results show that our approach is able to schedule and control a simple production system without a prearranged schedule.

***Keywords:*** flexible manufacturing systems, product approach, scheduling algorithm, multi-agent system

## 1 Introduction

### 1.1 Bionic manufacturing paradigm

Industrial manufacturing started with the Taylorian manufacturing paradigm about one century ago. At that time, the nature of manufacturing processes was understood to be deterministic. Processes were designed to last and to produce enormous quantities of products of the same type.

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New manufacturing paradigms emerged within the last twenty years: holonic [1], fractal factory [2], complex manufacturing system [3] and bionic [4].

These paradigms address and solve challenges of modern production, which needs to be flexible, distributed, adaptive, lean, cost and quality effective, and environmentally friendly.

The present work builds on the principles of the bionic manufacturing paradigm [5].

The paradigm looks at Nature and builds from the principles that can be discovered while studying survival techniques, evolution principles and bio-physical-chemical foundations of life. While these work for Nature, they have the potential to work for human activities, even highly organized and structured activities, i.e. manufacturing.

The bionic paradigm looks at Nature on a scale from individual cells to ecosystems. The mechanisms that were discovered while studying life on earth were distilled and reused for bionic control architectures in manufacturing. On a bio-cellular level, it is about throughput of substances and energy. It is enzymes within cells and hormones outside cells that control the throughput of substances and energy through cell boundaries. In a manufacturing cell, it is about the throughput of material and energy. Control decisions are performed on an intra- and inter-cellular level.

Biological cells build tissues, organs and bodies. Manufacturing cells are the basis for designing production floors, factories and enterprises.

The basic element in bionic manufacturing is the modelon [5]. It has mechanisms for production, for decision-making and for communication with other modelons. A modelon can consist of other modelons and it can be a part of a modelon – like objects in object oriented programming. A modelon structure is used to describe part-system, entity-whole relations, interaction and cooperation of building blocks and self-reflexive responsibilities. Structuring systems into modelons and relations among them provides the means to model, understand and design complex hierarchies of decision-making processes for control.

One example of implementation of a bionic distributed control system consists of machines and Automated Guided Vehicles (AGVs). The example is proposed and annotated on a theoretical level and it is evaluated by discrete event type simulation in this contribution. Modelons of parts in production, and modelons of machines and AGVs correlate their activities for the success of the whole, which is optimized production.

## 2 The product as a control actor in FMS

Let us remember that the problem of manufacturing control is in the classical approach typically approached by planning (level of production system) and by scheduling (production floor level). The problem is posed in terms of production flow and of resource allocation. The outcome of these steps is classically a Gantt chart that freezes the operations allocated to each resource, as a function of time. It can be said for this approach that it is mostly based on work with manufacturing operations. It is characterized by giving answers to three questions that are, in order: Which resource does the operation? – When does the operation take place? – What product is concerned by the operation? [6].

The product approach (PA) [7], aims at higher flexibility and reactivity. In this context *a product may represent an elementary component, an assembly of several elementary components or a set of similar components*. PA is based on a society model. Members of this model are both, products and resources. This approach leads to rearranging the order of the questions to: What product? Which resource? and When?

The product becomes an active element of the production system and takes part in the decision making process which defines its' further production. Each product communicates and negotiates with all the resources to make appointments for each operation. The products are like customers and the resources are service providers. As a result, the production system is made up of a set of autonomous members, i.e., products and resources, and they cooperate to achieve their goals. Agent structures can be a method to implement such a system.

A fundamental question of the applicability of this reasoning is the following one: if each member of the system optimizes his behavior for his benefits, how does that correlate to the benefit of the whole?

The question might seem trivial – at least it is not that much addressed in the technical literature. Based on the fact, one might conclude, that the skepticism is not justified. On the other hand, our approach to manufacturing imitates principles from animal and human world. Does such organization (group of local optimizations equals to global optimization) work for animals and humans? Regarding former, it looks it works for highly organized species, as bees are. It is just we do not know much, what kind of reasoning do they carry in their genes and pass on from generation to generation.

Regarding humans, history and daily life give us pro and contra examples on individual vs. collective optimization. Principles of democracy seem to correlate benefits of individuals and benefits of society the most. But principles of democracy involve lots of consideration and empathy, which don't promise much as mechanisms of optimization in manufacturing. Besides, many activities of human individuals are optimized for their individual well being (wild privatization, taikunization, shattering financial markets by intention), but they are catastrophic for the society. These examples convince us in relevance of questioning one to one mapping between individual and collective well being. However, a general positive correlation between the two can not be overseen. It convinces us that the socio approach to manufacturing is worth of exploration. Especially, since it is the designer of a manufacturing system, who plays God when designing a control system. He has free will to decide, what to take from the fields of sociology and psychology, and what to take not. One way to evaluate correlation between individual reasoning and its' benefit to the overall system is simulation.

### 2.1 Implementation of PA

Principles of PA associate all the knowledge and all the decision capacity that are required for production control. As a result, the product possesses the specific knowledge to search for and to process information on the production process: production goals, decision rules, equipment features and production environment [8]. This specific knowledge base contains all information on the product, as it passes phases of the production process, including:

- its identity, its functional and structural features, its parameters,
- the process and the operational sequence to produce the product,
- the priority weights,
- the equipment features and production environment.

Products' knowledge base also contains information on the prearranged schedule, on the up-to-the-time state of advancement and quality of performed operations, on production goals and decision rules. This information or knowledge is used to find out a heuristic solution to achieve the planned objectives, taking into account the unexpected events. Regarding behavior of resources, they are autonomous, as products are. Resources have a specific knowledge base containing required information to perform operations.

Two special entities are introduced to complete this structure, *Figure 1*.

- The first entity specializes in supervision and man/machine relationships. It acts when human decision is essential. Thanks to this entity, overall reliability of the system is increased because the human operator is always informed about, and involved into quantitative decisions, if needed or wanted.
- The second special entity is an expert system, which gives to the agent of each product (context of 'product': cf. section 2, paragraph 2) all the initial information, and the specific knowledge base required to schedule and to control itself and, from the product perspective, data on relevant system activities.

Behavior of these two entities depends on the global environment, on the global production goals and on course of production events. They form a link between the planning level, which defines the manufacturing objectives, and the control of the system [8]. Their global knowledge insures global consistency and vertical integration of production data.

The resulting schematic of the system is shown in Figure 1.

To establish a link with the well known CODECO approach (COordinated DEcentralized COntrol) [9], let us explain that the two specialized entities (Figure 1) represent a coordination level. Yet they do not interfere with the decision process and each execution entity is completely autonomous. The function of the two specialized entities is to prepare the production context and the decision framework to allow harmonized behavior of the manufacturing system on the start of production.

## 2.2 Architecture of the product-oriented approach

The proposed PA is characterized by decentralization of control. The control is based on a set of autonomous, homogenous and cooperative entities. In some previous research, we were developing a completely decentralized control approach [10, 11] in which each execution entity controls resources of the whole system. These execution entities are complemented are coordinated by their goals. We consider each element of the system as an autonomous entity. Each has a local knowledge base and ability of communication, decision making and action, *Figure 2*.

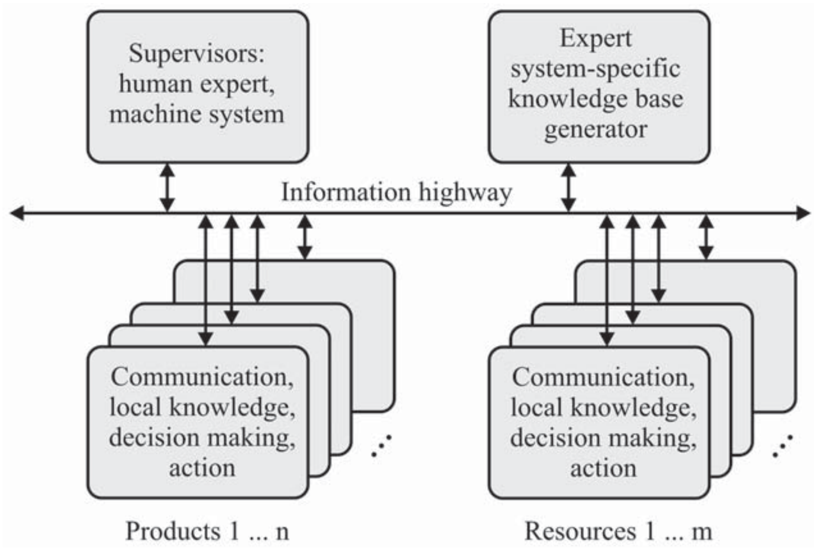


**Figure 1.** *General architecture of the product-oriented approach*

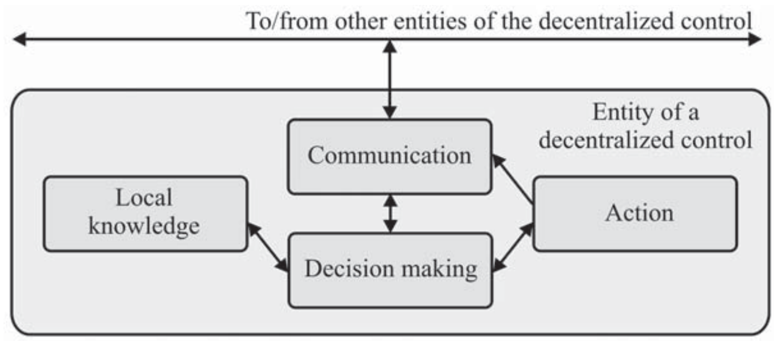


**Figure 2.** *Organization of an entity of the decentralized control*

by specialized entities for man/machine relationship and supervision to form a working management system. The new step in this approach is to consider that products are the entities that have power to manage production. As a result, products (context of 'product': cf. section 2, paragraph 2) become governors of a manufacturing system.

The fundamental principle of control decentralization relies on a homogeneous set of elements, communicating and making decisions at the same time. These elements are autonomous, cooperative and

Action block represents the ability to control the physical part in the process. Action corresponds to an elementary operation of the manufacturing process.

Decision block gives the ability to coordinate actions of the entity with other entities and to react on unexpected events.

Communication block creates the link for collaboration and information exchange among entities.

As a result, each entity is a performer of the control, able to accomplish depending tasks in collaboration with other actors. It is understandable that all levels of the classical hierarchy of control theory must be present inside each performer of a product or a resource [12].

The proposed decentralized approach simplifies control of a manufacturing system. It assigns a particular importance to events that involve actions [12]. Autonomy, which is given to each module, results in the local ability to deal with disturbances and, consequently, the system reacts physically as close as possible to the place where events occur [13]. Furthermore, with this approach, architecture of a control system allows complete integration of all control levels into a homogeneous, modular and open structure.

### 2.3 Self-scheduling and control, driven by the product

Product (context of 'product': cf. section 2, paragraph 2) is an order-giver in proposed control for manufacturing. The product negotiates with production resources or servers, to determine the best production schedule.

Products (sub-products, parts) are able to not only organize and control their behavior, but also to control the machines. Each product keeps an agenda in which it records operations to be carried out, for its' flow of production. For each operation the identity of the server, the time stamps of start and end are recorded. Resources are also autonomous and are able to accept or to refuse order-givers' request. They have their own agendas. In order to avoid combinatory explosion and to reduce computing time, a product searches for shortest operation time for two or three consecutive operations only. In case of a disruption, autonomous entities react rapidly and locally. Appointments with the stopped machine are cancelled and the products search for another machine.

A product is negotiating appointments for its' manufacturing since it is equipped with the information on its' sequence of operations and their approximate duration, its' due date and its' production progress. It also knows the suitable resources for each operation. The negotiation protocol is the following:

1. For the first operation to carry out, the product communicates with all suitable resources and makes a provisional appointment. A start date and an end date are negotiated. The product takes into account the transportation time and the resource takes into account its potential setup time.
2. For the next operation, it communicates with all the suitable resources and makes provisional appointments. As a result, the product obtains one or more appointment sequences for two consecutive operations. It can communicate further and make provisional appointmen ts for next remaining operations.
3. Then, the product chooses the best sequence of operations and communicates with all the machines to confirm the chosen appointments and to cancel the others.

If a breakdown occurs, the affected autonomous entities react locally and quickly: the appointments with a stopped machine are cancelled and the product tries to find another machine [14].

When conflicts in search for appointments do arise, a product with the highest assigned priority makes its appointment before others can. Many standard decision rules may be used: FIFO (First In First Out), LIFO (Last In, First Out), SPT (Shortest Processing Time), EDD (Earliest Due Date), MOR (Most Operation Remaining), FOR (Fewest Operation Remaining), and others.

### 2.4 Quality of solutions and functions of supervision

Each product and each resource aim at satisfying its own criteria. The quality of the global solution (in terms of productivity) depends on the proper succession of all the operations for all the products on all the resources of the manufacturing system. Products and resources do not take into account the global state of the system and only solve local problems. However, the presented negotiation protocol allows consecutive operations to be linked to find favorable sequences, to control waiting time for the products, to control idle and setup time for resources and to control transport time.

An almost just-in-time behavior with a steady flow of production is expected, even if it cannot be absolutely demonstrated (in the current state of our work and other known work). Effectively, with the appointment mechanism and with the use of priority rules, each product is programmed to progress as fast as possible and each resource is to sequence operations with a minimum lost time.

## 3 Simulation of production in a Robotic cell and results

This approach has been validated by queuing simulation [15]. All entities (products and machines) have been represented as objects (literally, it is object programming that is used in the simulation). The objects possess the necessary information for communication, negotiation and decision. Simulation of activities and events gives us insight into workings of a proposed manufacturing system, either with or without disturbances. We modeled the prototype of an FMS, which is shown in *Figure 3* below. This system consists of:

– an automated storage and retrieval system (AS/RS),
– a storekeeper robot (R1),
– three process robots (R2-R4),
– four belt conveyors (a conveyor for each robot),
– a central conveyor.

The assumptions are that:

– the robots are able to carry out six different operations with a specific tool, operations have a different setup time and a different processing time,
– the operation process is made up of no more than six different

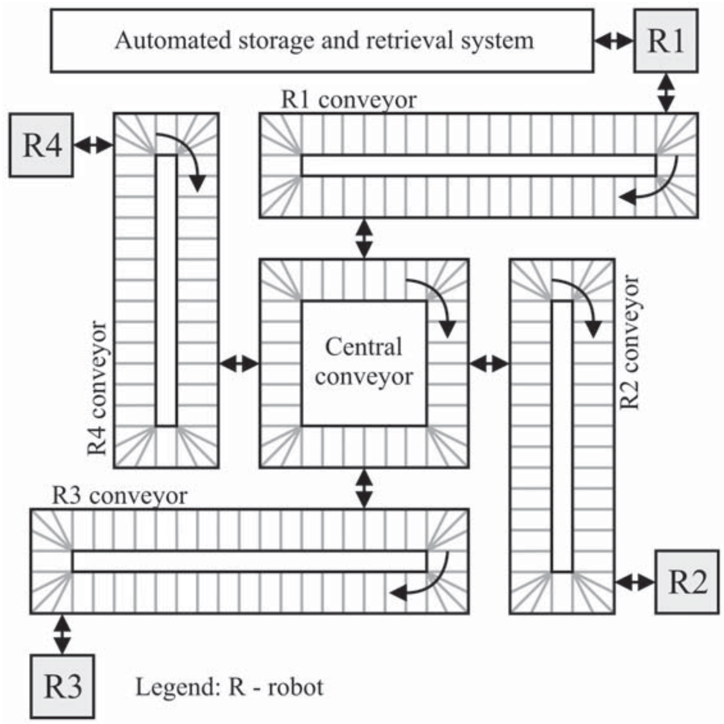


**Figure 3.** *Structure of the FMS*

operations, but one operation can be repeated several times

– the priority weight of each item in production depends on its due-date and on estimated duration of the remaining operations. The priority weight is gradually increasing as more time passes from the last operation.

## 3.1 Conflict problem and coordination mechanism

To avoid communication conflicts among products and machines, only one communication token is used for all the products that are present on the conveyor. In this way, at any one time, only one product can communicate with machines and request appointments. This is not a problem because the required time to make an appointment is very short. If two or more products need the token simultaneously, the product with the smallest ratio of available time over the priority weight gets the token.

When a product tries to find a machine for assigning one of its operations, it communicates with all the suitable machines. The products have all the required information to compute the transport time from one machine to another. The resources have all the required information to find out the set-up time and the duration of operations. Furthermore, each resource and each product have an agenda (book of appointments). These agendas represent the negotiated appointments among products and resources, the operations to carry out, the start and end times. The interactive procedure between a product and resources is organized in four steps:

– The product requests the earliest available date for each machine and the expected duration for the operation. It checks if it is possible to reach the machine before this date and proposes a provisional appointment.

– Taking into account the results of a first step, in case of remaining operations, the product communicates again to request appointment for the next operation.

– The product keeps the solution, which gives the best end time for the second operation (or for the first operation if it is the last one).

– It communicates once again to confirm the chosen appointments for the two consecutive operations. If the product has a high level of priority, it immediately makes another sequence of appointments.

Afterwards, the product materializes the appointments in order to carry out its production operations. The appointment mechanism begins again when its last operation ends, in order to take into account the effective end time of this operation.

## 3.2 Disruption case. Simulation results

When a breakdown is detected for a machine, its appointments that have not been carried out are not valid and the products that were assigned to this machine need to find another machine. We choose to cancel all next appointments with all the machines and to restart the appointment procedure. This proposal is motivated by the following reasons:

– in a new situation, priority levels of products need to be respected,

– since it is a new situation, schedules from the old situation should not apply,

– the number of products on the conveyor is limited and the decision times are very short compared with the operation time. When a failure occurs, all the appointments can be cancelled and the appointment procedure begins again, without loss of production time for new decisions.

In the first simulation, without introduction of unanticipated events, we assumed that:

– there is no breakdown in the production system, and the priority weight is the same for each product,

– the machines are able to carry out several operations and an operation can be carried out on several machines,

– the conveyor capacity is unlimited.

Results of this simulation show that the:

– average machine utilization time for this system is eighty seven

percent,
- average processing time for an item in production is forty-nine percent. Average waiting time for an item is forty-three percent. The rest of the time, eight percent on average, is spent in transport.
- decrease in number of products being simultaneously present on the conveyor results in a decrease of the waiting time (obvious),
- reduction in the number of operations that each machine can perform, results in increased waiting time and in decreased transport time.

The results show also, that:
- a reduction in the number of operations that each machine can carry out results in increase of waiting time and in a decrease of transport time.
- the increase in the priority weight does not change the global results.

Generally, in the first simulated situation, the machine utilization rate is always more than eighty-six percent.

In the second situation, breakdown constraints were imposed. On average, the machine utilization rate, the transport time and the waiting time do increase. In general, a very good rate of utilization for the machines (almost identical to the first case) has been obtained but the rate of transport time has increased by thirty percent. The best conditions for self-scheduling are observed in the case where duration of the operations is quite conforming. As a result, it is profitable, if possible, to group short operations in one operation and to subdivide long operations.

## 4 Conclusions

In this paper, a self-scheduling approach and control approach, in which the products as order-givers are autonomous and intelligent entities, has been presented. Each product has all the information on its manufacturing process (operation sequence, production rules, priority weight, due date) and has a direct access to information of all other entities. The results are very encouraging when this approach is applied, because the machine-utilization rate in both cases (normal case and disruption case) is high. Moreover, using this approach, waiting time is short and a near just-in-time control is obtained. The results also show that our approach is able to schedule and control a simple production system without a prearranged schedule. This aspect will be explored further.

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## Upravljanje proizvodnega sistema z vidika proizvoda, ob prisotnosti naključnih dogodkov – simulacija in rezultati


### Razširjeni povzetek

Predstavljeno je agentsko vodenje proizvodnje, kjer agenti predstavljajo produkte, sestave in dele v proizvodnji. Zasnovano je na bionski proizvodni paradigmi, kjer materiali vsebujejo informacije, potrebne za potencialno obdelavo. Proizvodni sistem upravljajo avtonomni agenti tako, kot nastajajo aktivnosti v družbi preko aktivnosti posameznikov. Diskretna simulacija upravljavskega sistema, sestavljenega iz agentov delov, sklopov in proizvodov, potrjuje potencial samoupravljanja proizvodnje. S simulacijo študiramo eksperimentalni primer. Agenti delov, sklopov in proizvodov so opremljeni z informacijami o potrebnem procesiranju, omejitvah, pravilih in o proizvodnem okolju. Agenti odločajo in komunicirajo in s tem upravljajo proizvodnjo. Simulacija pokaže, da predlagani pristop lahko vodi enostaven proizvodni sistem brez vnaprejšnjega planiranja, tudi ob pojavljanju naključnih dogodkov.

Pri poročanju o upravljavskih sistemih, sestavljenih iz agentov in interakcij med njimi, je smiselno vprašanje o kvaliteti in zanesljivosti tako izvedenega odločanja. To zato, ker gre za distribuirano odločanje in komunikacijo med relativno enostavnimi entitetami odločanja. Konceptualno gre za lokalno odločanje oziroma za lokalne optimizacije. Ali je skupek lokalnih optimizacij identičen globalni optimizaciji oziroma optimiziranemu delovanju celotnega proizvodnega sistema? Narava nas uči, da enoličnega odgovora na to vprašanje ni. Na primer: človekova lokalna optimizacija transporta (avtomobil) uničuje zemeljski ekosistem (globalna optimizacija?). Čebelja lokalna optimizacija in interakcije v panju rezultirajo v skladnem življenju v panju s konkretnim produktom. Problem preslikave lokalnih optimizacij v globalno optimizacijo ni problem arhitekture distribuiranega odločanja, pač pa lokalno uporabljene logike in vsebine interakcij.

Raziskavo o potencialu kratkoročnega lokalnega odločanja ob prisotnosti naključnih dogodkov smo namenoma zasnovali na enostavni proizvodni celici, sestavljeni iz obdelovancev, štirih robotov, petih transportnih trakov in avtomatiziranega lokalnega skladišča. Odločanje agentov obdelovancev in orodij poteka sekvenčno, odločitve so kratkoročne. Ob vnosu naključnih odpovedi strojev sistem distribuiranega odločanja reagira tako, da prekine proizvodni scenarij in se samoorganizira v novih okoliščinah.

Simulacija odločanja pokaže, da v obeh primerih, z naključnimi odpovedmi strojev ali brez njih, dosegamo primerljivo visoko obremenitev razpoložljivih strojev. V primeru odpovedi je povečan transport. Simulirani proizvodni proces poteka brez vnaprejšnjega planiranja, kar motivira k delu za samoorganizacijo vsaj manj zahtevnih segmentov proizvodnega procesa.


***Ključne besede:*** proizvodni sistemi, produktni pristop, planiranje, agentski sistem,