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PRIMJENA MULTIAGENTSKE TEHNOLOGIJE I HETERARHIJSKE ARHITEKTURE U PLANIRANJU PROIZVODNJE
APPLICATION OF MULTI-AGENT TECHNOLOGY AND HETERARHICAL ARCHITECTURE FOR PRODUCTION SCHEDULING

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Sažetak: *Kompleksnost proizvodnog okruženja, kao i složenost rješavanih zadataka unutar njega, kontinuirano i eksponencijalno raste. U mnogim industrijskim scenarijima tradicionalni centralizirani i hijerarhijski pristup nije adekvatan kada se primijeni za upravljanje složenim proizvodnim procesima, te može dovesti do neadekvatnog i sporog odaziva modeliranog sustava prema sustavima s visokim stupnjem kompleksnosti i praktičnih zahtjeva za robusnosti i rekonfigurabilnosti. Stoga smo u ovom radu primijenili moderne metode modeliranja kompleksnih proizvodnih sustava zasnovane na heterarhijskom modelu (biološki proizvodni sustavi – BMS), s primjenom multiagentske tehnologije za opis pojedinih komponenti sustava. Poslije definirane metodologije razvijen je simulacijski model fleksibilne obradne ćelije i simuliran je njezin rad u stvarnim proizvodnim uvjetima.*

Ključne riječi:
– heterarhijska arhitektura
– multiagentska metodologija
– biološki proizvodni sustavi
– fleksibilna obradna ćelija

Abstract: *The complexity of the production environment and the sophistication of solved tasks from within the same, continuously and exponentially increases. In today's industrial scenarios, the traditional centralized and hierarchical approach is not adequate for the control and scheduling of the complex production processes. This can lead to an inadequate and slow response of the system to systems with a high level of complexity and practical demands for robustness and reconfiguration. Due to that reason, in this paper we have introduced modern methods for the modelling of complex production systems that are based on the heterachical model (Biological Manufacturing Systems–BMS), with the implementation of multi-agent technology for description of some of the system entities. After this methodology has been defined, a simulation model of a flexible manufacturing cell was developed and its work was simulated in real production conditions.*

Keywords:
– heterachical architecture
– multi-agent methodology
– biological production systems
– flexible manufacturing cell

1. UVOD

U suvremeno doba kompleksnost proizvodnog okruženja, kao i složenost rješavanih zadataka unutar njega, kontinuirano i eksponencionalno raste. Poradi toga tradicionalni način vođenja proizvodnje, zasnovan na hijerarhijskoj arhitekturi protoka informacija i načina upravljanja ne daje zadovoljavajuće rezultate. Najveći je problem u tome što tradicionalni način upravljanja može dovesti do neadekvatnog i sporog odaziva modeliranog sustava prema sustavima s visokim stupnjem kompleksnosti i za koje se u praksi zahtijeva da su robusni i rekonfigurabilni [1].
Stoga smo u ovom radu primijenili moderne metode modeliranja kompleksnih proizvodnih sustava zasnovane

1. INTRODUCTION

Current complexities of the production environment and processes are continuously and explicitly increasing. Because of that, the traditional approaches for production scheduling and control, based on the hierarchical architecture of the information flow and production system design are not suitable. The main problem of the traditional approach for control and scheduling is a high possibility for slow and inappropriate response of the modelled system in comparison to the complex and highly uncertain environment in which the production system exists. This kind of approach for the production environment requires robustness and a high level of the reconfigurability [1].

na heterarhijskom modelu (koncept *emergent synthesis* zasnovan na implementaciji *bioloških proizvodnih sustava* – BMS), s primjenom multiagentske tehnologije za opis pojedinih komponenti sustava [2, 3]. Za primjer smo modelirali jednostavnu fleksibilnu obradnu ćeliju koja se sastoji od tri radna elementa (CNC obradni centar, CNC tokarilica i robot za manipulaciju).

2. EMERGENT SYNTHESIS KONCEPT

Emergent synthesis koncept (slika 1) može se izravno lateralno definirati prema svojem nazivu. Lateralna definicija sinteze je da spaja više elemenata u jednu cjelinu. Taj je termin vrlo usko vezan s ljudskim aktivnostima stvaranja umjetnih tvorevina, a značenje pojma *sinteza* usko je povezano sa značenjem pojma *analiza*. Taj je proces bitan u cjelokupnom predloženom konceptu: da bi se stvorila nova pragmatična struktura potrebno je izvršiti njezinu analizu i analizu njezinih funkcionalnih dijelova. To je potrebno radi razumijevanja i definiranja funkcionalnih odnosa i veza u predloženoj pragmatičnoj strukturi [2-4].

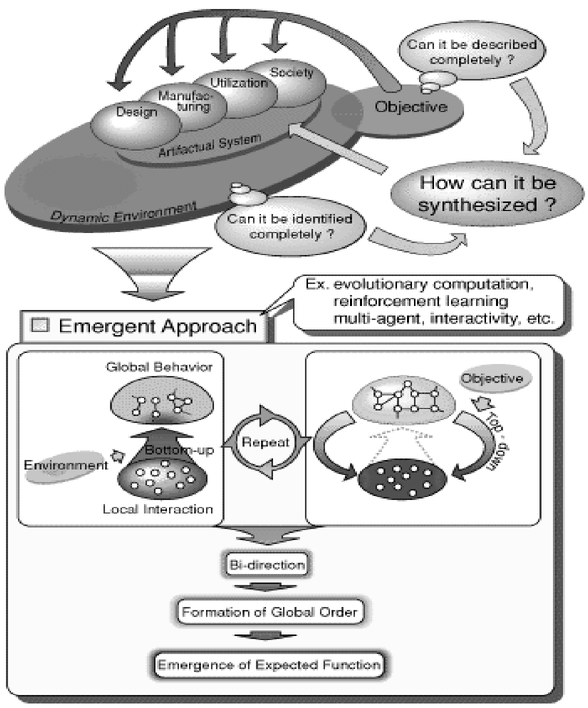
Sam izraz *emergence* (nastanak, izranjanje) može biti definiran sa stanovišta evolucije, fizike, matematike, itd. U oksfordskome rječniku pojam *emergence* definiran je kao nešto što postaje poznato ili novo. Tijekom zadnjeg desetljeća taj se termin pojavljuje u mnogim znanstvenim granama u kojima opisuje kvalitativno raznovrsne pojave.

Due to that reason, in this paper we presented a modern approach for the modelling of a complex production system based on the heterachical model (Emergent Synthesis concept by implementing BMS), with implementation of the multi-agent technique for object description [2, 3]. Using this approach we have modelled a simple flexible manufacturing cell, which consists of three production entities (CNC machining centre, CNC turning machine and robot for manipulation).

2. EMERGENT SYNTHESIS CONCEPT

The Emergent Synthesis approach (Figure 1) can be literally defined by its name. The literal definition of the synthesis is “combined elements into a whole”. The term synthesis here is closely related to human activities for creation of the artificial things. However, in this case the synthesis is also closely related to the analysis. This is because all elements of the system are ordered to utilise a pragmatic structure, a “new whole”, prior to which an analysis of the functional parts is needed. This is needed in defining their functional interrelationship and nature inside of the proposed pragmatic structure [2-4].

The term emergence can be defined from a linguistic, evolutionary, physical, mathematical, etc. point of view. The Oxford dictionary defined emergence as something to become known, be revealed. The term emergence has, in recent years, been used in many fields to describe qualitatively different observations.



Slika 1. Prikaz metodologije koncepta emergent synthesis *(Prof. Kanji Ueda)* [4]
Figure 1. Methodology of Emergent Synthesis (by Prof. Kanji Ueda) [4]

Prema Carianiu[5], različite definicije *emergence* mogu biti svrstane u tri glavne kategorije: računalna (matematički zasnovan koncept), termodinamička (fizikalno zasnovani materijalizam) i relativna prema modelu (funkcionalni hilemorfizma). Novi smjer u predstavio je Langton [6] u *Artificial Lifeu*. On je definirao *emergence* kao postupak povratne veze između više nivoa dinamičkog sustava, gdje lokalna mikrodinamika uzrokuje globalnu makrodinamiku sustava, ali globalna makrodinamika ograničava lokalnu mikrodinamiku. Prema toj se definiciji može zaključiti da cjelokupna kompleksnost sustava proizlazi iz eksplicitne jednostavnosti lokalnih komponenti.

Prema navedenim razmatranjima i definicijama možemo koncept *emergent synthesis* definirati kao metode koje primjenjuju takozvane *bottom-up* i *top-down* karakteristike, suprotno tradicionalnim analitičkim i determinističkim pristupima koji su zasnovani na primjeni tzv. *top-down* problematike raščlanjivanja kao što su *operational research, symbolic artificial intelligence* itd.

According to Cariani [5], the various definitions of emergence can be broken down into three broad categories: computational (a mathematically based concept), thermodynamic (physically based materialism) and relative to a model (functionally based hylomorphism). New direction in Artificial Life was introduced by Langton [6]. He defines emergence in terms of a feedback relation between the levels in dynamical system; where the local micro-dynamics causes global macro-dynamics while global macro-dynamics constrain local micro-dynamics. This definition implies that implicit global complexity emerges from explicit local simplicity.

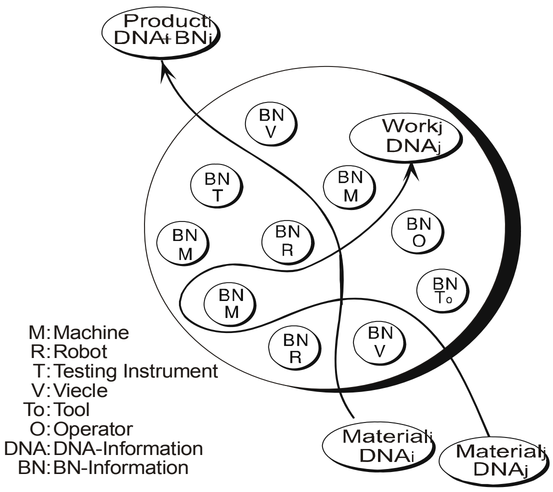
According to the definitions and explanations given above, it can be said that Emergent Synthesis related approaches use both bottom-up and top-down features, unlike traditional analytical, deterministic approaches based on top-down problem decomposing; such as operational research, symbolic artificial intelligence, etc.

2.1. Biološki proizvodni sustavi (BMS)

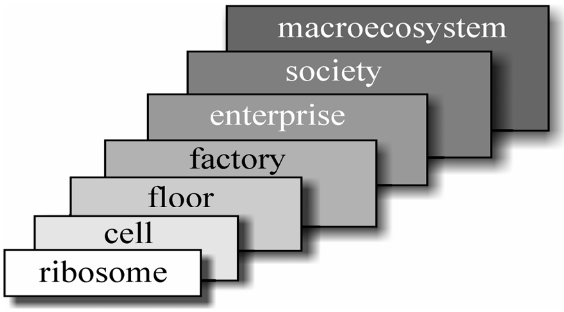
Koncept *bioloških proizvodnih sustava* (BMS), koji je predložio Ueda [2], zasnovan je na osnovnim karakteristikama i ponašanju bioloških organizama. Biološki organizmi osiguravaju svoj opstanak i imaju sposobnost adaptacije u dinamičkom životnom okružju, a pri tome pokazuju funkcije kao što su: samoprepoznavanje, samorazvoj, samoobnovljivost, prilagodljivost i evolucija. Te su funkcije organizama predstavljene pomoću dvaju tipova bioloških informacija, genetske informacije koje evoluiraju kroz generacije (DNA-tip) i individualno ostvarene informacije jedinke kroz životni ciklus (BN-tip) (slika 2). Fuzija bioloških informacija s individuama čini živući organizam kompleksnim, ali adaptivnim [7].

2.1 Biological Manufacturing Systems (BMS)

The Biological Manufacturing System (BMS), proposed by Ueda [2], is a concept that is based on an essential biological organisms' characteristics and behaviour. Biological organisms insure their existence and they are capable of adapting themselves in a dynamic living environment by showing functions such as self-recognition, self-development, self-recovery, adaptability and evolution. Those functions of organisms are displayed by expressing two types of biological information, i.e. genetic information evolving through generation (DNA-type) and individually achieved information during one's lifetime (BN-type) (Figure 2). Fusion of biological information with individuals makes the living systems complex but adaptive [7].



Slika 2. Funkcionalni prikaz prijenosa i sastava informacija prema metodologiji BMS [2]
Figure 2. Functional representation of information statement and transmission in BMS [2]



Slika 3. Prikaz arhitekture sustava zasnovane na metodologiji BMS [2]
Figure 3. The description of the system based on the BMS methodology [2]

BMS može biti opisan u više nivoa: ribosom, ćelija, proizvodni pogon, tvornica, poduzeće, društvo i makroekosustav (slika 3).
Prezentirani pristup usredotočit će se na dio BMS-a koji opisuje proizvodni pogon. Strukturalni elementi BMS-a su proizvodna oprema kao što su: strojevi, strojevi za montažu, transport, kontrolu i skladištenje opreme, sirovca, proizvoda i alata, te su reprezentirani kao autonomne jedinke (organizmi). Tijekom proizvodnje sam proizvod evoluira iz sirovog materijala, koji posjeduje i prikazuje DNA-tip informacije. Proizvod je kroz proizvodni proces oblikovan od strukturalnih elemenata (proizvodne opreme) korištenjem BN-tipa informacija. Po završetku proizvodnje proizvod nastavlja prikupljati informacije tijekom svojega životnog ciklusa na način da nastavlja prikupljati BN-tip informacija. Kao rezultat proizvod je u mogućnosti prevladavati pogreške koje se mogu pojaviti tijekom proizvodnje, te vršiti samo optimizaciju. Model proizvodnoga pogona (fleksibilne ćelije) modeliran je primjenom multiagentske tehnike.

The BMS can be described in several architecture levels: ribosome, cell, floor, factory, enterprise, society and macroecosystem (Figure 3). In the proposed approach we will concentrate on the floor level of BMS. Structural elements in BMS are manufacturing equipment such as machining, assembly, transportation, testing, and storage equipment, tools and materials, parts, products, etc., and they are comparable to autonomous organisms. During production, products evolve from raw materials expressing their own DNA-type information. A product is shaped from the raw material by structural elements (manufacturing equipment) by using the BN-type of information. The product continues to collect knowledge during its lifetime, in the form of obtaining BN-type information. As a result, the product is able to deal with malfunctions which occur in manufacturing systems during production. The multi-agent technique was used for modelling the components of the simulated production model.

2.2 Agenti i multiagentski sustavi

Prvi važniji pomaci u primjeni agentske tehnologije napravljeni prošlog desetljeća kada je u općem istraživanju umjetne inteligencije pomaknut naglasak s logike na traženje rješenja i na racionalno ponašanje; s idealnog zaključivanja na zaključivanje bazirano na ponuđenim mogućnostima; sa skupljanja ekspertnog znanja u uskim okvirima na ponovno upotrebljive repozitorije znanja koji se mogu i dijeliti; s individualnih na višedijelne kognitivne entitete koji djeluju u zajedništvu. Taj je napredak doveo do onoga što danas smatramo agentskom paradigmom računalstva. Dok ta nova paradigma ima nekoliko izvora u teorijskom smislu, tehnologije koja to omogućuje i razmatra primjene, također postoji i opći konsenzus oko njezinih dviju glavnih apstrakcija [1]:

- agent je računalni sustav smješten u dinamičkom okruženju i sposoban je pokazati autonomno i inteligentno ponašanje,
- agent može imati okruženje koje uključuje druge agente. Zajednica agenata u međusobnoj interakciji kao cjelina djeluje kao multiagentski sustav.

2.2 Agent and multi-agent systems

The first important results in the implementation of agent technology have been presented in the last decade, when the research emphasis on artificial intelligence was moved from a logical point of view to solution searching and rational behaviour, from ideal reasoning to reasoning based on the proposed possibilities, from collecting expert knowledge in narrow frames to reuse of repository knowledge that is shared and updated, from individual to multipart cognitive entities which perform in cooperation. This improvement has lead to something that today we understand as an agent-based computational paradigm. While this new paradigm has several sources in a theoretical sense, the technology which makes it possible and analyses implementation, there is an overall general consensus about two of their main abstractions [1]:

- the agent is a computational system based in a dynamical environment; it has the ability to show autonomous and intelligent behaviour,
- in the agent environment there can exist other agents. A community of agents in mutual interaction acts as a whole and describes a multi-agent system.

Agent djeluje u okruženju od kojega je jasno odvojen. Stoga agent provodi svoja opažanja o svojem okruženju, posjeduje svoja znanja i svoja vjerovanja o svojem okruženju, ima svoje prioritete vezane za stanja okruženja, te konačno inicira i provodi akcije radi promjene okruženja.

Važne zajedničke značajke računskih agenata su [8, 9]:

- agenti djeluju radi postizanja određenog cilja u ime svojeg dizajnera ili korisnika kojeg predstavljaju,
- agenti su autonomni u tom smislu da kontroliraju i svoje interno stanje i ponašanje u okruženju,
- agenti pokazuju određen oblik inteligencije, koja proizlazi iz primjene fiksnih pravila na sposobnosti zaključivanja, planiranja i učenja,
- agenti su u interakciji sa svojim okruženjem, i s drugim agentima u zajednici,
- agenti su optimalno prilagodljivi, npr. sposobni su prilagoditi svoje ponašanje promjenama okruženja bez intervencije njihova dizajnera.

Multiagentski sustav formira se mrežom računskih agenata koji surađuju i međusobno komuniciraju [10, 11]. Agenti mogu imati samo djelomičan model svojeg okruženja. Mogu posjedovati ograničen skup sredstava za prikupljanje i integraciju novog znanja u svoje modele te isto tako i ograničene mogućnosti vođenja stanja sustava prema onom stanju koje odgovara njihovim ciljevima. Znanje dvaju agenata koje se odnosi na istu stvar ne mora se nužno podudarati te može biti drugačije predstavljeno. Ne moramo održavati pretpostavku sustava: MAS je uronjen u svoje okruženje te interaktivan s njim iako nije potpuno opisan formalnim sredstvima. Kada nastupe nove interakcije s okruženjem, MAS mora biti otvoren kako bi mogao evoluirati.

Agentski bazirano modeliranje posebno je pogodno za simuliranje ponašanja kompleksnih sustava koji djeluju u dinamičkom okruženju. Suprotno tradicionalnome *top-down* pristupu naglasak je na individui zajedno sa svim njezinim ograničenjima (kognitivnima i računalnima) i njezinim interakcijama. Stoga je agentski bazirano simuliranje postalo prihvatljiva metodologija za razvoj prihvatljivih objašnjenja novog (*emergence*) fenomena [12]. Najčešće korištena tehnika simuliranja je simulacija diskretnih događaja. U ovome radu fleksibilna obradna ćelija modelirana je u *eM-Plantu*, programskom okružju tvrtke *Siemens PLM*.

3. SIMULACIJSKI MODEL

Agentski model temeljen je na heterarhijskoj metodologiji dizajna i upravljanja. Naglasak je stavljen na decentralizaciju agenata te njihovo snalaženje u izrazito dinamičkom okruženju. Za razvoj agenta i njegove okoline korišten je programski paket *eM-Plant* u kombinaciji s *Visual Studio C++ 2008*.

The acting agent is clearly divergent from the environment. Due to that reason, it can be defined that the agent is executing its perception about its environment, possesses its knowledge and believes about the environment and has priorities connected to the state of the environment. According to all that information, it executes it actions to change the state of the environment.

Important characteristics of the computational agents are [8, 9]:

- agents act to be able to reach the specific goal in the name of its creator or user which it represents,
- agents are autonomous, are able to control its internal conditions and behaviour in its environment,
- agents present some level of intelligence, this is presented by the ability to conclude based on simple fixed rules, also they have the ability to plan and learn to some level,
- the agents interact with their environment and with other agents in it,
- the agents have the ability to optimally adjust, and are able to adapt their behaviour to changes in environment.

The network of agents forms the MAS system. Those agents cooperate and communicate with each other [10, 11]. The agents can have just a partial view of the system environment. Also they can posses a limited set of resources for collecting and integration of the obtained knowledge in its models and limited capabilities to lead the system to the condition which represents its goals. The knowledge about the same condition of the system does not need to be the same in two different agents. The agent does not need to represent the same goal which is defined in the MAS system, because it is a part of the system and it is not necessary to be completely and formally described by the same means. When new conditions appear in the environment, the MAS needs to evaluate it. Agent based modelling is especially adequate for simulating the complex behaviour of the system which is based on the dynamical environment. In contrast to the traditional top-down approach, in the MAS the emphasis is on the entity (with all it limitations at the cognitive and computational level) and its interactions. Due to that reason, agent based simulation is accepted as the methodology for the development of emergent behaviour [12]. The discrete event simulation technique is the most common technique used for developing the simulation models. In this paper we have been using eM-Plant programming environment (Siemens PLM) for modelling the flexible manufacturing cell.

3. SIMULATION MODEL

The agent model is based on the heterachical architecture (design and control). It emphasises the decentralization of the model and ability of the agent to adapt in a highly dynamic environment. For the development of the agent and its environment, the eM-Plant software package was used in combination with Visual Studio C++ 2008.

3.1. Osnovne značajke agentskog sustava

Prije početka razvoja heterarhijskog sustava potrebno je napraviti analizu agentskih jedinki koje će biti prisutne u sustavu jedne radne stanice. Osnovna se heterarhija, prema kojoj je dizajnirana radna jedinica, sastoji od:

1. Agenta određivanja rasporeda.
2. Agenta proizvoda:
   a. Agenta obratka.
   b. Agenta međuspremnika.
3. Agenta stroja:
   a. Agenta stanja stroja.
   b. Agenta rukovanja proizvodom.
   c. Agenta manipulatora.

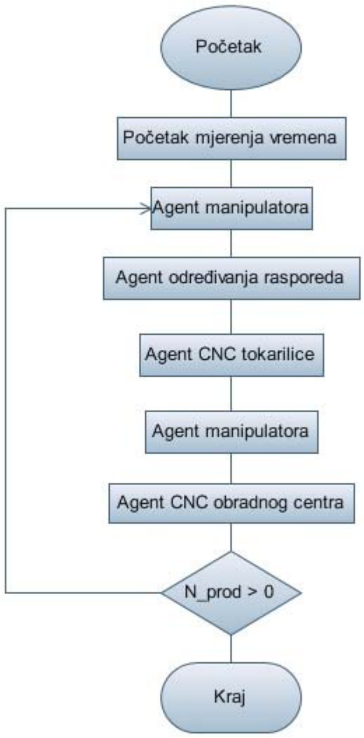
Modelirana fleksibilna obradna ćelija prilagođena je za izradu velikog broja manjih obradaka, koji će biti dinamički mijenjani i dopremani transporterima do nje. Tipovi proizvoda koji su simulirani u modelu fleksibilne obradne ćelije prikazani su u tablici 1. Transporteri i ostatak proizvodnog sustava neće biti razmatrani kroz taj model jer je naglasak stavljen na iskazivanje decentraliziranog rada jedne radne stanice. Logika komunikacije u sustavu MAS prikazana je na slici 4. Proizvodi su bili puštani u proizvodnju nasumično i simulirana je jednogodišnja proizvodnja.

3.1. Agent system description

For development of the heterachical architecture of the system it is necessary to perform analyses of the agent entities which will represent the flexible manufacturing cell. The main heterachical architecture was described as follows:

1. Production scheduling agent.
2. Product agent:
   a. Workpeace agent.
   b. Buffer agent.
3. Machine agent:
   a. Machine state agent.
   b. Product handling agent.
   c. Manipulator agent.

The modelled flexible manufacturing cell is adjusted for handling a large number of products with a small production time. The different series of products have been dynamically introduced in the system. The types of products which have been introduced in the model are presented in Table 1. The conveyers and the rest of the production system will not be taken into account in the simulation. This is done in order to be able to analyse the dynamic characteristics of the flexible cell as an entity. The logic of communication for the MAS system is presented in the Figure 4. The products have been randomly introduced in production, and the production period is simulated as a time period of one year.



Slika 4. Logika simulacijske procedure
Figure 4. The logic of the simulation procedure

Tablica 1. Tipovi proizvoda koji su korišteni u simulacijskom modelu
Table 1. The types of the products which have been used in simulation

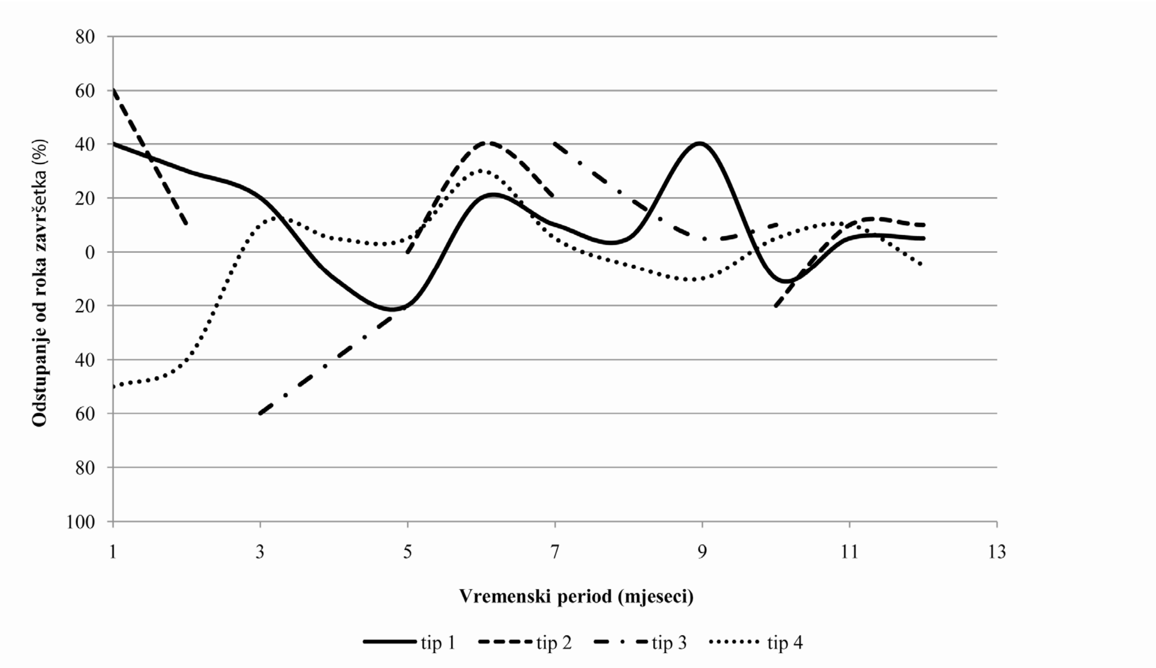
	1. Operacija	2. Operacija
Tip 1	CNC tokarilica	-
Tip 2	CNC tokarilica	CNC obradni centar
Tip 3	CNC obradni centar	-
Tip 4	CNC obradni centar	CNC tokarilica

5. REZULTATI I DISKUSIJA

Da bi se analiziralo ponašanje ovdje prezentiranoga simulacijskog modela, izvršena je simulacija rada fleksibilne obradne ćelije. Četiri tipa proizvoda uvođena su u proizvodnju prema nasumičnom odabiru. Na slici 5 prikazani su rezultati dobiveni iz jednoga srednjeg simulacijskog testa. Iz dobivenih rezultata mogu se izvući sljedeći zaključci. Prvo, može se vidjeti da sustav ima visoku prilagodljivost na promjene u svojem okruženju. Dva tipa proizvoda bila su u sustavu cijelo vrijeme izvođenja simulacije. Može se primijetiti da je sustavu bilo potreban određeni period da se prilagodi, tj. da stabilizira odstupanje od traženog vremena završetka proizvoda. Osobito se to može primijetiti na rezultatima na kraju simulacijskog testa, kada sustav prelazi u stabilno stanje. Moramo naglasiti da su pri samom dizajnu agenata u simulacijskom modelu korištena jednostavna pravila, a agenti također imaju limitiranu sposobnost učenja.

5. RESULTS AND DISCUSION

To analyze the behaviour of the proposed model, several simulation runs of the flexible manufacturing cell have been performed. Four product types have been simulated; their production was started in different time intervals by random choice. The results from one average simulation run are shown in Figure 5. From the presented results, the following can be seen: that the system overall has high adaptability to the dynamic changes in its environment. Two types of products have been introduced throughout the entire simulation time. The other two types have been introduced randomly. Due to that reason, the system needs some time to adapt to changes in the environment, to reach equilibrium state. The intention to reach the equilibrium state is strongly presented at the end of the simulation run. It is necessary to state that during agent model design, the simple rule set has been used to describe agent capabilities; also agents have a limited ability of knowledge gathering.



Slika 5. Rezultati ostvareni u jednom prosječnom ciklusu simulacijskog ispitivanja
Figure 5. Results obtained from one average simulation run

Tablica 2. Postotak iskorištenja proizvodne opreme
Table 2. Utilization of the production equipment

	$\eta = (t_k / t_s)100$ %
Tokarililca	52,8
Obradni centar	69,1
Međuspremnik	98,1

a) Simulacijski model zasnovan na modelu job-shop
a) Simulation model based on the job-shop

	$\eta = t_k / t_s$ %
Tokarililca	79,6
Obradni centar	86,8
Međuspremnik	89,7

b) Simulacijski model zasnovan na multiagentnom modelu
b) Simulation model based on the multi-agent model

U tablici 2 prikazane su kumulative iskoristivosti pojedine proizvodne opreme modelirane u simulaciji, za model zasnovan na multiagentnom planiranju i na *job-shop* modelu upravljanja. Da bismo mogli kvalitativno evoluirati ovdje predloženu metodologiju, morali smo simulirati istovjetni sustav gdje je planiranje proizvodnje bilo zasnovano na principu *job-shop*. Može se primijetiti da je kumulativa iskoristivost vrlo visoka za model zasnovan na metodologiji MAS. Pored limitirane sposobnosti učenja sustav MAS je uspio prilagoditi se relativno brzo i vrlo uspješno u vrlo dinamičnom proizvodnom okružju.

In Table 2, the result of the production equipment average utilization for the overall simulation run is presented, for the model in which production planning and control was based on the MAS concept and for the model where the job-shop approach was used. This was done in order to be able to qualitatively evaluate the proposed methodology. It can be noticed, based on the presented results, that the model based on the MAS concept has shown better performance. Also it can be concluded that the model based on the MAS concept has shown the ability to relatively quickly adapt to the dynamic production environment.

6. ZAKLJUČAK

U ovome je radu prezentiran model kompleksnog proizvodnog sustava – tj. jednog njegova dijela: fleksibilne obradne ćelije – čiji je model definiran prema konceptu *emergent synthesis* (heterarhijska arhitektura zasnovana na konceptu BMS), te modeliran primjenom tehnologije multiagenata. Kao komunikacijski protokoli između agenata primijenjena su jednostavna pravila, te agenti posjeduju limitiranu sposobnost učenja.

Pored svih navedenih ograničenja modelirani sustav je pokazao zavidan stupanj prilagodljivosti u dinamičkom proizvodnom okružju. U isto vrijeme može se zaključiti da je sustavu bilo potrebno relativno dugo vrijeme da postigne ekvilibrij, stoga je potreban daljnji razvoj primijenjenih agenata te povećanje njihove sposobnosti učenja.

6. CONCLUSION

In this paper, a model of the complex production system was presented, i.e. one part of the system which was presented by the flexible manufacturing cell. The model was developed based on the Emergent Synthesis concept (based on the heterarhical structure presented by BMS concept), and modelled by using multi-agent techniques. As communication protocols, simple predefined rules were used and agents have limited possibilities of learning.

Even taking into account limitations of the modelled system, a high level of adaptability in the dynamic production environment has been shown. However, the modelled system has revealed a relatively extended time span necessary in order to reach equilibrium. This observation shows the necessity of improving communication protocols of the agents and also the necessity for better learning ability in order to be able to reach a stable state faster.

7. POPIS OZNAKA

7. LIST OF SYMBOLS

iskoristivost kapaciteta alatnog stroja	η,	%	utilization of the production equipment
obradno vrijeme	t_k,	s	machining time
ukupno vrijeme trajanja simulacije	t_s,	s	overall simulation time

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