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Računalniško upravljanje z obdelovalnimi orodji v orodjarni, podprto s simulacijo

Simulation-Aided Management of Cutting Tools in a Tool-Making Company

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V proizvodnih stroških orodjarn pomenijo rezalna orodja, poleg samih obdelovalnih centrov, največji delež stroškov. Po večini slabo urejeno skladiščenje ter slab pregled stanja rezalnih orodij se kaže v premajhni zasedenosti obdelovalnih centrov ter v relativno velikih stroških za rezalna orodja. Z dobro organiziranim in računalniško podprtim upravljanjem obdelovalnih orodij je mogoče te stroške zmanjšati, vendar to še vedno ni dovolj za učinkovito načrtovanje proizvodnje. Zato je namen tega prispevka osvetliti to področje, prikazati koncept računalniškega upravljanja z obdelovalnimi orodji, podprtega s simulacijo (RUOS) in predstaviti glavne značilnosti sistema RUOS, ki je plod raziskovalno-razvojnega dela laboratorija LASIM v sodelovanju s slovensko orodjarno.

(Ključne besede: sistem upravljalni, baze podatkov, proizvodnja, simuliranje, mreže Petri)

With the exception of machining centres, cutting tools are the most expensive items in the production costs of a tool-making company. Unorganised warehousing and poor monitoring of the condition of the cutting tools are still typical of such companies, and this results in the underuse of machining centres and high costs for the cutting tools. By using well-organized and computerized tool management of the cutting tools it is possible to reduce costs, but for the efficient planning of production this is still not enough. In this article we introduce the concept of Simulation-Aided Tool Management (SATM) and the main features of the SATM system, which was developed in cooperation with a tool-making company.

(Keywords: management systems, database, production, simulations, Petri nets)

0 UVOD

Večina orodjarn, ki izdelujejo orodja za preoblikovanje pločevine in brizganje plastike, ima posamezno proizvodnjo, za izdelavo pa uporabljajo najsodobnejše obdelovalne tehnologije in stroje. Tako se pojavlja vprašanje, kako povezati na eni strani popolnoma posebne proizvodne metode, na drugi strani pa velike stroške proizvodnje tako, da bo proizvodnja čimbolj donosna. Odgovor na to je zagotovo tudi dobro upravljanje s proizvodnimi sredstvi, med katerimi imajo obdelovalna orodja pomembno vlogo, saj so poleg samih obdelovalnih strojev tudi največji strošek.

O obdelovalnih orodjih in upravljanju z njimi je bilo že veliko govora, narejenih že veliko raziskav in razvitih že veliko sistemov. Obravnavani so bili tako z organizacijskega ([1] in [2]) kakor s tehnološkega vidika ([3] in [4]), na trgu pa se dobijo tržno dostopni programi za upravljanje z orodji, na primer CoroTAS, TDMeasy, ZOLLER Toolmanager

0 INTRODUCTION

Most tool-making companies still have individual methods for producing tools for sheet-metal forming and injection moulding, but for their machining they use the most up-to-date technologies and machines. The question is how to bring together the totally individual methods of production and the high costs of such an industry in such a way that the business is profitable. The solution is an appropriate production-management system in which the machining tools play a very important role, since they represent – after machining centres – the most expensive item in the production costs.

There has already been much discussion about the management of cutting tools, a lot of investigations have been made in this area, and a lot of systems have already been developed. The systems were treated from the organizational ([1] and [2]) as well as from the technological point of view ([3] and [4]), and there are many programmes for tool management already available on in drugi [5]. Vendar so redke orodjarne, ki so tak sistem uvedle in ga učinkovito uporabljajo v praksi, in to kljub temu, da se v orodjarnah zavedajo, da so stroški za obdelovalna orodja preveliki in da so stroji zaradi neustrezne logistike orodij slabše izkoriščeni.

Razlogov za tako stanje je več, glavni pa se kažejo v tem, da so orodjarne tipično posebna proizvodnja s svojimi posebnimi zahtevami in da kupljeni sistemi za upravljanje z orodji ne rešujejo organizacijskih problemov, saj so bolj ali manj namenjeni le upravljanju s podatki o orodjih. Tudi na splošno informacijske tehnologije same ne morejo reševati organizacijskih problemov, lahko pa dobro organiziran sistem podprejo, da je še bolj učinkovit. Pomemben razlog pa je tudi cena komercialno dostopnih sistemov in dejstvo, da ga je treba prilagoditi potrebam posameznih orodjarn in povezati z njihovo znano informacijsko tehnologijo.

Da bi osvetlili ta vprašanja predvsem z organizacijskega, se pravi logističnega vidika, in da bi postavili ogrodje sistema za upravljanje z obdelovalnimi orodji, ki bi bil prilagojen potrebam orodjarn, ter ga uvedli v prakso, je nastal projekt Računalniško upravljanje z obdelovalnimi orodji (RUO) [6]. Rezultati tega projekta so bili podlaga za koncept računalniškega upravljanja z obdelovalnimi orodji s podporo simulacije (RUOS), katerega namen v praksi je zmanjšanje stroškov za nakup in vzdrževanje obdelovalnih orodij, povečanje izkoriščenosti obdelovalnih strojev ter s tem povečanje dejanske zmogljivosti orodjarne ob ohranjenih enakih preostalih obratovalnih stroških ter povečanje zanesljivosti izpolnjevanja naročil.

1 KONCEPT RUOS

Koncept RUOS je osredotočen predvsem na upravljanje z obdelovalnimi orodji v oddelku z računalniško krmiljenemi centri (RK) obdelovalnimi centri, saj je tam izredno pomembno, da so obdelovalna orodja pripravljena v pravem trenutku in da so s tem stroji čimbolj izkoriščeni, se pravi, da čim več časa delajo in ne čakajo na obdelovance ali orodja.

Glede na to, da se vpenjanju ali prevpenjanju obdelovancev na stroju skoraj ne moremo izogniti, pa so lahko orodja že prej pripravljena in shranjena v zalogovniku orodij na samem stroju ali pa v vmesnem skladišču poleg njega. Da bi ugotovili, kako poteka delo, povezano z obdelovalnimi orodji, kakšno je stanje orodne logistike in katere so informacije, povezane z njimi, je bila narejena analiza, katere rezultati so bili podlaga za določitev želenega načina dela.

the market: for example, CoroTAS, TDMeasy and ZOLLER Tollmanager [5]. Still, it is hard to find a tool-making company that has introduced a tool-management system into its production in spite of an awareness that the costs of cutting tools are too high, and the machining centres are not used as they could be because of inappropriate tool logistics.

There are several reasons for this situation, but the main one is that tool shops tend to be based on individual forms of production that have particular demands. This means that the purchased tool-management system does not solve the organizational problems because these systems are designed only for the management of cutting-tools data. In general, information technologies cannot solve organizational problems; however, they can support a well-organized system in becoming more efficient. An important reason for this also lies in the price of commercially available systems – which is not negligible – and the fact that such a system has first to be adapted to the requirements of a particular production and integrated within existing information technologies.

The aim of the project called Computerized Tool Management (CTM) [6] is to help answer some of the questions of organizational, i.e. the logistical, point of view of cutting tools, and to develop the framework of an advanced tool-management system. This system should be adaptable to the needs of tool shops and should be initiated in practice. The results of the CTM project were used as a base for the new concept called Simulation-Aided Tool Management (SATM). The practical aim of SATM is to reduce the purchasing and maintenance costs of cutting tools, to increase the efficiency of machining centres with other fixed production costs (and with that, also the actual capacity of the tool-making company) and to increase the reliability with which orders are accomplished.

1 THE CONCEPT OF SATM

The concept of SATM is focused on tool management for CNC machining centres, because in these facilities it is very important that the cutting tools are prepared for machining at the right time, and that the machining centres are used as much as possible, e.g. the cutting tools work most of the time and do not wait on the work-piece or cutting tools.

If clamping or re-clamping of the work-piece on machining centres is unavoidable, the cutting tools can be prepared beforehand and stored on the machining centre or in the buffer nearby. To find out the present course of the work and the state of the tool logistics as well as the information connected with them, an analysis was made, the results of which were a basis for the definition of the desired mode of work.

1.1 Želeni način dela

Na podlagi pogovorov s tehnologi, programerji, operaterji ter vodji proizvodnje in delavnice v orodjarni se je izoblikovalo želeno stanje, ki se da povzeti v naslednjih točkah:

- Tehnolog in programer programov števislkega krmiljenja (ŠK) izbirata orodja iz sedanje zaloge orodij, pri čemer so jima na voljo potrebni tehnološki podatki, parametri obdelav iz katalogov, parametri obdelav, ki so bili nastavljeni med samo obdelavo, in stanje, mesto nahajanja in razpoložljivost posameznega orodja.
- Izbrana orodja naj bi rezervirali, kar pomeni, da bi za vsak izdelek določili potrebno količino orodij in, če jih ne bi bilo dovolj, bi jih lahko pravočasno naročili.
- Poleg števila porabljenih orodij za vsak izdelek naj bi shranjevali tudi podatke o obdelovalnih parametrih, ki so bili predpisani, in njihove morebitne spremembe med samo obdelavo.
- Iskanje orodij v kartoteki ali pa v seznamu sedanjih orodij naj poteka tako po njihovih glavnih značilnostih kakor tudi po oznaki orodja in kataloški številki proizvajalca. Za boljši prikaz naj bodo seznami opremljeni s slikami posameznega orodja.
- Orodja, ki se ne uporabljajo, naj bodo shranjena na enem mestu, in sicer v osrednjem skladišču orodij (npr. v regalnem skladišču), ki ga upravlja en operater. Operaterji na strojih si jih lahko tudi sami izposojajo, s tem da se sproti zapisuje izdajanje in skladiščenje orodij.
- Orodja, ki so določena za uporabo v določenem dnevu, se prej pripravijo, kar lahko naredi operater skladišča. Če pride do obrabe ali loma orodja med obdelavo, lahko to stori tudi operater stroja, če je operater skladišča prezaposlen ali odsoten.
- Vsi podatki o lastnostih nastavljenega orodja se zapišejo in vnesejo v krmilnik obdelovalnega stroja, ko se določeno orodje uporabi, ali pa ob polnjenju zalogovnika za orodja.

Naštete so le najpomembnejše značilnosti želenega dela z orodji, ki so bile osnova za snovanje sistema za računalniško upravljanje z obdelovalnimi orodji v orodjarni(RUOS).

1.2 Koncept RUOS

RUOS je sistem, s katerim načrtujemo, krmilimo in nadzorujemo tok obdelovalnih orodij in njihove informacije v orodjarni.

Aktivnosti, ki jih sistem pokriva, so naslednje:

- izbira rezalnih orodij in rezalnih razmer,
- nakup in skladiščenje sestavljenih orodij ali njihovih delov,
- montaža in nastavljanje orodij,

1.1 Desired mode of work

On the basis of many discussions with technologists, programmers, operators and workshop chiefs, the desired conditions were obtained and are listed below:

- The technologist and the NC programmer choose the cutting tools from the existing tool store and they have to have at their disposal the required technological data, the machining parameters from catalogues, the machining parameters which were set during machining and the condition, the location and the availability of an individual cutting tool.
- The selected cutting tools should be reserved beforehand, which means that the required quantity of each cutting tool should be anticipated and if not enough of them are available in the workshop then they can be ordered in time.
- In addition to the number of cutting tools used for each product the machining-parameters’ data that was prescribed should also be stored as well as their eventual changes during machining.
- Searching for cutting tools in the card index or in the list of existing tools should be based on their characteristics as well as on the cutting-tool designation and the producer’s catalogue number. For a better review, lists should be equipped with images of individual cutting tools.
- Cutting tools that are not in use should be stored at a single location, at the central cutting-tool warehouse (in an automatic shelf warehouse), managed by a single operator. Operators at machining centres can lend cutting tools, but they must note down every time a tool is removed or returned to storage.
- Cutting tools that are required for use on a particular day are given a preliminary preparation, and this is the warehouse operator’s duty. If the tool wears out or breaks during machining each machine operator can do the preparation if the warehouse operator is busy or absent.
- All data about a particular cutting tool’s attributes are written down and entered in the controller of the machining centre when a defined cutting tool is in use or at a cutting tool’s magazine filling.

Only the most significant requirements that contribute to the planning of the system for Simulation-Aided Tool Management (SATM) are included.

1.2 Concept SATM

SATM is a system for planning, controlling and monitoring a cutting tool’s flow as well as the information flow in a tool-making company.

The system covers activities like:

- tool and machining-condition selection,
- purchasing and warehousing of the cutting tools and their parts,
- assembly and presetting of cutting tools

- transport orodij na obdelovalne stroje,
- posodabljanje podatkov o obrabljenosti in stanju orodij,
- čiščenje, demontaža in pregled orodij in njihovih sestavnih delov,
- vzdrževanje razalnih orodij in njihovih sestavnih delov,
- ponovno skladiščenje orodij ali njihovih delov.

Ker je ta krog uporabe zelo dinamičen, je zanj potrebna računalniška podpora, saj lahko le z njeno uporabo spremljamo dejansko stanje in razpoložljivost posameznega orodja ali delov v orodjarni, kar je za načrtovanje proizvodnje in sprejemanje naročil bistveno.

Sistem je zasnovan na splošnem modelu sistema za upravljanje z orodji [5] in obsega bazo podatkov orodnih kart, delov orodij in sestavljenih orodij. Dodatni uporabniški programi skrbijo za uporabniško primeren vnos in iskanje podatkov v bazi, za načrtovanje in krmiljenje poti in terminov orodij v orodjarni ter za nadzor stanja orodij. Sistem je načrtovan sicer za določeno orodjarno, vendar pa je odprt in prilagodljiv katerikoli orodjarni.

V konceptu so bile opredeljene, pri razvoju pa so bile vodilne pomembne značilnosti sistema RUOS, te so:

- Odprtost, ki omogoča preprosto prilagoditev ali razširitev sistema posebnim zahtevam posameznih orodjarn.
- Modularnost, ki omogoča preprosto sestavo želenega sistema (aplikacije za vodenje razvoja orodij in rezalnih razmer, za nadzor obrabe orodij in za napovedovanje razpoložljivosti so posebni moduli, ki se lahko poljubno dodajo osnovnemu modulu).
- Uporabniška primernost (uporabniški vmesnik), ki ji je posvečena posebna pozornost, saj je od enostavnosti uporabe (na primer vnašanja in iskanja podatkov) odvisna uspešnost uvajanja sistema v prakso (človeški dejavnik).
- Avtomatsko vnašanje podatkov, kjer je to le mogoče. Tako porabi operater na stroju, pri nastavljanju ali montaži orodij in tudi pri skladiščenju kar najmanj časa za vnašanje ali iskanje podatkov.
- Sprotni in točni podatki o stanju in mestu orodij v orodjarni, ki se uporabljajo pri načrtovanju proizvodnje in načrtovanju tehnologije (programiranje ŠK).
- Integracija nadzora obrabe orodij v sistemu za upravljanje z orodji, saj je to podatek, ki poleg kraja in razpoložljivosti najbolje popiše stanje posameznega orodja v sistemu.
- Sistem za napovedovanje uporabe orodij, ki temelji na tehniki simuliranja diskretnih sistemov, saj lahko le z njo na podlagi predvidenega proizvodnega načrta in znanih postopkov obdelave dovolj natančno določimo, kakšno bo stanje sistema v prihodnje.

- transport of the cutting tools at machining centres,
- updating of information about cutting-tool usage and condition,
- cleaning, disassembly and inspection of cutting tools and their parts,
- maintenance of cutting tools and their parts,
- resume warehousing of cutting tools or their parts.

Because this life-cycle is very dynamic, computer support is required. Only with a computer-based system can the actual condition and availability of a particular cutting tool, or its parts, in a tool shop be obtained online. This is essential for production planning and the receiving of orders.

The system is designed on a common model of a system for tool management [5], and includes a tool card database, parts of tools and assembled tools. Additional user programs take care of user-type entering and searching data in the database, for planning and course control and tool terms in a tool shop and for monitoring the cutting tool's condition. The system has been planned for a specific tool-making company, but it is still open and adaptable to any tool-making company.

The essential characteristics that were considered and followed during the design of the SATM's system are:

- Openness, which enables simple adaptation or system widening to the specific demands of separate tool-making companies.
- Modularity, which enables the simple composition of a desired condition (applications for the history of the cutting tools' management and machining conditions, monitoring of the cutting tools' wear and modules for predicting availability, which can be easily connected by an elementary module).
- User friendliness (human-machine interface), to which special attention is paid because the efficiency of the SATM system depends on the simplicity of its use (for example, data entering and searching).
- Automatic data entry, whenever possible, so that the operator at the machining centre uses the minimum time during presetting or assembly or during warehousing for the entering or searching of data.
- Continuous and correct data about the cutting tool's condition and its place in the tool shop, both of which are used for production planning and technology planning (NC programming).
- Integration of tool-wear monitoring into the system for tool management. This is the information, which in addition to location and availability, best describes the condition of a particular cutting tool in the system.
- System for predicting a cutting tool's usage, which is based on the simulation technique of discrete systems. Only with this can we, on the basis of the expected production plan and the known machining procedure, define sufficiently accurately what will be the condition of the system in the future.

- Vodenje "razvoja" uporabe, obrabe in uporabljenih rezalnih razmer je potrebno tako za kasnejšo analizo toka orodij kakor tudi za analizo in izbiro orodij in rezalnih pogojev.

1.3 Zgradba sistema RUOS

Na podlagi želenih lastnosti sistema RUOS je bil razvit osnovni koncept njegove zgradbe, ki temelji na tehniki baz podatkov in simulacije in jo sestavljata dva modula, in sicer:
- osnovni modul, ki obsega podatkovno bazo vseh elementov rezalnih orodij, prav tako pa tudi sestavljenih orodij v orodjarni,
- modul za napovedovanje razpoložljivosti rezalnih orodij.

1.3.1 Osnovni modul

Osnovni modul je dejansko podatkovna baza, ki vključuje vse tehnične podatke, trenutni kraj in trenutno stanje posameznega rezalnega orodja v orodjarni. Modul je urejen tako, da ima vsako posamezno orodje enoznačno določeno prepoznavno številko. Sestavljena orodja so prepoznavna pod prepoznavno številko držala orodja, vsak na novo vnesen del v sistem pa dobi novo še ne uporabljeno prepoznavno številko. Deli, ki so izrabljeni in so zato izločeni iz sistema, "odnesejo" prepoznavno številko (PŠ) s seboj, tako da le-ta ne more biti uporabljena za označitev novih delov.

Podatki o različnih elementih orodij, na primer držala, adapterji, svedri, frezala, so shranjeni v različnih preglednicah z namenom, da je struktura podatkov zmanjšana na najmanjšo mero. Poleg teh preglednic je v sistemu ustvarjena preglednica vseh elementov v sistemu, v kateri so shranjeni podatki o PŠ, tipu, stanju ter lokaciji posameznega elementa.

Forme in poizvedbe so v osnovnem modulu izoblikovane na uporabniško primeren in učinkovit način. To je mogoče izvesti z uporabniškim vmesnikom, ki vključuje uporabo črtne kode ter posebnih nosil PŠ za vse sestavne dele orodij.

Pomemben del osnovnega modula je tudi preglednica vseh sprememb. V tej preglednici se zapisujejo vse spremembe pomembnih značilnosti za vsak sestavni del ali element. Tako je mogoče z uporabo te preglednice pridobiti stanje poljubnega rezalnega orodja v poljubnem trenutku preteklosti. Prav tako ta preglednica zagotavlja podatke o vodenju popolnega razvoja za vsak posamezen element in je pomembna kot vir podatkov za kasnejše analize.

1.3.2 Modul napovedovanja razpoložljivosti

Modul napovedovanja porabe orodij temelji na zamisli, ki pravi, če je mogoče iz preglednice

- Managing the "history" of usage, wearing out and the applied machining conditions are needed for later analysis of the cutting tool's flow as well as for analysis and selection of the cutting-tools and the machining conditions.

1.3 Developed tools of SATM

Based on the desired characteristics of the SBTM system, a conceptual solution has been proposed that is based upon a database and a simulation technique. It consists of two modules:
- a basic module that includes a database of all tool elements and parts as well as the assembled tools in the workshop,
- a module for predicting the cutting tools' availability.

1.3.1 Basic module

The basic module is actually a database with all the data relating to the technical specification, the location and the temporary condition of the cutting tools in the workshop. It is organised in such a way that each part of the tools has a unique identification (ID) number. The assembled tools take over the identification number of the tool holder and each new part of the tools gets a new identification number. The parts that are worn out and removed from the system take the ID number with them, so it cannot be used for any new parts.

The data of different types of parts, such as tool holders, adapters, drills or milling borers, for example, are recorded in different tables, so the data structure is reduced to a minimum. Besides these tables, there is also a table of all the elements in the system, where the ID, type of element, condition and location of the element are recorded.

The forms and queries of the basic module are organised in a user-friendly way. With the implementation of barcode readers and special ID holders for all the parts or elements, the human-machine interface is as efficient as possible.

The important part of the basic module is the table of all the changes. In this table all the changes to any significant characteristics of every part or element in the database are recorded. In this way, from any state of the database, previous states can be restored. In fact for each element the whole history is recorded and can be implemented for analysis.

1.3.2 Predicting module

The predicting module is based on the idea that if any previous state of the tools in the system sprememb dobiti podatke o stanju sistema za poljuben čas v preteklosti, je mogoče za znano preglednico sprememb dobiti tudi stanje v prihodnosti. Iz tega stanja pa je mogoče napovedati razpoložljivost rezalnih orodij v prihodnosti.

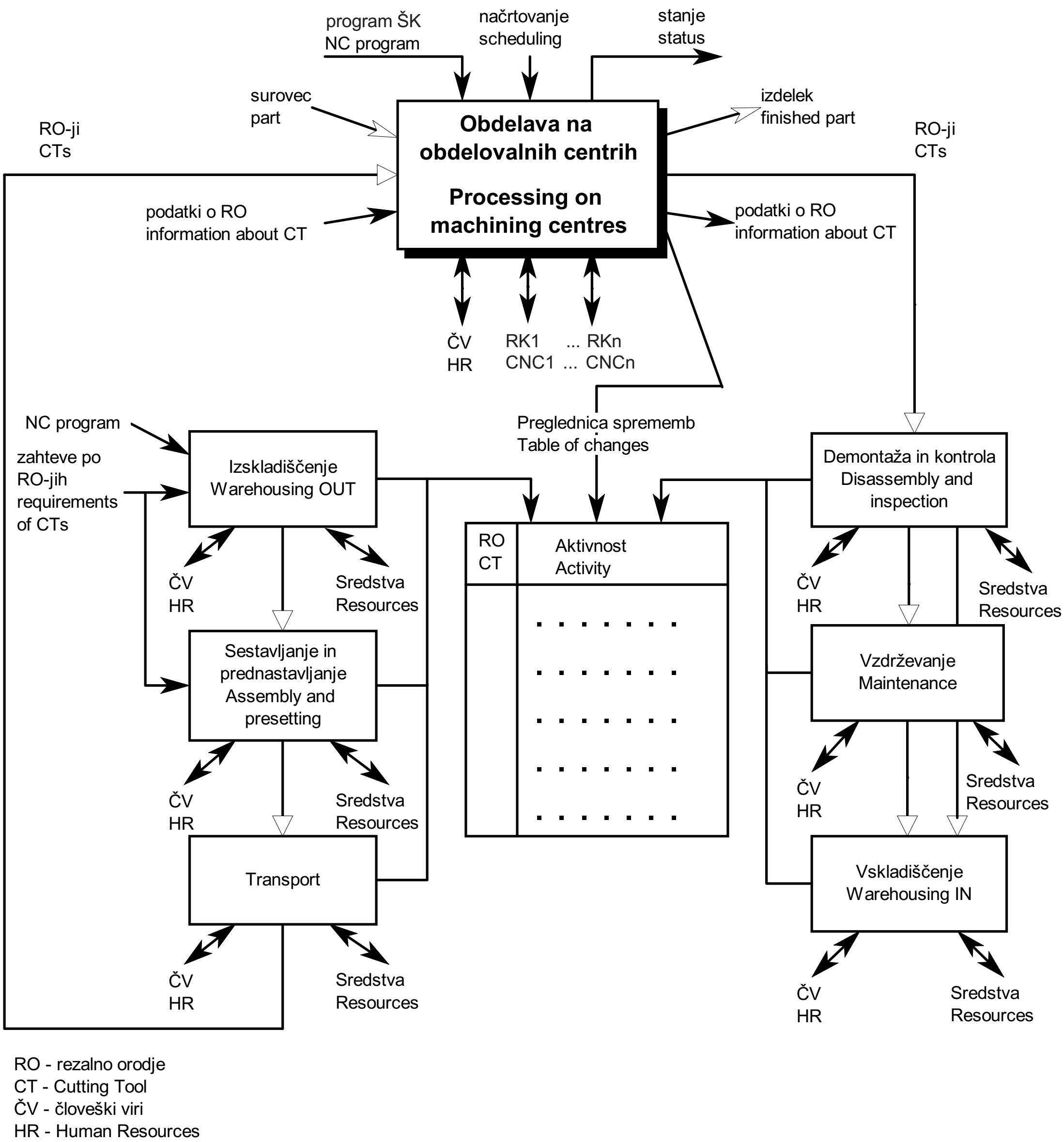
Toda vprašanje je, kako dejansko dobiti preglednico sprememb vnaprej. Ena od možnosti je z uporabo simulacije, saj je na podlagi poznanega proizvodnega načrta, terminskega načrta, programov ŠK ter obdelovalnih parametrov mogoče "dejansko" proizvodnjo simulirati. Tako je mogoče dobiti podatke o razpoložljivosti in stanju rezalnih orodij za določeno časovno obdobje vnaprej.

S simulacijo proizvodnje lahko tako dobimo podatke o potrebnih rezalnih orodjih. Če vsebuje simulacijski model toka elementov v orodjarni tudi tok rezalnih orodij, potem so aktivnosti, ki so potrebne za podporo tega toka, neposredno povezane s

can be obtained using the table of changes, then any future state can also be obtained if the recorded changes are known. From this the availability of tools during a particular period in the future can be predicted.

However, there is the question of how the table of changes can be obtained in advance. One approach is to implement a simulation technique. If the production plan, scheduling, NC programmes and operating parameters are known, "real" production can be simulated in advance. So the future state of the system can be obtained for the period of time when we want to know the availability and condition of the cutting tools.

So the simulated production can be a generator of requirements for the cutting tools. If the simulation model of the part flow on the shop floor is extended with cutting-tools flow, then the activities



Sl. 1. *Aktivnosti, ki podpirajo tok rezalnih orodij in preglednica sprememb*
Fig. 1. *Activities supporting the cutting-tools flow and the table of changes*

spremembo podatkov v podatkovni bazi orodij. Ta postopek je dejansko način za ustvarjanje preglednice sprememb (sl. 1), s tem da mora biti v tem primeru simulacijski model povezan ali pa integriran s podatkovno bazo.

2 SIMULACIJA NA PODLAGI RAZŠIRJENIH PETRIJEVIH MREŽ

Na trgu je dandanes mogoče dobiti več simulacijskih programov in jezikov, ki pa niso praktični za preprosto uporabo, niti jih ni mogoče preprosto integrirati v sistem podatkovnih baz, kar sta zahtevi koncepta RUOS. Zato je bilo treba razviti poseben modul, s katerim lahko uporabnik transparentno izvaja simulacijo. Jedro tega modula je teorija Petrijevih mrež, saj so le-te na splošno zelo primerno orodje za modeliranje in simulacijo diskretnih sistemov in so tudi zelo dobro matematično podprte.

2.1 Petrijeve mreže

Od njihovega nastanka leta 1967 so osnovno teorijo Perijevih mrež nenehno razvijali in razširjali z namenom, da bi lahko z njimi čim bolje popisali in analizirali strukturo in obnašanje diskretnih sistemov ([7] in [8]). Prednost Petrijevih mrež se pokaže predvsem pri modeliranju, saj je to preprosto in močno orodje, ki ima tudi matematično podlago in s katerim lahko razumljivo popišemo strukturo opazovanega sistema. Šibkejša stran pa je analiza dinamičnega obnašanja opazovanega sistema, saj analitične rešitve v praktičnih primerih hitro pridejo do svojih meja.

Tako ostane za analiziranje dinamičnega obnašanja diskretnega sistema tehnika diskretne simulacije praktično najbolj sprejemljiva. Sicer je simulacija na podlagi modela aktivnosti (Petrijeve mreže) v praksi najmanj uporabljana, saj naj bi bila počasnejša od simulacije na podlagi modela dogodkov in procesov, je pa za uporabo, pri kateri se med samo simulacijo poleg parametrov spreminja tudi model in pri kateri je potrebno sodelovanje drugih programov ali pa uporabnika, bolj primerna [9].

V bistvu je Petrijeva mreža (PM) usmerjen, obtežen, dvostranski graf z dvema tipoma vozlišč, in sicer z mesti in prehodi (teoretične osnove razširjenih Petrijevih mrež so podane v [10]), v pričujoči uporabi pa lahko mesta uporabimo kot stanje sistema, prehode pa kot aktivnosti, ki vodijo iz enega stanja v drugo. Mesta na vhodu v aktivnost lahko razumemo kot pogoje in mesta na izhodu iz aktivnosti kot posledico izvajanja te aktivnosti. Iz take opredelitve že lahko intuitivno sklepamo, da obstaja formalna povezava med preglednico sprememb, ki je jedro sistema RUOS, in načinom modeliranja s Petrijevimi mrežami.

needed to support this flow are directly connected with the changing of information in the tool database. In this way the table of changes can also be obtained (Fig. 1). For this, however, the simulation has to be connected or integrated with the tool database.

2 SIMULATION BASED ON EXTENDED PETRI NETS

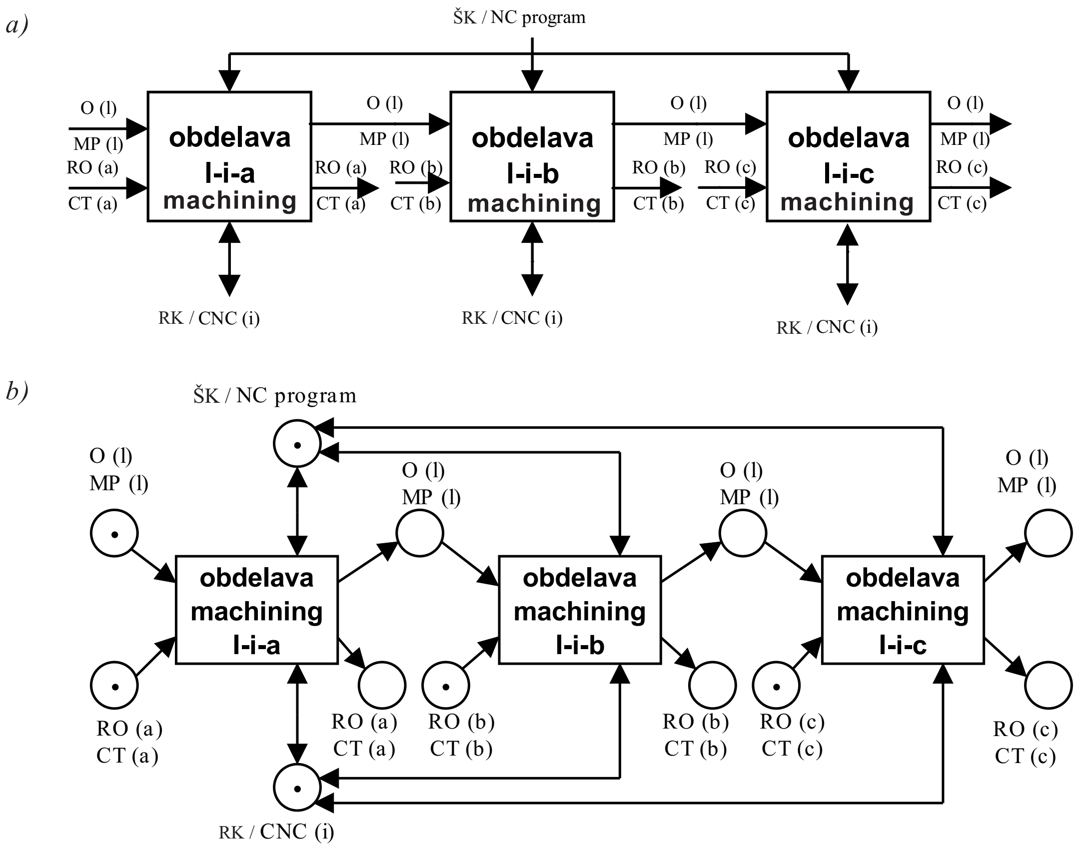
There are many simulation programmes and languages available on the market, but they cannot be so easily integrated into the database system as the SATM concept. For this reason a special module has to be developed that enables a transparent wxecution of the simulation. The core of this module is the Petri nets' theory, which is a very convenient tool for modelling and simulating discrete systems because it is mathematically well supported.

2.1 Petri nets

The basic theory of Petri nets was developed in 1967, and since then it has been constantly developed and enhanced with the aim of using it to describe and analyse the structure and behaviour of discrete systems as well as possible ([7] and [8]). The advantage of using Petri nets is their modelling ability, they are easy to use and are powerful tools that make it possible to describe an observed system's structure. Their weak point is an ability to analyse the dynamic behaviour of an observed system because of the limitation of analytical solutions for practical cases.

The discrete simulation technique is, in practice the most appropriate way to obtain the dynamic behaviour of a discrete system. In practice, the simulation on the basis of the activity model (Petri nets) is not often used because it would be slower than event- or process-based simulations. But in cases when the parameters and model are changing during the simulation process and the interaction of other programmes or users is needed, the activity-based simulation is more convenient [9].

In the basic theory, the Petri net (PN) is a directed, weighted, bipartite graph consisting of two types of nodes, called places and transitions (the theoretical basis of extended Petri nets can be found in [10]). In the present case, places represent the state of the system and transitions represent activities that lead from one state to another. Input places of particular activity can be understood as conditions, and output places of activity as consequences of activity execution. From this definition we can infer intuitively on a formal connection between the table of changes, that is the core of the SATM system, and the modelling method with Petri nets.



O - obdelovanec
MP - machninig part
RO - rezalno orodje
CT - cutting tool

Sl. 2. *Primer dela obdelave na RK stroju, predstavljen z modelom aktivnosti (a) in modelom Petrijevih mrež (b)*
Fig. 2. *An example of CNC machining, represented by (a) activity model and (b) Petri nets' model*

2.2 PM in preglednica sprememb

Preglednica sprememb je dejansko zaporedje aktivnosti v delavnici, ki so povezane s sestavljenimi orodji ali njihovimi elementi. Če pogledamo na primer obdelavo na RK obdelovalnem centru RK(i) z določenim orodjem(j), potem lahko diagram aktivnosti (generični diagram aktivnosti GDA) prevedemo po analogiji GDA-PM [9] v graf Petrijeve mreže (sl. 2) v razširjeni inačici, pri kateri so uporabljeni žetoni objektnega tipa z atributi, ki se med aktivnostjo lahko spremenijo. V preglednico sprememb se zapišejo samo aktivnosti in posledice (stanja na izhodu iz aktivnosti). Za primer modela na sliki 2 je preglednica sprememb prikazana na sliki 3.

Izvajanje modela Petrijeve mreže oziroma simulacija poteka tako, da se v določenem trenutku izvede tisti prehod t_i, ki je takrat omogočen, s tem pa se spremeni stanje M_k v M_{k+1}, kar lahko zapišemo z enačbo stanja kot:

2.2 PN and table of changes

The table of changes is actually a sequence of activities in a workshop that are related to cutting tools or their parts. For example, the activity diagram (generic activity diagram GAM) for a process on a CNC machining centre CNC(i) with a particular cutting tool (j) can be translated, on the basis of an analogy between GAM and PN [9], into an extended Petri nets' graph, where an object type of tokens with attributes are implemented and can be modified during activity execution. The table of changes contains records of particular activity, and the changes related to the cutting tools (output places of an the activity). The table in Figure 3 is, for example, a table of changes for the model in Figure 2.

The execution of the Petri nets' model, e.g. a simulation, is carried out by firing the enabled transitions. In a single moment only a transition t_i, which is enabled, fires, and so changes the state M_k to a new state M_{k+1}, which can be written using the state equation as:

$$M_k = M_{k-1} + C^T u_k \quad (1),$$

aktivnost activity	PŠ orodja cutting tool ID	atribut 1 attribut 1	atribut 2 attribut 2	…	atribut n attribut n
…	…	…	…	…	…
obdelava () cutting process ()	orodje j cutting tool j	preostala doba trajanja orodja residual life span of cutting tool	parametri obdelave cutting process parameters	…	mesto v zalogovniku place in tool storage
obdelava () cutting process ()	orodje j cutting tool j	preostala doba trajanja orodja residual life span of cutting tool	parametri obdelave cutting process parameters	…	mesto v zalogovniku place in tool storage
obdelava () cutting process ()	orodje j cutting tool j	preostala doba trajanja orodja residual life span of cutting tool	parametri obdelave cutting process parameters	…	mesto v zalogovniku place in tool storage
…	…	…	…	…	…

Sl. 3. *Preglednica sprememb*
Fig. 3. *Table of changes*

kjer sta C dogodkovna matrika in u_k vektor proženja , v katerem so vsi elementi nič razen na i- tem mestu je 1, kar pove, da se je v k-tem proženju izvedel prehod t_i.

where C is the incidence matrix and u_k is the firing (or control) vector with all the elements equal to zero, except for the element on the i^{th} place, which is equal to 1. This represents to execution of the transition t_i at k- firing.

Proženje prehodov se ponavlja, dokler se izvajanje modela ne ustavi. Celoten potek simulacije lahko zapišemo tudi kot zaporedje prehodov:

The firing of enabled transitions is repeated until the execution of the model is interrupted or there are no more enabled transitions. The total simulation course can also be written as a firing sequence:

$$\{u_1, u_2, \dots u_d\} \quad (2),$$

ki pripeljejo sistem iz začetnega M_0 v končno stanje M_d, samo izvajanje pa zapišemo z enačbo stanja kot:

that brings the observed system from the initial state M_0 to the final state M_d. This can be written using the state equation as:

$$M_d = M_d + C^T \sum_{k=1}^{d} u_k \quad (3).$$

Preglednico sprememb za celoten model lahko zapišemo kot zaporedje elementov:

The table of changes for the entire system can be written as a sequence of components:

$$\{\{u_1, M_1\}, \{u_2, M_2\} \dots \{u_d, M_d\}\} \quad (4),$$

kjer nam pove u_k, kateri prehod oziroma katera aktivnost se je izvedla v določenem trenutku, M_k pa stanje po tem izvajanju. Seveda bi bil tak zapis preobsežen in tudi nepotreben, saj nas zanimajo samo aktivnosti, ki povzročijo spremembo stanja na mestih, ki so povezana z orodji oziroma njihovimi elementi (RO(i) na sliki 2). Zato tvorimo podmnožico množice vsem prehodov:

where u_k represents a transition (activity) that has been executed in the instance k, and M_k represents the conditions (state) after that execution. This type of record is too extensive and unnecessary for the table of changes because the table only has important activities that cause changes to the places that are related to cutting tools or their elements (CT(i) on Figure 2). So a subset of all the transitions is determined as:

$$T_{RO} \subseteq \{t_1, t_2, \dots t_n\} \quad (5),$$

kjer velja za vsak t, da je vsaj eno vhodno ali izhodno mesto iz P_{RO} oziroma iz podmnožice množic vseh mest:

where for each t it holds that at least one input or output place is from P_{RO}, i.e. from a subset of all the places:

$$P_{RO} \subseteq \{p_1, p_2, \dots p_m\} \quad (6),$$

kjer velja za vsak p, da so v njem lahko objektni žetoni, ki pomenijo orodja ali njihove elemente.

Nadalje lahko opredelimo $\{v_1, v_2, \ldots v_l\}$ kot zaporedje, ki ga sestavljajo samo tisti elementi zaporedja $\{u_1, u_2, \ldots u_d\}$, katerih prehodi t so iz množice T_{RO}.

V preglednici sprememb stanja orodij tudi ne potrebujemo stanja celotnega sistema M_k, temveč samo stanje izhodnega mesta $p \in P_{RO}$ prehoda t, ki se je izvedlo v proženju k, kar zapišemo z r_k.

Iz tega lahko zapišemo preglednico sprememb stanja orodij kot zaporedje elementov:

which only places, with object-type tokens that represent cutting tools or their elements can be part of.

A further sequence $\{v_1, v_2, \ldots v_l\}$ can be defined, which contains only elements from the sequence $\{u_1, u_2, \ldots u_d\}$, whose transitions t are from the set T_{RO}.

In the table of changes of the cutting tools' state, there is no need for a record of the entire system state M_k, but only the state r_k, which describes the condition of the output place $p \in P_{RO}$ of transition t that has been executed in the firing instance k_k.

So the table of changes can be determined as a sequence of elements:

$$\{\{v_1, r_1\}, \{v_2, r_2\} \ldots \{v_l, r_l\}\} \quad (7).$$

Ker imajo vsa mesta $p \in P_{RO}$ kapaciteto 1, kar pomeni, da je lahko v določenem trenutku v takem mestu samo en objektni žeton, je stanje izhodnega mesta r_k opredeljeno kar z žetonom oziroma z atributi tega žetona, ki dejansko pomenijo stanje določenega orodja ali elementa orodja.

The capacity of all the places from P_{RO} is 1, so in a particular place $p \in P_{RO}$, only one object's token can be present at a time. From that the output place condition r_k is determined with a token or attributes that actually represent the condition of a particular cutting tool or its elements.

2.3 Izvajanje simulacije

Opisana povezava modela Petrijeve mreže in preglednice sprememb je formalna in tudi matematična osnova za razvoj simulacijskega sistema, s katerim lahko zgradimo model in izvajamo simulacijo, pri čemer se ustvari tudi preglednica sprememb.

Jedro sistema je simulacijski programom PN_EXE [9], ki izvaja na teoriji razširjenih Petrijevih mrež osnovan model opazovanega sistema. Za simulacijo delavnice in toka orodij je bil PN_EXE razširjen z objektnimi žetoni in z možnostjo generiranja preglednice sprememb.

2.3 Executing the simulation

The described relationship between the Petri-net model and the table of changes is a formal and also a mathematical basis of the developed simulation system, which is used for model generation and simulation execution, where the table of changes is also obtained.

The core of the system is the simulation programme PN_EXE [9] that executes the simulation model of the observed system based on extended Petri nets' theory. For the workshop and cutting-tools flow simulation the PN_EXE has been extended with object tokens, which represent cutting tools, and have te ability to generate the table of changes.

3 PRIMERI IN UGOTOVITVE

Preizkus delovanja postavljenega koncepta je bil izveden na preprostem primeru iz prakse, ki obsega regalno skladišče orodij in delo operaterja, ki jemlje in vrača orodja v skladišče. Tak preprost primer je bil uporabljen predvsem zato, ker so bili na voljo dejanski podatki o stanju orodij v regalnem skladišču in preglednica sprememb za obdobje treh mesecev, ki jo je v dejanski orodjarni izpolnil za omenjeno obdobje operater sedanjega regalnega skladišča.

Za preizkus sta bila izdelana baza podatkov obdelovalnih orodij (kot sistem RUO) in simulacija delovanja opisanega primera (kot modul za napovedovanje razpoložljivosti obdelovalnih orodij). Za bazo podatkov je bil uporabljen MS Access, aplikacija pa je bila napisana s programskim jezikom Visual Basic.

Preizkus je bil sestavljen iz ažuriranja baze podatkov obdelovalnih orodij na podlagi prejšnjega

3 EXAMPLES AND DISCUSSION

The SATM concept was tested on a simple practical example that includes a cutting-tools warehouse and an operator that takes cutting tools from and back to the warehouse. This simple example was used as a test bed because we had the actual data about cutting tools in the warehouse as well as the table of changes for a period of three months, which was completed by the operator of the warehouse.

For a test, a database of cutting tools (as a CTM system) and the simulation model of the described example (as a module for forecasting the availability of cutting tools) were completed. For the database management system we used MS Access, and the application program were written in the Visual Basic program language.

The test was conducted by updating the database of the cutting tools on the basis of the previstanja ter dejanske preglednice sprememb in nastajanja preglednice sprememb s simulacijo dela operaterja. Glavne rezultate preizkusa in izkušnje, pridobljene pri razvoju sistema RUOS in pri praktični uporabi baze podatkov obdelovalnih orodij v orodjarni (RUO), lahko strnemo v naslednje ugotovitve:

– Baza podatkov obdelovalnih orodij se je pravilno ažurirala, saj so bili podatki o obdelovalnih orodjih v bazi enaki dejanskemu stanju orodij v sistemu. To dokazuje uporabnost izdelanega algoritma.
– Tudi na temelju simulacije nastala preglednica sprememb je bila enaka dejanski preglednici sprememb, kar potrjuje pravilnost simulacijskega programa glede na postavljeno matematično formulacijo in potrjuje veljavnost modela glede na dejanski opazovani sistem.
– Za industrijsko uporabo bo potrebno razviti koncept in algoritme uporabiti na primernejšem informacijskem sistemu kakor je MS Access, tako da ga bo moč integrirati z veljavnimi informacijskimi tehnologijami posamezne orodjarne in tako uporabiti že znane podatke in tudi drugim uporabam omogočiti dostop do podatkov o obdelovalnih orodjih.
– Sistem RUOS bo glede na izkušnje s sistemom RUO za regalno skladišče v praksi za uporabnika uspešen le z učinkovitim vmesnikom, saj bo deloval pravilno le, če bo zagotovljeno dosledno vnašanje in ažuriranje podatkov.

4 SKLEPI

Koncept računalniškega upravljanja z obdelovalnimi orodji je nastal na podlagi potreb in želenega načina dela v orodjarnah. Kljub njihovi enostavnosti in razumljivosti je orodjarna oziroma njen proizvodni del tako zapleten sistem, da je težko preprosto razviti in vpeljati tak informacijski sistem, ki bi izpolnil vse potrebe in želje. Kljub temu pa rezultati dosedanjega dela pri razvoju sistema RUOS kažejo, da bo mogoče postavljen koncept tudi uresničiti.

Seveda pa bo treba imeti za uvajanje sistema RUOS v orodjarne poleg znanja in izkušenj tudi zaupanje potencialnih uporabnikov, da bo njegova uvedba v orodjarnah res reševala problematiko orodne logistike. Zato je treba hkrati z izdelavo industrijske različice sistema RUOS razviti tudi sistem, s katerim se bo lahko prikazalo, da obstaja v orodjarnah veliko pomanjkljivosti, za katere niti ne vejo, ker nimajo o tem ustreznih podatkov, in ki jih je z uvedbo sistema RUOS mogoče odpraviti.

ous state and the actual table of changes, and by generating the table of changes with the simulation of the operator's work. The results of the test and the experience gained by developing the SATM system and by practical use of the cutting tools' database in the tool-shop (CTM) can be summarised as follows:

– The database of cutting tools was updated correctly since the data of the cutting tools in the database were the same as the actual state of the cutting tools in the warehouse. This proves the applicability of the elaborated algorithm.
– The table of changes generated with the simulation was identical to the actual table of changes, which confirms the simulation program regularity regarding the set of the mathematical formulation and confirms the model validity regarding the actual observed system.
– For an industrial application it will be necessary to apply the developed concept and algorithms on a more suitable information platform than MS Access, so that it will be possible to integrate the SATM system within the existing information technologies of a particular tool-shop. In this way the SATM can use the necessary data from other applications and give other applications access to the cutting-tools data.
– According to our experiences with the SATM if will only be successful in practice if there is an efficient user interface. In other words, the SATM system will operate properly only if consistent recording and updating of the cutting-tools data is ensured.

4 CONCLUSIONS

The concept of computerized tool management was developed on the basis of requirements and the requested way of working in tool shops. In spite of its simplicity and comprehensibility, the tool shop, or its production part, is a very complex system. An informational system that would satisfy all the needs and requests is hard to develop and introduce. In spite of this the results of the SATM system development indicate the possibility of realizing the planned concept.

In order to introduce the SATM system in tool shops it will certainly be necessary to make potential users of the SATM system believe will help it them to solve problems of cutting-tool logistics. In parallel with the development of an industrial version of SATM it is necessary to develop a system that will point out the existence of deficiencies in tool shops, which are unknown because of the unsuitable data and which could be easily suppressed by initiating the SATM system.

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