

Metodologija upravljanja in nadzora kompleksnih prilagodljivih obdelovalnih sistemov

Scheduling of Complex Flexible Manufacturing Systems - Methodology Design

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V članku je opisana postopna metodologija gradnje strategije upravljanja in nadzora kompleksnih prilagodljivih obdelovalnih sistemov za različne scenarije delovanja. Metoda omogoča problematiko usmerjeno upravljanje sistemov. Z njo lahko zagotovimo dva najpomembnejša cilja: funkcionalnost in velik izkoristek obdelovalnega sistema. Model sloni na metodah prioritete in čakalnih vrst za naročila in posamezne aktivnosti. Model je bil izveden v praksi za tri segmente prilagodljivega obdelovalnega sistema: prilagodljivo obdelavo, montažo in transport (POMT).

Ključne besede: sistemi obdelovalni fleksibilni, načrtovanje, upravljanje, optimiranje, sistemi logistični, analize sistemov

The step-by-step methodology of design of scheduling scenarios and strategies for different complex flexible systems is described. This approach offers the possibility of designing a task oriented scheduling of the system and achieving the two main aims: functionality and high efficiency of the system. The concept is based on priority structures and queues of orders and activities. This concept is implemented and verified on three flexible systems: flexible manufacturing system, flexible assembly system and flexible transport system; as a part of CIM factory solution.

Key words: flexible manufacturing systems, scheduling, planning, optimization, logistics systems, system analysis

0 UVOD

Moderno prilagodljivo obdelovalno sistemi (POS) so sestavljeni iz standardnih strojnih komponent, to so: obdelovalni stroji, avtomatsko upravljeni vozički (AGV), roboti, skladiščni vmesniki, avtomatska skladišča (AS), računalniki in programska oprema. Posamezne komponente še ne zagotavljajo zadovoljive funkcionalnosti POS. Pri snovanju in gradnji POS moramo najprej rešiti probleme informacijske povezave. Izkoristek sistema je namreč neposredno odvisen od kakovostnih in inteligentnih rešitev, ki jih vgradimo v sistem. To je izjemno pomembno, saj medsebojno združimo vse funkcije in aktivnosti v POS, ki jih izvajajo različne komponente v sistemu, vključno s strojno in programsko računalniško opremo [1] in [13]. Da bi zagotovili optimalno delovanje kompleksnih POS z omejenimi viri in mnogimi ozkimi grli, moramo uporabiti inteligentna orodja in metode za optimizacijo delovnih scenarijev in reševanje konfliktnih situacij na inteligentni način. Ta zamisel je bila razvita v zadnjih sedmih letih v [2] do [5] in nato razširjena v [8]. Nanasi je razvil inteligentni nadzorni modul, Balič [9] in Pahole [10] sta razvila inteligentni vmesnik in model določanja prilagodljivosti POS. Rezultati praktične realizacije in preizkušanja so dobri. Slika 1 prikazuje tri najpomembnejše podsisteme POS in njegove strojne komponente.

Ta zamisel je primerna za uporabo v širokem razponu POS, z naslednjimi karakteristikami:

- 1) Raznolikost izdelkov: se spreminja v času dobe trajanja sistema.

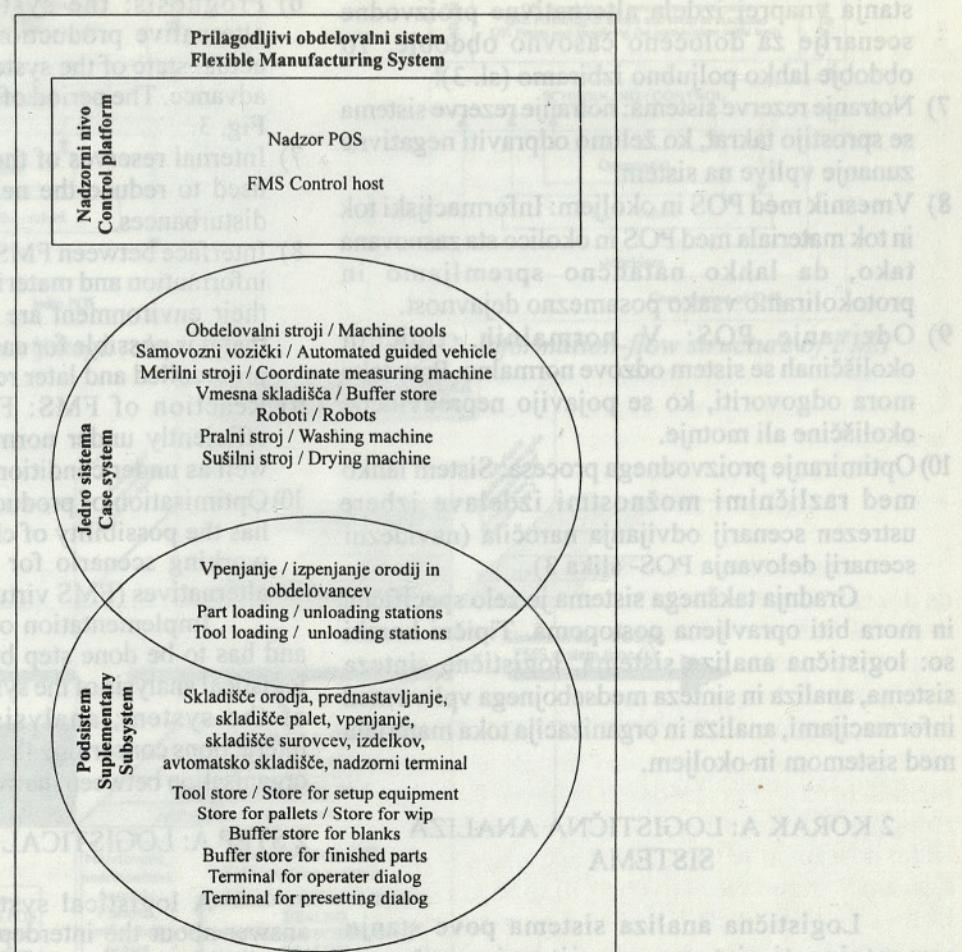
0 INTRODUCTION

Modern Flexible Manufacturing Systems (FMS) are composed from standard hardware components such as machine tools, computers, Automatic Guided Vehicles (AGV), robots, buffers, Automatic Storage and Retrieval Systems (ASRS) and software. The system components alone cannot guarantee the functionality of FMS. The information integration is the first and also the most important problem to be solved during the design of FMS. The efficiency directly depends on the quality of ideas and intelligence which are implemented during design. This is the unique medium which ties together all the operational functions and activities that are completed by different components of the system inside the FMS system border, including hardware and software [1] and [13]. In order to realise the complex FMS with limited resources, and overcoming a lot of bottlenecks, it is necessary to design and implement intelligent tools for optimisation of FMS working scenarios and to solve the conflict situation, and also to control such a system in an intelligent way. This concept has been developed during the last seven years in [2] to [5] and later expanded by Nanasi [8], Balič [9] and Pahole [10], who developed an intelligent interface module and a model of flexibility in FMS. The concept has been implemented in practice, has been tested and has shown good results. The three main subsystems of FMS and hardware system components are shown in Fig. 1.

This concept is most suitable for application over a wide range of flexible manufacturing systems with the following characteristics:

- 1) Range of products: open range changed during the lifetime of the system.

- 2) Velikost serije: od posameznih do več sto izdelkov.
- 3) Letna proizvodnja: od posameznih do več tisoč izdelkov.
- 4) Obdelovalni stroji: število in vrsta strojev sta v POS neomejena.
- 5) Koordinatni merilni stroji: vključeni so v sistem.
- 6) Merjenje in nadzor kakovosti med izdelavo.
- 7) Strežniki: Za normalno delovanje POS so potrebni intenzivni posegi operaterja v sistem. Njegove tipične naloge so: nastavljanje obdelovalnih strojev, zagotavljanje toka materiala, odpravljanje zastojev med delovanjem, upravljanje s centralnim nadzornim računalnikom.
- 8) Avtomatski transportni sistem.
- 9) Paletni sistem, ki se uporablja za tok materiala in orodij.
- 10) Material.
- 11) Omejeni proizvodni viri: proizvodni viri so omejeni tako po vrsti kakor po številu in se lahko časovno spreminja.
- 12) Vmesniki: jedro POS vsebuje različno število vmesnikov, ki se uporabljajo za začasno shranjevanje materiala in orodja.
- 2) Size of the run: from a few to several hundred pieces.
- 3) Yearly production: from a few to several thousand pieces.
- 4) Machine tools: the number and type of machine tools of one FMS is unlimited.
- 5) Co-ordinate measuring machine: included in FMS.
- 6) Measurement and quality control during the machining.
- 7) Servers: For the normal operation of FMS, intensive work by operators is required. Typical duties of operators involve the following: set up of machine tools; ensuring and supporting the material flow; correction of interruptions during production; operating the central FMS computer.
- 8) Automatic transport system.
- 9) Pallets: The whole material flow (the tools and pieces) is organised with pallets.
- 10) Material.
- 11) Limited production resources: The production resources are limited in type and number, and can vary from time to time.
- 12) Buffers: The core system of FMS includes a number of buffers which can be used for temporary storage of tools and pieces.



Sl. 1. Struktura POS in podsistemov

Fig. 1. FMS hardware structure and subsystems

1 LASTNOST POS

Z izvedbo zamisli, ki je prikazana na sliki 2, je mogoče doseči naslednje lastnosti POS:

- 1) Sistemsko samostojnost: POS postane avtonomen, ko imajo zunanje motnje omejen vpliv na izkoristek in funkcionalnost sistema.
- 2) Način delovanja: POS lahko deluje na dva načina:
 - a) vse obdelovalne stroje so upravlja en nadzorni računalnik,
 - b) sistem upravlja en centralni računalnik, vendar je določeno število obdelovalnih strojev izvzeto.
- 3) Izmensko prilagojeno delo: sistem lahko deluje s spreminjačim se številom operaterjev, glede na potrebe in izmeno dela.
- 4) Upravljanje in optimizacija uporabe proizvodnih virov: Vse proizvodne vire, ki bi lahko povzročili ozka grla, podredimo načinu upravljanja proizvodnih virov.
- 5) Diagnoza: Sistem ima vgrajene podsisteme za podrobno in obširno diagnozo, ki zajema stanje naročil v POS, proizvodne vire in trenutno stanje sistema.
- 6) Prognoza: Sistem lahko na podlagi trenutnega stanja vnaprej izdela alternativne proizvodne scenarije za določeno časovno obdobje. To obdobje lahko poljubno izbiramo (sl. 3).
- 7) Notranje rezerve sistema: notranje rezerve sistema se sprostijo takrat, ko želimo odpraviti negativne zunanje vplive na sistem.
- 8) Vmesnik med POS in okoljem: Informacijski tok in tok materiala med POS in okolico sta zasnovana tako, da lahko natančno spremljamo in protokoliramo vsako posamezno dejavnost.
- 9) Odzivanje POS: V normalnih, tipičnih okoliščinah se sistem odzove normalno. Prav tako mora odgovoriti, ko se pojavijo nepredvidene okoliščine ali motnje.
- 10) Optimiranje proizvodnega procesa: Sistem lahko med različnimi možnostmi izdelave izbere ustrezni scenarij odvijanja naročila (navidezni scenarij delovanja POS- slika 3).

Gradnja takšnega sistema je zelo specifična in mora biti opravljena postopoma. Tipični koraki so: logistična analiza sistema, logistična sinteza sistema, analiza in sinteza medsebojnega vpliva med informacijami, analiza in organizacija toka materiala med sistemom in okoljem.

2 KORAK A: LOGISTIČNA ANALIZA SISTEMA

Logistična analiza sistema pove stanje samostojnosti sistema, omejitve in možnosti celotnega sistema. Opraviti jo moramo v času snovanja sistema. Analize morajo biti opravljene za:

1 BEHAVIOUR OF FMS

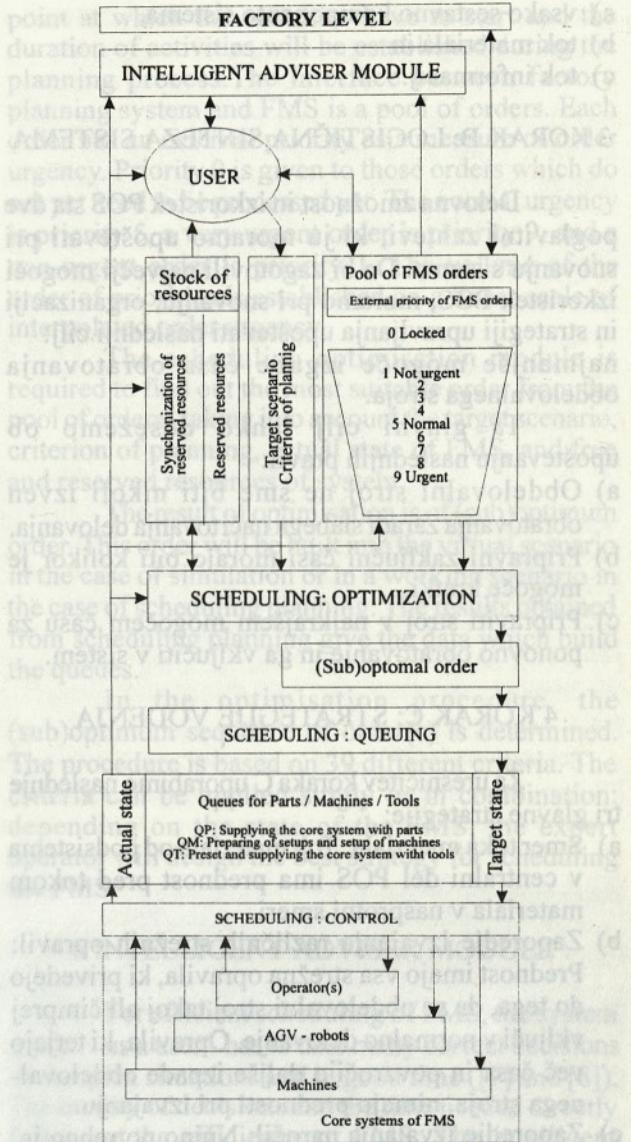
Through realisation of the concept shown in Figure 2, it is possible to achieve the following behaviour of FMS:

- 1) System autonomy: FMS achieves autonomy, which means that the disturbances coming from outside have a limited negative influence on the efficiency and function of the system.
- 2) Working mode: FMS has two working modes:
 - a) all machine tools are scheduled from a FMS control host computer,
 - b) the system is scheduled from the FMS control host computer but some machine tools are excluded.
- 3) Shift specific mode: The system can work in a situation of a varying number of shop floor operators during a shorter period of time, or even during shifts.
- 4) Management and optimisation of use of the production resources: All production resources which might cause a bottle-neck will be organised by the management resources.
- 5) Diagnostic: the system has a very detailed and broad diagnostic which refers to the FMS orders, production resources and state of the system.
- 6) Prognosis: the system is able to develop alternative production scenarios, based on the actual state of the system, for a period of time in advance. The period of time can be freely chosen, Fig. 3.
- 7) Internal reserves of the system: reserves will be used to reduce the negative influence of outer disturbances.
- 8) Interface between FMS and the environment: the information and material flow between FMS and their environment are organised in such a way that it is possible for each single transaction to be protocolled and later reconstructed.
- 9) Reaction of FMS: FMS react flexibly and efficiently under normal, typical conditions as well as under conditions of disturbance.
- 10) Optimisation of production process: The system has the possibility of choosing the most suitable working scenario for the different production alternatives (FMS virtual scenarios - Fig. 3).

Implementation of this concept in specific and has to be done step by step. Typical steps are: logistical analysis of the system; a logistical synthesis of the system; analysis and synthesis of the interactions concerning the information, material and organisation between the system and its environment.

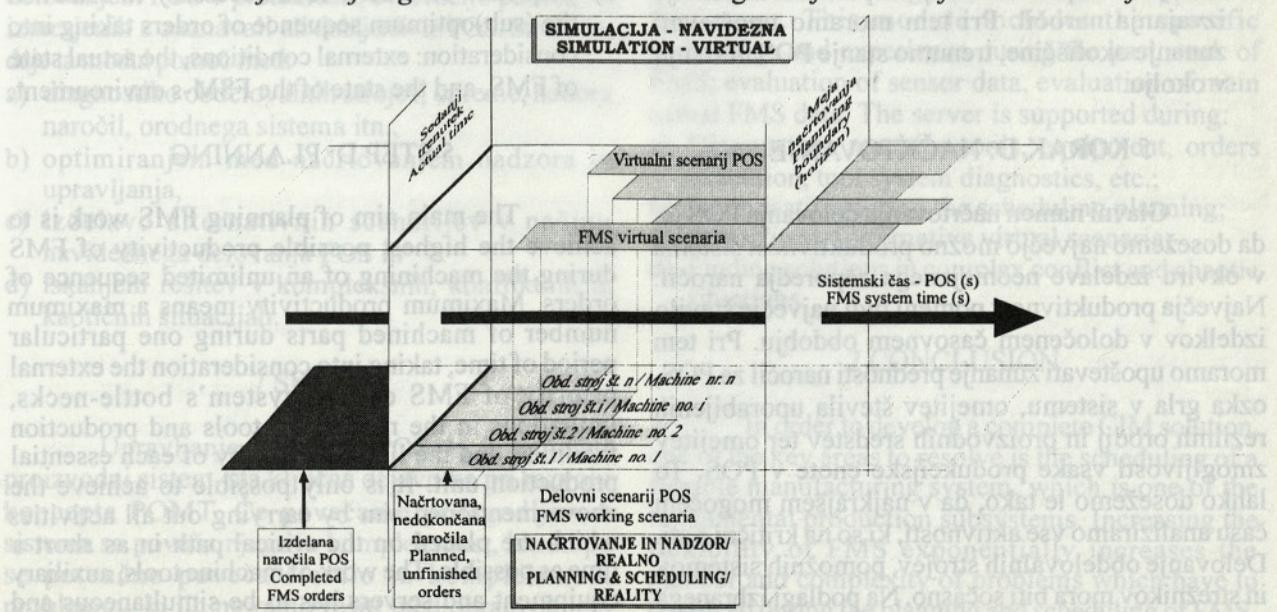
2 STEP A: LOGISTICAL SYSTEM ANALYSIS

A logistical system analysis, giving an answer about the interdependence, limitations and possibilities of the whole system in the process of building up the system from the components. This analysis has to be done for:



Sl. 2. Struktura informacijskega toka v POS

Fig. 2. Information-flow structure of FMS



Sl. 3. Delovni in navidezni scenarij obratovanja POS

Fig. 3. Working and virtual scenaria of FMS

- a) vsako sestavno komponento sistema,
- b) tok materiala in
- c) tok informacij.

3 KORAK B: LOGISTIČNA SINTEZA SISTEMA

Delovna zmožnost in izkoristek POS sta dve poglavitni zahtevi, ki ju moramo upoštevati pri snovanju sistema. Da bi zagotovili največji mogoči izkoristek POS, moramo pri snovanju, organizaciji in strategiji upravljanja upoštevati naslednji cilj: najmanjše mogoče izgube časa obratovanja obdelovalnega stroja.

Ta glavni cilj lahko dosežemo ob upoštevanju naslednjih pravil:

- a) Obdelovalni stroj ne sme biti nikoli izven obratovanja zaradi slabega načrtovanja delovanja.
- b) Pripravni zaključni časi morajo biti kolikor je mogoče kratki.
- c) Pripraviti stroj v najkrajšem mogočem času za ponovno obratovanje in ga vključiti v sistem.

4 KORAK C: STRATEGIJE VODENJA

Za uresničitev koraka C uporabimo naslednje tri glavne strategije:

- a) Smer toka materiala: Tok materiala od podistema v centralni del POS ima prednost pred tokom materiala v nasprotni smeri.
- b) Zaporedje izvajanja različnih strežnih opravil: Prednost imajo vsa strežna opravila, ki privedejo do tega, da se obdelovalni stroj takoj ali čimprej vključi v normalno delovanje. Opravila, ki terjajo več časa in povzročijo daljše izpade obdelovalnega stroja, nimajo prednosti pri izvajanju.
- c) Zaporedje izvajanja naročil: Nujno potrebno je, da najdemo optimalno ali podoptimalno zaporedje izvajanja naročil. Pri tem moramo upoštevati zunanje okoliščine, trenutno stanje POS in stanje v okolju.

5 KORAK D: NAČRTOVANJE

Glavni namen načrtovanja delovanja POS je, da dosežemo največjo možno produktivnost sistema v okviru izdelave neomejenega zaporedja naročil. Največja produktivnost pomeni tudi največje število izdelkov v določenem časovnem obdobju. Pri tem moramo upoštevati zunanje prednosti naročil za POS, ozka grla v sistemu, omejitev števila uporabljenih rezilnih orodij in proizvodnih sredstev ter omejitev zmogljivosti vsake produkcijske enote v POS. To lahko dosežemo le tako, da v najkrajšem mogočem času analiziramo vse aktivnosti, ki so na kritični poti. Delovanje obdelovalnih strojev, pomožnih sistemov in strežnikov mora biti sočasno. Na podlagi izbranega scenarija delovanja POS (sl. 3) določimo zaporedja aktivnosti in čas začetka posameznih dejavnosti.

- a) each single essential component of the system,
- b) flow of material,
- c) information flow.

3 STEP B: LOGISTICAL SYSTEM SYNTHESIS

The working ability and efficiency of FMS are the two main design requirements. To achieve the maximum possible efficiency of FMS it is necessary to design, organise, and schedule them with the following system design aim: minimum amount of lost machine time.

This main design aim can be realised through the following three sub - aims:

- a) The machines must never cease working because of poor organisational planning.
- b) The time required for setting up the machine must be as short as possible.
- c) Getting machines working again. It is vital that any machines that have stopped working are put into action again as soon as possible.

4 STEP C: SCHEDULING STRATEGIES

To realise this aim the following three fundamental strategies are defined:

- a) Direction of material flow. The material flow from the supplementary subsystem of FMS to the core system of FMS has a higher priority than the material flow in the opposite direction.
- b) Order of execution of different server activities; The carrying out of all activities which get the machine tools working again either immediately or in a short time has a higher priority than the activities, which will entail machine tools being out of order for a longer time.
- c) Sequence of orders. It is necessary to establish the (sub)optimum sequence of orders taking into consideration: external conditions, the actual state of FMS, and the state of the FMS-s environment.

5 STEP D: PLANNING

The main aim of planning FMS work is to achieve the highest possible productivity of FMS during the machining of an unlimited sequence of orders. Maximum productivity means a maximum number of machined parts during one particular period of time, taking into consideration the external priority of FMS orders, system's bottle-necks, limitations in the number of tools and production facilities, and the limited capacity of each essential production unit. It is only possible to achieve the above-mentioned aim by carrying out all activities which are placed on the critical path in as short a time as possible. The work of machine tools, auxiliary equipment and servers has to be simultaneous and synchronised. Based on the chosen FMS working scenario, (Fig. 3), the sequence of activities, the time

Zaloga naročil pomeni vmesnik med sistemom načrtovanja proizvodnje v tovarni in POS. Vsako naročilo dobi interno prioriteto, ki pomeni nujnost naročila. Prioritet 0 dobijo naročila, ki jih še ni treba obdelati, normalna prioriteta je 5, zelo nujno naročilo ima prednost 9, naročilo, ki ni nujno, pa dobi prioriteto 1. Število naročil za posamezno prioriteto se določi linearno z interpolacijo.

Optimizacijski modul za upravljanje in nadzor mora iz nabora naročil izbrati najustreznejše naročilo. Pri tem mora upoštevati ciljni scenarij, planske kriterije, trenutno stanje POS in proste ali rezervne vire v sistemu.

Rezultat takšnega optimiranja je optimalni ali podoptimalni vrstni red, ki se nato uporabi pri simuliranju delovanja POS v navideznem scenariju ali pa v delovnem scenariju. Rezultat je vrsta čakajočih naročil.

V postopku optimiranja so torej določena optimalna ali podoptimalna zaporedja izvajanja naročil. Postopek temelji na 39 različnih kriterijih, kijih lahko uporabimo posamezno ali v kombinaciji, kar je odvisno od stanja POS. Odločitev o trenutno najboljši strategiji upravljanja POS izvede strokovnjak, strežnik sistema.

6 INTELIGENTNI SVETOVALNI MODUL

Za uspešno upravljanje POS mora strežnik v kompleksnih situacijah nenehno sprejemati veliko pravočasnih in pravilnih odločitev ([7] in [8]). Kakovost teh odločitev in čas njihovega sprejemanja neposredno vplivata na gospodarno delovanje POS. Inteligentni nadzorni sistem je bil zasnovan kot interaktivna podpora strežniku. Zajema posebno znanje in izkušnje strežnikov, ki so jih dobili med delovanjem POS v preteklosti, evalvacijo podatkov, izmerjenih z zaznavali ali dobljenih iz POS. Strežniku daje ta modul pomoč med:

- a) diagnostiko obdelovalnih strojev, opreme, nabora naročil, orodnega sistema itn.,
- b) optimiranjem med načrtovanjem nadzora in upravljanja,
- c) izdelavo alternativnih scenarijev v načinu navideznega delovanja POS in
- d) iskanjem rešitev v kompleksnih, konfliktnih in kaotičnih situacijah.

7 SKLEP

Upravljanje in nadzor POS, ki je temeljni proizvodni sistem, sta ključna dejavnika pri razvoju koncepta POMT. Če povečamo prilagodljivost sistema se poveča njegova kompleksnost, hkrati pa se potenčno poveča število in kompleksnost problemov, ki jih moramo rešiti med obratovanjem takšnega sistema. Za POS z največjo prilagodljivostjo bi bile rešitve prezapletene. Razvita zamisel omogoča

point at which the activities have to start and the duration of activities will be established during the planning process. The interface between factory planning system and FMS is a pool of orders. Each order has an external priority as a measure of order urgency. Priority 0 is given to those orders which do not yet need to be processed yet. The normal urgency is priority 5, a very urgent order is priority 9, and a non-urgent order is priority 1. The volume of the order of priorities is established on a linear scale of interpolated order urgency.

The scheduling optimisation module is required to find out the most suitable order from the pool of orders, taking into account the target scenario, criterion of planning, actual state of FMS, and free and reserved resources of system.

The result of optimisation is of (sub)optimum order. This order will be built into the virtual scenario in the case of simulation or in a working scenario in the case of scheduling planning. The results obtained from scheduling planning give the data which build the queues.

In the optimisation procedure, the (sub)optimum sequence of order(s) is determined. The procedure is based on 39 different criteria. The criteria can be applied singly or in combination; depending on the state of the FMS, the expert operator will design the best strategy for scheduling the FMS.

6 INTELLIGENT ADVISER MODULE

For efficient scheduling of FMS, the system server - as a user - has to take many correct decisions in complex situations and in good time ([7] and [8]). The quality of decisions and the time needed directly influence the efficiency of FMS. The intelligent adviser module is designed as interactive support for the server. This module includes the specific knowledge and experience during the past work of FMS; evaluation of sensor data, evaluation of main actual FMS data. The server is supported during:

- a) Diagnostics: machine tools, equipment, orders execution, tool system diagnostics, etc.;
- b) Optimisation during the scheduling planning;
- c) Projection of alternative virtual scenarios;
- d) Finding solutions in complex conflict and chaotic situations.

7 CONCLUSION

In order to develop a complete CIM solution, one of the key areas to resolve is the scheduling of a flexible manufacturing system, which is one of the fundamental production subsystems. Increasing the flexibility of FMS exponentially increases the number and complexity of problems which have to be solved during the planning and scheduling of FMS. For FMS with high flexibility the solutions have to be complex and sophisticated. We developed a

nadzor in upravljanje POS z veliko prilagodljivostjo in integracijo v POMT.

Zamisel je bila uspešno uvedena v prakso. Bazira na standardni filozofiji POMT [11] in pomeni korak k povečanju inteligence sistema, ni pa to popolnoma nov postopek, kakor ga predlaga [12].

Zamisel je primerna za uporabo v prilagodljivih obdelovalnih sistemih.

concept to schedule FMS with high flexibility in a CIM environment.

The concept has been applied successfully and verified in practice. This concept is based on classical CIM philosophy [11], as a step towards increasing the intelligence of the system, and is not a basically new approach such as made by [12].

It is suitable for application by most complex flexible manufacturing systems.

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