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# Optimiranje pretoka naročil v prilagodljivih obdelovalnih sistemih z genetskimi algoritmi

## Optimisation of the Flow of Orders in a Flexible Manufacturing System

**Ivo Pahole - Mirko Ficko - Igor Drstvenšek - Jože Balič**

*Optimiranje pretoka naročil v prilagodljivih obdelovalnih sistemih je vedno znova zelo pereče. Poleg znanih običajnih metod optimiranja pretoka se uveljavljajo tudi nedeterministične metode. Metode optimiranja pretokov z genetskimi algoritmi spadajo med omenjene metode. V prispevku sta definirani dve prilagoditveni funkciji, ki opišeta problem optimiranja časov in stroškov izvedbe naročila. Z metodo genetskih algoritmov je nato izvedeno iskanje takšnega pretoka, da je vrednost prilagoditveni funkcij čim manjša.*

**(Ključne besede: sistemi obdelovalni prilagodljivi, pretok naročil, optimiranje, algoritmi genetski)**

*In this paper we propose a method of searching for the optimum order flow through a flexible manufacturing system, with respect to transport times, preparation/completion times, manufacturing times and relevant costs. The paper defines two fitness functions describing the problem of the optimisation of times and costs of the execution of order. Then, using the genetic-algorithm method, a flow is found, such that the values of the fitness functions are as small as possible.*

**(Keywords: flexible manufacturing systems, order flow, optimization, genetic algorithms)**

## 0 UVOD

Pri optimiranju z znanimi običajnimi metodami je problem optimiranja pretoka naročil v prilagodljivih obdelovalnih sistemih (POS) težko obvladljiva naloga. Tako smo velikokrat prisiljeni optimirati le na eno veličino (čas izdelave, cena itn.). Poleg tega večina metod optimiranja pretoka temelji na hevrističnih metodah oblikovanja rešitve in na ekspertnem znanju izvedencev. Razlog je ta, da se pojavlja veliko različnih veličin, ki vplivajo na optimalno rešitev. Velikokrat smo prisiljeni postaviti omejitve sistema. V prispevku je opisan eden od postopkov iskanja optimalnega pretoka naročila skozi POS glede na čase prenosa, pripravno končnih časov, čase izdelave in pripadajoče stroške. Uporabljene so predpostavke, da pripravno končne čase in izdelavne čase poznamo (dobimo jih iz modulov CAPP - računalniško podprto načrtovanje postopkov). Zaradi svojih lastnosti se pri optimizacijskih problemih, kakršen je ta, izkažejo genetski algoritmi, saj lahko iščejo rešitve problemov, ki so sestavljeni iz zapletenih medsebojno odvisnih delov in bi jih bilo zelo težko modelirati [6].

## 0 INTRODUCTION

In addition to the well-known, conventional methods for the optimisation of order flow, also the nondeterministic methods have also become widespread. In the case of optimising with the conventional methods, the problem of optimising the orderflow in a flexible manufacturing system is a hardly controllable task. Thus, we are often restricted to optimising only one variable (the manufacturing time, the price etc). In addition, most methods for optimising the flow are based on heuristic methods of conceiving the solution and making use of the knowledge of experts. This is because there are a lot of different variables influencing the optimum solution, and we are frequently forced to set the limitations of the system. This paper describes one approach to searching for the optimum order flow through a flexible manufacturing system with respect to transport times, preparation/completion times, manufacturing times and relevant costs. The assumption is made that the preparation/completion times and the manufacturing times are known (they are obtained from CAPP - computer aided process planning, modules). Because of their properties, genetic algorithms have proved to be useful in optimisation problems like this one, since they can reach for the solutions of problems that consist of complex, mutually dependent parts, and so would be hard to model [6].

## 1 OPTIMIRANJE PRETOKA Z GENETSKIMI ALGORITMI

Genetske algoritme je razvil John Holland v 60. in zgodnjih 70. letih [4]. So prilagodni hevristični iskalni algoritmi, ki jih uporabljamo za reševanje zahtevnih iskalnih in optimizacijskih problemov. Ta metoda simulira razvojne postopke oziroma »preživetje najprilagojenejšega« [4].

Najprej ustvarimo začetno generacijo organizmov, ki se nato z reprodukcijo, mutacijo in križanjem iz generacije v generacijo izboljšujejo. Tako dobimo postopoma vedno kakovostnejše pripadnike (organizme), ki so pravzaprav rešitve zastavljenega problema. Glavni koraki metode so:

- ustvaritev začetne generacije organizmov,
- ovrednotenje organizmov z uporabo prilagoditvene funkcije,
- izbira organizmov, ki najbolje rešijo zastavljeni problem, in
- ustvarjanje nove generacije s križanjem, reprodukcijo in mutacijo.

### 1.1 Prilagoditvena funkcija

Pri optimizaciji z genetskimi algoritmi moramo najprej določiti prilagoditveno funkcijo, s katero lahko ocenimo kakovost rešitev. V našem primeru je kakovostnejša tista rešitev, ki ima nižjo vrednost prilagoditvene funkcije. Uporabimo lahko tudi več prilagoditvenih funkcij naenkrat. Izbrali smo dve prilagoditveni funkciji: funkcijo spremenljivih izdelovalnih stroškov in funkcijo porabljenega časa. Glede na trenutne zahteve izbira uporabnik med tema dvema funkcijama. V proizvodnih sistemih namreč prihaja do različnih stanj. Včasih so namreč ključnega pomena stroški, včasih pa porabljen čas.

#### *1.1.1 Iskanje najmanjših stroškov*

Stroškovna funkcija je sestavljena iz treh delov. Sestavljajo jo prenosni stroški naročila, pripravljalno končni stroški na posameznih strojih in čisti stroški obdelave. Tako zberemo večino spremenljivih stroškov pri izvajanju naročila:

## 1 OPTIMISING THE FLOW BY USING GENETIC ALGORITHMS

Genetic algorithms were developed by John Holland in the 1960s and early 1970s [4]. They are adaptive, heuristic searching algorithms used for solving demanding search and optimisation problems. The genetic-allgorithm method simulates evolutionary processes, or the “survival of the fittest” [4].

First, we create the initial generation of organisms, which then improve by reproduction, mutation and crossover from generation to generation. Thus, we gradually obtain members (organisms) of ever higher quality which, in fact, are the solutions to the set problem. The principal steps of the method are:

- creation of the initial generation of organisms,
- evaluation of the organisms by means of the fitness function,
- selection of the organisms that best solve the set problem,
- creation of a new generation by crossover, mutation and reproduction.

### 1.1 Fitness functions

In the case of optimisation by using genetic algorithms, it is necessary to first determine the fitness function, enabling the calculation of the quality of the solutions. In our case, the solution, which has a lower value of the fitness function, is of higher quality. It is also possible to use several fitness functions at one time. We selected two fitness functions: the function of the variable manufacturing costs and the function of the time spent. Taking the current requirements into account, the user selects between these two functions, because in production systems, different situations occur. Sometimes the costs are of key importance and sometimes it is the spent time.

#### *1.1.1 Searching for the minimum costs*

The cost function consists of three parts: the transport costs for the order, the preparation/completion costs on the individual machines and the net cost of the machining. In this way, the majority of the variable costs for the execution of the order are covered. The cost function is:

$$\min\ Z = \sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij}\cdot x_{ij}\cdot c_{tij} + \sum_{i=1}^{n} t_{pzi}\cdot y_i\cdot c_{si} + \sum_{i=1}^{n}\sum_{j=1}^{k} t_{tij}\cdot c_{si} \qquad (1),$$

pri tem so:
$n$ – število strojev v prilagodljivem obdelovalnem sistemu, $d_{ij}$ – razdalja med strojema $i$ in $j$, $x_{ij}$ – prisotnost giba med strojema $i$ in $j$ pri naročilu (obstaja, ne obstaja) – vrednost je 0 ali 1, $c_{tij}$ - stroški prenosa med strojem $i$ in $j$ na enoto dolžine, $t_{pzi}$ – pripravljalno zaključni čas na stroju $i$, $y_i$ – uporaba stroja $i$ pri naročilu –

where:
$n$ – number of machines in the flexible manufacturing system, $d_{ij}$ – distance between the machine tools $i$ and $j$, $x_{ij}$ – indicates the presence of a connection between machines $i$ and $j$ for the order (exists, does not exist) – the value is 0 or 1, $c_{tij}$ – transport cost between the machines $i$ and $j$ per unit length, $t_{pzi}$ – preparation/completion time on machine tool $i$, $y_i$ – utilization of machine tool $i$ for the order – the value

vrednost je 0 ali 1, $k$ – število opravil naročila, $t_{tij}$ – tehnološki čas obdelave za stroj $i$ in opravilo $j$, $c_{si}$ – cena strojne ure za stroj $i$.

$d_{ij}$ dobimo iz matrike razdalj med posameznimi stroji. Ta matrika je nespremenljiva. $x_{ij}$ pove ali gib med strojema i in j obstaja ali ne. Dobimo ga iz genotipa organizma. $c_{tij}$ dobimo iz matrike stroškov za povezave med strojema $i$ in $j$. $t_{pzi}$ dobimo iz CAPP modula glede na uporabljeni stroj $i$ in naročilo. $y_i$ dobimo iz genotipa organizma. $t_{tij}$ dobimo iz številsko krmiljenega (ŠK - NC) programa in je odvisen od uporabljenega stroja $i$ in operacije $j$.

is 0 or 1, $k$ – number of operations for the order, $t_{tij}$ – technological time of machining for machine tool $i$ and operation $j$, $c_{si}$ – price of a machine tool hour for machine tool $i$.

$d_{ij}$ is obtained from the matrix of distances between the individual machine tools. This matrix is constant. $x_{ij}$ tells whether a connection between the machine tools $i$ and $j$ exists or not. It is obtained from the genotype of the organism. $c_{tij}$ is obtained from the matrix of costs for interconnections between machine tool $i$ and $j$. $t_{pzi}$ is obtained from the CAPP module with respect to the used machine tool $i$ and the order. $y_i$ is obtained from the genotype of the organism. $t_{tij}$ is obtained from the NC program and depends on the used machine tool $i$ and the operation $j$.

*1.1.2 Iskanje najmanjših časov*

Tudi časovna funkcija je sestavljena iz treh delov in izhaja iz stroškovne funkcije.

*1.1.2 Searching for the minimum times*

The time function also consists of three parts and isbased on the cost functions.

$$\min\ Z = \sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij}\cdot x_{ij}\cdot\frac{1}{v_{ij}} + \sum_{i=1}^{n} t_{pzi}\cdot y_i + \sum_{i=1}^{n}\sum_{j=1}^{k} t_{tij} \qquad (2),$$

$v_{ij}$ je hitrost prenosa med strojema $i$ in $j$, $v_{ij}$ dobimo iz matrike hitrosti posameznih prenosnih naprav.

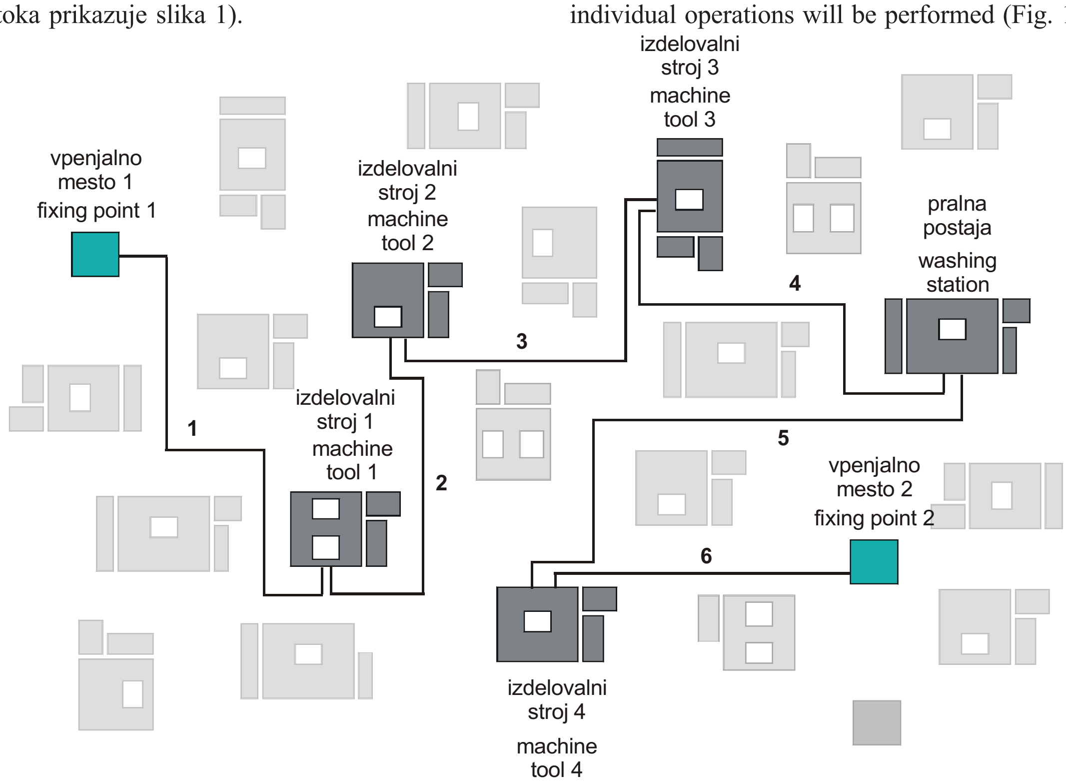
$v_{ij}$ is the speed of the transport between machines $i$ and $j$, $v_{ij}$ is obtained from the matrix of speeds of the individual transport devices.

**1.2 Kodiranje**

Na podlagi razčlenitve delovnega poteka na posamezna opravila in določitve strojev, na katerih se bodo posamezna opravila izvajala, določimo zaporedje pretoka (primer zaporedja pretoka prikazuje slika 1).

**1.2 Coding**

The sequence of the flow is determined in accordance with the breakdown of the work progress into the individual operations and on the basis of a determination of the machine tools on which the individual operations will be performed (Fig. 1).




Sl. 1. *Primer zaporedja pretoka za izpolnitev naročila*
Fig. 1. *Example of the sequence of flow for the execution of order*

Organizem mora nositi informacije o tem, katera opravila se morajo izvesti, da bo naročilo izpolnjeno in na katerih strojih se morajo omenjena opravila izvesti. Organizem je tako dvorazsežna matrika, ena razsežnost matrike je enaka 2 in druga razsežnost matrike je enaka številu opravil naročila. En gen obsega eno opravilo in stroj, na katerem se opravilo izvaja. Za določanje izvedljivosti množice opravil na določenem stroju je uporabljena metoda standardnih opravil po standardu DIN.

*1.2.1 Način iskanja obdelovalnega stroja pri znanem tehnološkem postopku*

Pri načrtovanju tehnologije določimo tehnološki postopek. Določimo delovna opravila, ki jih zahteva oblika in geometrijska oblika izdelka. Opravila se v glavnem opisujejo z opisnim načinom (čelno poravnati, frezati do globine itn.). Tak način opisovanja pa otežuje obdelavo s poznanimi programskimi orodji na računalnikih. V znanih standardih lahko zasledimo, da je področje opisovanja delovnih opravil zelo natančno obdelano (pregl. 1).

Takšen način označevanja delovnih opravil omogoči bistveno lažje opisovanje opravil. Tehnolog mora torej uporabiti standardni zapis. V veliko olajšanje so mu lahko grafični pripomočki na računalniku. Tako lahko kot rezultat iz modula CAPP, dobimo naslednje podatke:

- oznaka (zaporedna številka naročila) naročila za določeno obdobje načrtovanja,
- enolična oznaka naročila,
- šifra ali ime obdelovanca ali obdelovancev v naročilu,

The organisms must carry the information about which operations have to be performed for the order to be fulfilled and on which machine tools these operations must be carried out. Thus, the organism is a two-dimensional matrix: one dimension of the matrix is equal to 2 and the other dimension of the matrix is equal to the number of operations for the order. One gene comprises one operation and the machine tool on which the operation is performed. The method of standard operations according to the DIN standard is used for verifying the feasibility of the group of operations on a machine.

*1.2.1 How to search for a machine tool in the case of a known technological process*

During the planning of technology the technological process is determined, as are the work operations required by the shape and geometry of the product. The operations are mainly defined by a describing (to be face milled, to be milled up to a depth, etc.). Such a description, however, makes it difficult to process using known programme tools on computers. From the known standards it is possible to conclude that the area of describing the work operations has been studied very precisely (Table 1).

Designating the work operations in this way makes describing the operations considerably easier. Thus, the technologist must use the standard designations. However, graphic devices on a computer can be of great assistance to the technologist. We can obtain the following data from the CAPP module:

- designation (serial number) of the order for a certain period of planning,
- unambiguous designation of order,
- code or description of workpiece(s) in order,
- number of workpiece(s),

Preglednica 1. *Primer pregleda izvedljivih delovnih opravil za obdelovalni stroj*
Table 1. *Example of a survey of feasible work operations for a machine tool*

| Pregled možnosti izvedljivih delovnih opravil za večopravilni obdelovalni stroj za vrtanje in frezanje (primer)<br>Survey of possibilities for the execution of standard operations on a multiple–operation drilling and milling machine (example) | | |
|---|---|---|
| Zap. št.<br>Ser.No. | Šifra opravila po DIN 8589<br>Code of operation according to DIN 8589 | Opis opravila za lažje razumevanje<br>Description of operation for easier understanding |
| 1 | 3.2.2.1. | skupina opravil čelnega grezenja<br>group of operations for face sinking |
| 2. | 3.2.2.2. | skupina opravil vrtanja<br>group of drilling operations |
| 3. | 3.2.2.3. | skupina opravil izdelave navojev v izvrtinah<br>group of thread-cutting operations (is drilled holer) |
| 4. | . . . . . | . . . . . . |
| 4. | . . . . . | . . . . . . |
| 7. | 3.2.3.1. | plano frezanje<br>plans milling |
| 8. | 3.2.3.2. | frezanje okroglih oblik<br>milling of round shapes |

- število obdelovancev,
- potrebni programi ŠK za določena opravila na določenih enotah,
- opis standardnih opravil po standardu DIN,
- predvideni časovni termin začetka,
- predvideni vnaprej določeni normativni čas za naročilo.

*1.2.2 Določitev spektra izvedljivih opravil na obdelovalnem stroju*

Za znani obdelovalni stroj lahko določimo standardna opravila, ki jih je mogoče izvesti na obdelovalnem stroju. Pod standardna opravila so mišljena opravila iz standarda DIN [3] (sl. 2). Preglednica 1 prikazuje vidno obliko datoteke za opis izvedljivih standardnih delovnih opravil na določenem obdelovalnem stroju.

V primeru, ko pa že imamo naročilo uvedeno v proizvodnjo, je velikokrat treba iskati alternativni obdelovalni stroj za določeno opravilo oziroma skupino opravil. Aktualni primeri so:

- če pride do zastoja, okvare na načrtovanem obdelovalnem stroju,
- če imamo, iz določenih drugih razlogov, proste delovne zmogljivosti na podobnih obdelovalnih strojih in želimo zmanjšati ali celo odpraviti ozko grlo;
- če se iz kakršnih koli razlogov spremeni prednost naročil (nujna naročila);
- če ni na voljo ustreznih delovnih pripomočkov ali orodij, ki so namensko vezana na določen obdelovalni stroj.

*1.2.3 Izvršitev in rešitve*

Želja uporabnika je gotovo avtomatizirano iskanje alternativnega obdelovalnega stroja pri izvajanju vodenja proizvodnje. Kaj hitro lahko pridemo do sklepa, popolna avtomatizacija ni

- required NC-programmes for certain operations on certain units,
- description of standard operations according to the DIN standard,
- anticipated start time,
- anticipated calculated time for order, defined in advance.

*1.2.2 Determination of the spectrum of feasible operations on a machine tool*

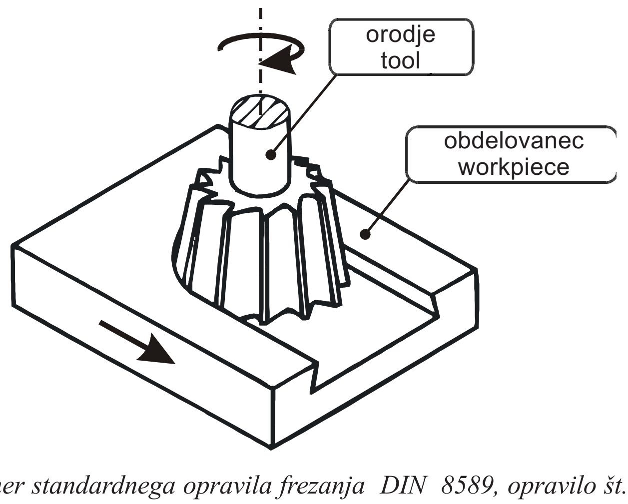
For a known machine tool it is possible to determine the standard operations that can be effected on the machine tool. The standard operations are meant to be operations defined in the DIN standard [3], (Fig. 2). Table 1 shows the visible shape of the data file for describing the feasible, standard work operations on a machine tool.

When an order has already been introduced into production, it is often necessary to search for an alternative machine tool for a certain operation or group of operations. Typical examples are:

- if stoppage, defect occurs on the planned machine tool,
- if for some other reasons there are free working capacities on similar machine tools, and a reduction or even the removal of a bottle-neck are desired,
- if for any reasons the priority of orders (urgent order) is changed,
- if proper working devices or tools, specifically connected with a certain machine tool, are not available.

*1.2.3 Realisation and solutions*

Automated searching for an alternative machine tool during the performance of production management is certainly the user's wish. We can come quickly to the conclusion that complete automation is




Sl. 2. *Primer standardnega opravila frezanja DIN 8589, opravilo št. 3.2.3.5.1.*
Fig. 2. *Example of standard milling operation DIN 8589, operation No. 3.2.3.5.1.*

mogoča, saj skoraj ni mogoče obdelovanca enolično opisati z ustrezno metodo ([5], [7] in [8]).

Pri iskanju rešitev prikazanega problema naletimo na več dejavnikov, od katerih je odvisna končna rešitev, če ta sploh obstaja. V sami fazi načrtovanja je mogoče izdelati več alternativnih delovnih postopkov, ki jih optimiramo glede na:

- časovno najugodnejšo ali
- ekonomsko najugodnejšo različico.

Če se poveča število teh različic delovnih postopkov postane običajno tak način načrtovanja ekonomsko vprašljiv. Lahko pa se tudi zgodi, da takega načina časovno ne zmoremo. Število mogočih različic se namreč zelo hitro povečuje [1].

Hkrati moramo pripraviti pogoje za izvajanje določenega naročila na več enotah prilagodljivega obdelovalnega sistema [8]. Še posebej velja to za tista naročila, ki imajo veliko prednost.

Za določanje oziroma izbiro alternativnega obdelovalnega stroja je lahko tehnologu operaterju velik pripomoček programska oprema »ALTER«. Izdelana programska oprema omogoča poiskati ustrezen obdelovalni stroj. Programski modul deluje tako, da primerja opravila, potrebna za izvedbo naročila, s spektrom opravil, ki jih zmorejo obdelovalni stroji. V primeru ugodne rešitve je na koncu še predviden poseg človeka, izvedenca, ki da dokončno rešitev. Slika 3 prikazuje diagram poteka programskega modula.

*1.2.4 Izvedljivost naročil glede na orodja in delovne pripomočke*

Izhodni podatki iz take izbire so:

- izbrano naročilo,
- obdelovalni stroj, na katerem je izbrano naročilo izvedljivo,
- delovni pripomočki, ki morajo biti na obdelovalnem stroju za izbrano naročilo,
- orodja, ki morajo biti na obdelovalnem stroju za izbrano naročilo,
- časovni čas začetka opremljanja stroja [9].

**1.3 Nastanek začetne generacije**

Organizem bi lahko bil sestavljen samo iz zaporedja strojev, tako da bi bil posamezni stroj zapisan tolikokrat, kolikor bi bilo na njem izvedenih opravil. Vendar pa je izvedljivost opravila neposredno vezana na stroj.

Kodiran organizem:

not possible, since it is almost impossible to describe a workpiece by a suitable method ([5], [7] and [8]).

When searching for solutions to the problem presented across several factors by which the final solution – if it exist at all – is conditioned. During the planning stage it is possible to work out several alternative working procedures, which we optimise with regard to:

- the most favourable version with respect to time,
- the most economically favourable version.

If the number of these versions of working processes increases, such a way of planning usually becomes economically questionable. It can also happen that such a method cannot be applied because it is time-consuming [1].

In parallel, it is necessary to prepare the conditions for the execution of a certain order on several units of the flexible manufacturing system [8]. This applies particularly for orders of high priority.

The programme equipment can be of great assistance to the technologist/operator for the determination and/or selection of the alternative machine tool. The “ALTER” programme ensures that a suitable machine tool can be found. The programme module functions so that it compares the operations required for the execution of the order with the spectrum of operations that the machine tools can perform. Figure 3 shows a diagram of the flow of the programme module.

*1.2.4 Feasibility of orders with respect to tools and working devices*

Output data from such a selection are:

- order selected,
- machine tool on which the selected order is feasible,
- working devices that must be provided on the machine tool for the selected order,
- tools that must be available on the machine tool for the selected order,
- start time of the equipped machine [9].

**1.3 Creation of the initial generation**

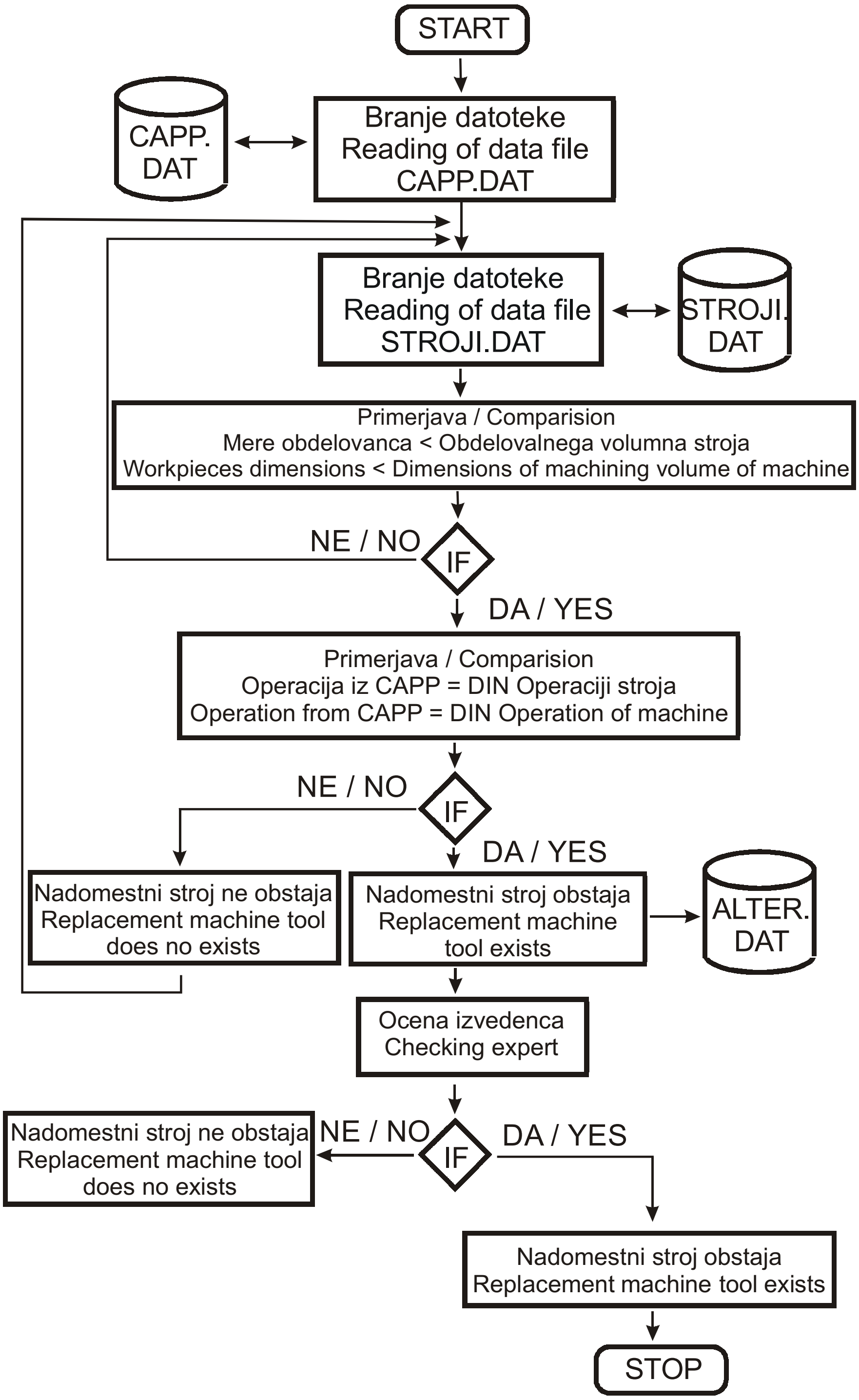
The organism may only consist of the sequence of machines, such that the individual machine would be mentioned so many times as the number of operations directly connected to the machine.

Coded organism:

$$\begin{bmatrix} o_1 & o_2 & o_3 & o_4 & o_5 & o_6 & o_7 & o_8 & o_9 \\ s_1 & s_3 & s_8 & s_8 & s_2 & s_4 & s_4 & s_4 & s_1 \end{bmatrix}$$

Ugotovimo, da je število pravilnih genov omejeno. Vsako opravilo lahko opravi le omejeno število strojev. To pomeni, da je število genov

Each operation can be performed only by a limited number of machines, which means that the number of genes is limited. Therefore, first, all pos-



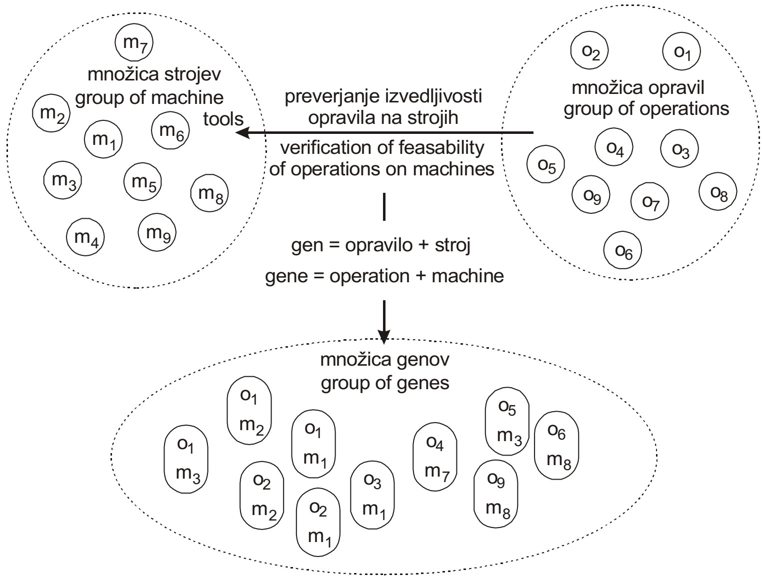

Sl. 3. *Diagram poteka programskega modula »ALTER« za določanje nadomestnega obdelovalnega stroja*
Fig. 3. *Diagram of flow of programme module for the determination of the replacement machine tool*

omejeno. Zato najprej ustvarimo vse možne gene in tako ustvarimo množico genov (sl. 4).

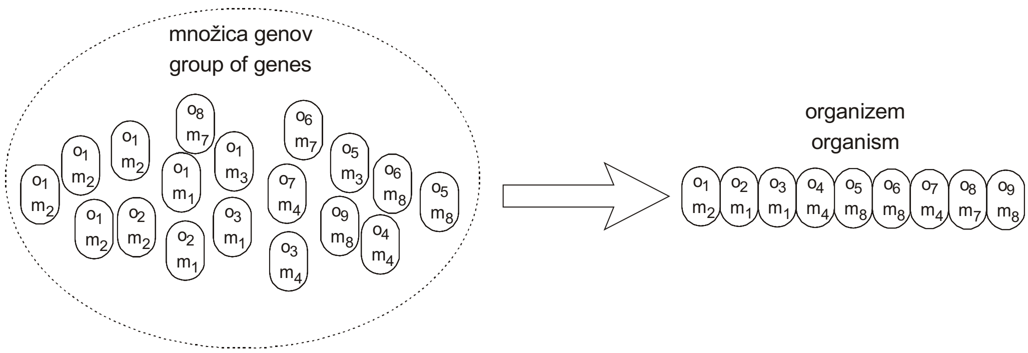
Iz te množice nato izbiramo posamezne gene in jih zlepimo skupaj v pravilne organizme (sl. 5). Pravilni organizmi so tisti, ki predstavljajo takšno zaporedje pretoka, da dobimo za rezultat izpolnjeno naročilo. Množico genov uporabimo tudi pri opravilu mutacije.

sible genes are generated and thus a group of genes is created (Fig. 4).

Out of the group, we then select the individual genes and assemble them together in correct organisms (Fig. 5). The appropriate organisms are those that represent such a sequence of the flow which results in the fulfilled order. The group of genes is also used in the operation of mutation.




Sl. 4. *Prikaz nastanka genov*
Fig. 4. *Representation of the coding of solutions*



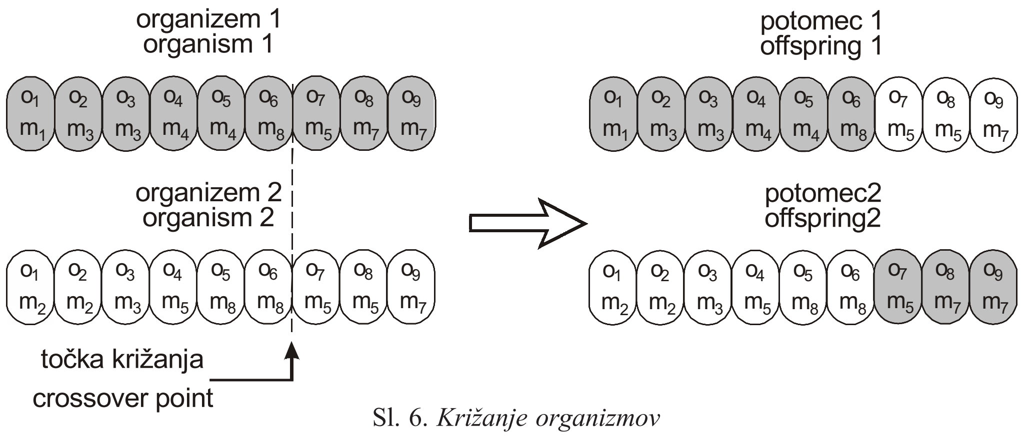

Sl. 5. *Oblikovanje organizma iz množice genov*
Fig. 5. *Forming the organism from a group of genes*

### 1.4 Razvojna in genetska opravila

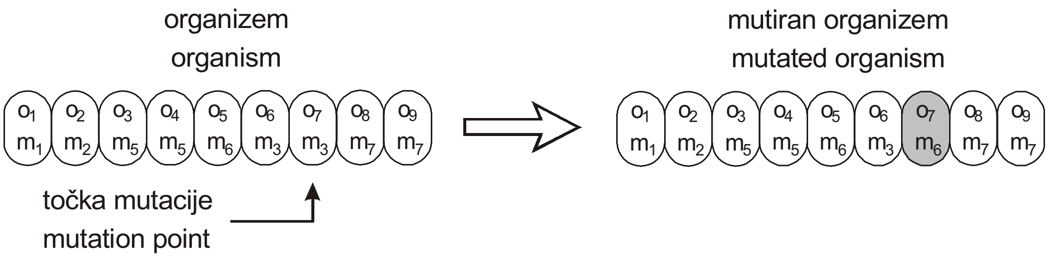
Zaradi samega načina kodiranja in ustvarjanja začetne generacije lahko uporabimo najpreprostejše enotočkovno ali večtočkovno križanje (sl. 6).

### 1.4 Evolutionary and genetic operations

Due to the method of coding and the generation of the initial operation, we can use the simplest single-point or multiple-point crossover (Fig. 6).




Sl. 6. *Križanje organizmov*
Fig. 6. *Crossover of organisms*




Sl. 7. *Mutiranje organizmov*
Fig. 7. *Mutation of organisms*

Prav tako kakor križanje je tudi mutacija pri tej vrsti kodiranja zelo preprosta (slika 7). Edini pogoj, ki se mora pri mutaciji upoštevati, je, da se zamenjani geni v organizmu nadomestijo s takšnim genom, ki vsebuje enako opravilo. Nadomestni gen izberemo iz množice genov.

### 1.5 Ovrednotenje

Vsak organizem ovrednotimo z dvema stroškovnima funkcijama. Pri tem ima večji pomen tista stroškovna funkcija, ki je v danem trenutku za uporabnika pomembnejša. Zaporedje pretoka lahko namreč optimiramo glede na najkrajši potreben čas za izpolnitev naročila ali glede na najmanjše stroške. V primeru, da dobimo več enako dobrih rešitev glede na prvo stroškovno funkcijo, poiščemo med temi rešitvami tisto rešitev, ki najbolje reši drugo stroškovno funkcijo.

Glede na organizem se ustvarita matriki [X] in [Y], ki vsebujeta vrednosti $x_{ij}$ in $y_i$ in matrike tehnoloških časov [$t_t$] in pripravljalno končnih časov [$t_{pz}$], ki jih izdelajo moduli CAPP. Na podlagi teh matrik, ki so odvisne od samega organizma in preostalih matrik, ki so nespremenjene za postavljeno izdelavo, se izvede računanje vrednosti stroškovnih funkcij.

## 2 SKLEP

V nasprotju z drugimi metodami optimizacije pretoka v prilagodljivih obdelovalnih sistemih imajo genetski algoritmi nekaj neizpodbitnih prednosti. V nasprotju z večino drugih metod z genetskimi algoritmi izdelujemo rešitve po načelu naključnosti z genetskimi in evolucijskimi operacijami in ne uporabljamo nobenih pravil oblikovanja rešitve. Edina omejitev je ta, da mora biti izdelana rešitev mogoča. Kakovost izdelanih rešitev ovrednotimo s prilagoditvenima funkcijama. Pri reševanju s to metodo sicer ni nujno, da bomo dobili najboljšo rešitev, vendar bo prav gotovo med boljšimi. Prednost te metode je tudi v tem, da lahko dobimo po več zagonih genetskega algoritma več različnih rešitev, ki imajo podobno vrednost stroškovnih funkcij.

Like the crossover, the mutation is also very simple, in terms of the type of coding (Fig. 7). The sole condition to be considered in the mutation is that the genes in the organism are to be replaced by the genes containing the identical operation. The replacement gene is selected from the group of genes.

### 1.5 Evaluation

Each organism is evaluated by two cost functions. The cost function that is more important for the user at a given moment is of greater weight. The sequence of flow can be optimised with respect to the minimum time required for the fulfilment of the order, or with respect to the minimum cost. In the event that several solutions are equally good with respect to the first cost function obtained, from these solutions we pick the solution which best solves the other cost function.

With respect to the organism, the matrices [X] and [Y] containing the values $x_{ij}$ and $y_i$ are generated. The matrices of the technological times [$t_t$] and the preparation/completion times [$t_{pz}$], made by CAPP modules, are also generated with respect to the organism. On the basis of those matrices, depending on the organism itself and on other matrices, which are constant for the existing manufacturing, the values of the cost functions are calculated.

## 2 CONCLUSION

In contrast to other methods for optimising the flow in a flexible manufacturing system, genetic algorithms have a number of advantages. Unlike most other methods, with genetic algorithms we obtain solutions according to the random principle, by genetic and evolutionary operations, and we do not use any rules when conceiving the solution. The sole limitation is that the solution must be feasible. The quality of the solutions is evaluated by the two fitness functions. When solving with this method, it is not certain that the optimum solution will be obtained, but it will certainly be a better one. Another advantage of this method is that after several runs of the genetic algorithm we can obtain several different solutions with similar values for the cost functions.

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