CODEN STJSAO
ZX470/1358
ISSN 0562-1887
UDK 658.511/.512:65.012.11:004.421

Optimizing Time Utilization of FMS

Mladen PERINIĆ, Tonči MIKAC* and *Sven MARIČIĆ

Tehnički fakultet, Sveučilište u Rijeci
(Faculty of Engineering, University of Rijeka),
Vukovarska 58,
HR - 51000 Rijeka,
Republic of Croatia

mperinic@riteh.hr

Keywords

Genetic algorithm
Simultaneous production
Time utilization optimization
Working order

Ključne riječi

Genetski algoritam
Optimizacija vremenskog iskorištenja
Radni nalog
Simultana proizvodnja

Received (primljeno): 2008-01-31
Accepted (prihvaćeno): 2008-10-31

Original scientific paper

The aim of the research is to solve the problem of simultaneous production on the flexible manufacturing system with different combination of product types and quantities that will give maximal utilization of production system. The presumption for good utilization of FMS (Flexible Manufacturing System) is in forming of working order with such product type structure that will make possible of production processing with minimal time load of complete production system. Working order structure from the point of product types and quantities is dictated by market demands that are known earlier. Because the structure of particular working order is not harmonized with the exploitation characteristics of FMS, we are faced with problem how to realize working order in such conditions as well as how to achieve main goal: shorter machining cycle with less time occupation of production system. The method based on two phases for solving problem of control working order realization is presented in the work. In the first phase the selection of optimal combination of process plans which gives minimal time load of production system through simultaneous production of different products and their quantities is given. In the second phase the order of part production and the order of particular operations processing is optimized. The optimization problem in both phases of control is solved by application of genetic algorithm approach. The software for computing and optimizing of processing order on FMS is developed.

Optimiziranje vremenskog iskorištenja FPS-a

Izvornoznanstveni članak

Cilj je rada istražiti problem simultane proizvodnje dijelova na FPS-u (Fleksibilni proizvodni sustav) s različitim kombinacijama tipova dijelova i količina, koja će osigurati maksimalno iskorištenje proizvodnog sustava. Pretpostavka za dobro iskorištenje fleksibilnog proizvodnog sustava je formiranje radnog naloga s takvom strukturom tipova dijelova, koja će omogućiti odvijanje proizvodnje uz najmanje vremensko opterećenje proizvodnog sustava kao cjeline. Struktura radnog naloga po pitanju tipova dijelova i količina diktirana je tržišnim zahtjevima, tj. unaprijed je zadana. Budući da struktura pojedinog radnog naloga nije u potpunosti usklađena s eksploatacijskim karakteristikama FPS-a koje proizlaze prvenstveno iz značajki strukture jezgre sustava, suočavamo se s problemom, kako u takvim uvjetima upravljati realiziranjem radnog naloga i pri tom postići glavni cilj: što manje vremensko zauzeće sustava odnosno što kraći ciklus izrade. U radu je prikazana metoda koja se temelji na dvije faze rješavanja problema upravljanja realiziranja radnog naloga. U prvoj fazi određen je izbor optimalne kombinacije planova procesa koja pri simultanoj proizvodnji različitih dijelova zadanih količina osigurava najmanje vremensko opterećenje proizvodnog sustava u cjelini. U drugoj fazi optimiran je redoslijed ulaska pojedinih dijelova u proces izrade i redoslijed izvođenja pojedinih operacija. Optimizacijski problem u obje faze upravljanja riješen je rabljenjem genetskog algoritma. Razvijen je računalni program za proračun i optimizaciju redoslijednog odvijanja procesa na FPS-u.

1. Introduction

The complexity of market demands is reflected in the need for more qualitative products which tend to become more complex. It is also necessary to meet specific costumer demands and retain reasonable prices. Except for these high expectations, the market also dictates diversification of ordered quantities which can vary from very large to small series or even custom designed products. Another requirement a product has to meet is keeping up delivery dates even at short notice. Many newly developed parts of a product, as well as the dynamical replacement of existing parts during production processes poses a significant problem to the production process of the assortment [1 – 4].

A set of products which make up the entire product population for manufacturing in a particular FMS enters the production line in subsets. These subsets consist of parts defined by work order. Progress of work order runs parallel during a particular time period. Regarding the diverse and variable market demands, a set of parts which make up the entire population of parts is a variable dependant on time. However it can be considered as stationary within boundaries of particular time intervals.

The composition and quantity of parts for individual work order during assembly cycle (1-day, x-days) arise from the assembly plan. The plan depends upon contract and delivery dates of the final product, as well as upon technical availability of the system. During system operation planning, composition and quantity for a subset of parts and partial task/work order or FMS operative plan are determined, based on the following data:

- work order priority,
- necessary *production means*[1]; regarding their type and time consumption,
- available production means; regarding their type and time consumption,
- criteria for work order selection.

Main goals must be taken into consideration:

- keeping up with delivery dates,
- maximum efficiency of the production system,
- maximum stock,
- maximum flow rate,
- maximum economical effects.

Forming the partial task with a convenient structure of work order is an assumption for high efficiency of the production system. Beneficial structure of work order implies a set of parts whose production requires all available machines with similar time consumption. Required time interval should be as small as possible, and combined with good synchronization of personnel and good tool usage. High efficiency of FMS which is one of previously set goals depends on a number of factors:

- technical and organizational solutions used during design and operation of the system which can be referred to as its technical availability;
- properties of the partial task regarding number of parts, quantities, number of operations and machining time and refitting of work places due to implementation sequence;
- partial task processing sequence.

Due to the fact that the assembly plan has the primary influence on present technical and organizational solutions of manufacturing systems, the sequence of occurrence of manufacturing steps within the work order remains as the primary element which dictates the efficiency of the FMS.

The following section of the paper will be dealing with the influence of operation sequence which is determined within FMS control. Here, each operation is seen as a separate event, which enters the control process with following information:

- completion of prior operation,
- machine selection which has been prepared to perform a particular operation during refitting stage,
- initiation of operation,
- duration of operation.

FMS control system must select one of the products which is available for operation execution. The selected product must utilize the first free machine in such a way that it allows most convenient further selections.

There are certain restrictions which limit options for associating operation to a work station:

- number of machine tools within the system and similarities/differences regarding technical properties, tools and equipment,
- characteristics of work order operation sets.

2. Problem solution

In this paper, the problem has been analyzed, and the conducted research has resulted in the development of a method based on two problem solving phases, Figure 1:

I. control phase – selection of optimal process plan combination,

II. control phase – optimization of sequential process event.

[1] Production means is a common term for machines, drive systems, paletes and other means necessary for operation.

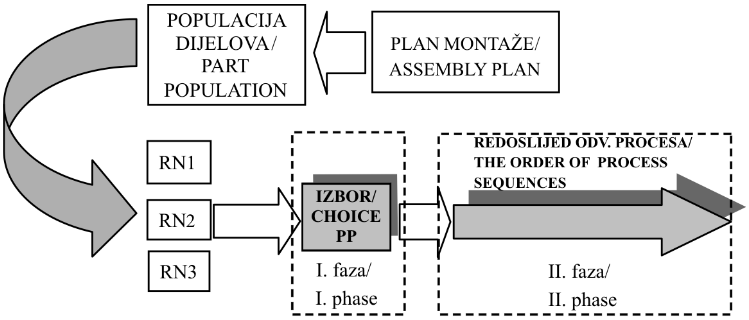


Figure 1. Diagram of I. and II. FMS control phase

Slika 1. Shematski prikaz I. i II. faze upravljanja FPS

The method is based on the existence of alternative (variant) process plans for particular parts, which utilize a different arrangement of FMS machines during processing [5 – 7].

Selection of one process plan combination among developed process plans is conducted within the first phase, which will ensure minimum time load of the production system of known features, by applying the simultaneous production of randomly combined parts.

The second phase requires controlling of the sequential events for particular partial task operations to lower the overall manufacturing cycle. Thus, it is necessary to optimize the entering sequence of each part into the production process as well as the operations while bearing in mind two important criteria:

- minimum time load of the whole system (work stations, automated transport systems),
- equal engagement of each work station.

The problem occurring during phase one has been solved by means of a genetic algorithm approach, as a powerful and widely applied stochastic search engine based on evolution theory principles [8, 9].

Second phase problem solution requires adequate strategy for operation set selection, as well as association of a particular operation to a work station. The entering sequence of parts into the process must be optimized. In this paper this was achieved by utilization of genetic algorithm.

Optimization problem of processing order sequences process is among the most difficult combinatorial optimization problems [10 – 14].

3. Optimization of sequence of events in FMS with genetic algorithm

3.1. Chromosome coding and decoding

It is of utmost importance to adequately code chromosomes, so that chromosomes generated in the evolution process bring forth a realizable sequence of work order operations [15,16]. If each chromosome is coded in a way that each gene represents one single operation, coded by means of a whole number which represents an index of the operation, problems occurs. There are restrictions in operation sequences, so the permutations of the mentioned indexing system would not always give realizable sequences. Hence, the idea is discarded. Gen, Tsujimura and Kubota have suggested an alternative. They have named all operations for a specific part of work order with the same number which is interpreted according to its appearance in the chromosome sequence [17 – 19]. Since there are work orders which consist of more part units of the same type, each part unit of the same type will be labeled with the same number. Each part of the same type is presented by operations with equal sequence of events and defined operation duration and transport routes.

The principle of chromosome coding and decoding will be explained with the example presented in Table 1.

Table 1. Example of work order with 3 part types and different number of pieces

Tablica 1. Primjer radnog naloga s 3 vrste dijelova s različitim brojem komada

Part type / Vrsta dijelova	Part unit / Jedinka dijela	Operation / Operacija	Machine / Stroj	Duration / Trajanje aktivnosti		
				Operation / Operacija	Transport to the machine / Transport do stroja	Transport from the machine / Transport od stroja
1	1 2 3	1 2	1 2	10 15	5 3	3 4
2	1 2	1	2	5	3	4
3	1	1	1	20	5	6

As can be seen from Table 1 the first part type has 3 units, each of them having 2 operations, the second part type consists of two units with one operation each, and the third part type consists of one unit which has one operation.

Each operation is noted with the index rjo; r referring to part type, j to unit type and o to operation of the part unit. For example, index 123 stands for the third operation of the second unit of the first part type.

In total there are 3x2 +2x1+1x1=9 operations. Since there are 3 part types, chromosome genes are represented by numbers 1, 2 and 3. The first part type r_1 has 6 operations, so the chromosome will contain number one 6 times. Second part type r_2 has 2 operations so the chromosome will contain number 2 two times. Third part type r_3 has one operation, so the chromosome will contain number 3 once. There are 9 operations, so chromosome length is 9 genes.

For example, the chromosome [1 2 1 3 2 1 1 1 1]:

1 – first part type, first part unit, first operation;

2 – second part type, first part unit, first operation (last for part unit);

1 – first part type, first part unit, second operation (last for part unit);

3 – third part type, first (and only) part unit, first operation (last for part unit);

2 – second part type, second part unit, first operation (last for part unit);

1 – first part type, second part unit, first operation;

1 – first part type, second part unit, second operation (last for part unit);

1 – first part type, third part unit, first operation;

1 – first part type, third part unit, second operation (last for part unit).

The absolute operation indexes are:

1 – first part type, first part unit, first operation;

2 – first part type, first part unit, second operation;

3 – first part type, second part unit, first operation;

4 – first part type, second part unit, second operation;

5 – first part type, third part unit, first operation;

6 – first part type, third part unit, second operation;

7 – second part type, first part unit, first operation;

8 – second part type, second part unit, first operation;

9 – third part type, first part unit, first operation.

Therefore, after decoding, the real realizable operation sequence for the given chromosome is the following:

Chromosome: 1 2 1 3 2 1 1 1 1.

Sequence: 1 7 2 9 8 3 4 5 6.
(operation priority)

A sequence is created:

The earliest time for operation with index 1 (since all machines are free, and the first operation is about to commence, the only condition is transport to machine where the operation is carried out).

The earliest time for commencement of operation 7 (first operation, one of the conditions is transport to machine where operation 7 is carried out; if part type 1 and part type 2 share the same machine, the second condition is the occupation of the machine by part type 1 units).

The earliest time for commencement of operation with index 2 (first condition is completion of operation 1, and the second is transport time from the previous machine where operation 1 was performed to the machine where operation 2 is to be carried out).

The earliest time for commencement of operation 9 (first and only operation) is longest of time needed for the transport to machine where the operation is carried out, and the availability of the same machine (which might be busy performing other operations at that time).

etc. for following operations of the realizable sequence

Therefore one can conclude that a particular operation which has been noted later in the chromosome, can be performed before the one which appears earlier. With this algorithm, a shifting to the left is performed while at the same time creating an operation sequence and the completion of work order.

1. Operation 1

1 – first part type, first part unit, first operation

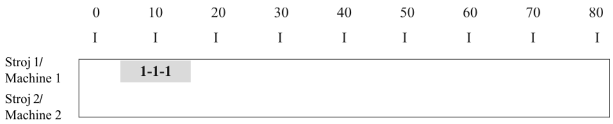


Figure 2. Completion of operation with index 1

Slika 2. Terminiranje operacije s indeksom 1

2. Operation 7

2 – second part type, first part unit, first operation (last for part unit)

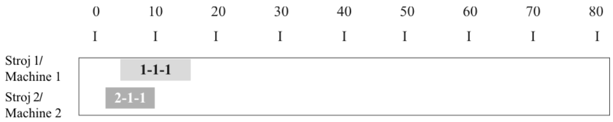


Figure 3. Completion of operation with index 7

Slika 3. Terminiranje operacije s indeksom 7

3. Operation 2

1 – first part type, first part unit, first operation (last for part unit)

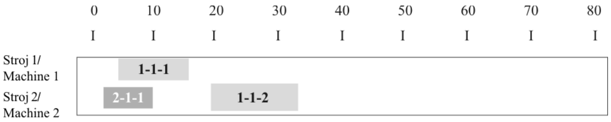


Figure 4. Completion of operation with index 2

Slika 4. Terminiranje operacije s indeksom 2

4. Operation 9

3 – first part type, first (and only) part unit, first operation (last for part unit)

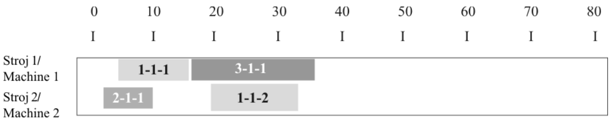


Figure 5. Completion of operation with index 9

Slika 5. Terminiranje operacije s indeksom 9

It is important to note that one basic assumption was used for example from Table 1. The assumption is that the transport of the part from buffer store to machine depends only on the availability of the machine which performs the operation. This means that the transporter is available at any moment which is, of course, contrary to the real case.

4. Practical presentation of the approach on a specific task

The application of genetic algorithm approach to selection of process plan (first control phase) was presented on a specific task. For work order consisting of four part types (N=1, 2, 3, 4) at determined quantities (q=50, 20, 80, 60), alternative process plans have been defined by sets of parameters:

These processes have been developed for the usage on flexible manufacturing systems with four different work stations and automated transport system, as shown in Figure 6.

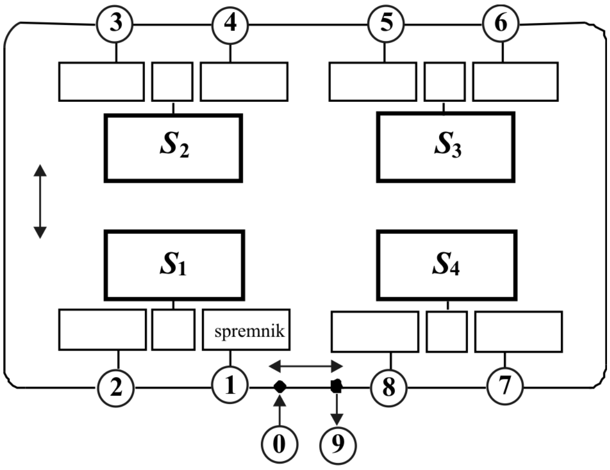


Figure 6. Flexible manufacturing system with four work stations and automated transport system

Slika 6. Fleksibilni proizvodni sustav s 4 radne stanice i automatskim transportnim sustavom

First phase problem was solved by means of genetic algorithm, using 4 genes per chromosome, 20 chromosomes within a population (*popSize* =20), 20 generations (*maxgen* =20), stochastic replacement selection, linear scaling, one point cross over (*pcross* =0,5), one gene mutation (*pmutation* = 0,3) and one population.

An optimum solution was achieved consisting of sets of plans $\{p_{13}, p_{24}, p_{32}, p_{41}\}$ [8, 9, 20].

For the selected process plan combination $\{p_{13}, p_{24}, p_{32}, p_{41}\}$, it is necessary to optimize entering sequence of particular parts for the manufacturing cycle to be shorter and machine load to be equally distributed (second control phase).

Part type 1	p_{11}	$= \{(d_{01}=14, t_{111}=30), (d_{23}=8, t_{112}=15), (d_{45}=4, t_{113}=35), (d_{67}=8, t_{114}=30), (d_{89}=2)\}$
	p_{12}	$= \{(d_{03}=10, t_{122}=35), (d_{47}=13, t_{124}=28), (d_{81}=6, t_{121}=45), (d_{29}=5)\}$
	p_{13}	$= \{(d_{03}=10, t_{132}=35), (d_{45}=4, t_{133}=20), (d_{67}=8, t_{134}=60), (d_{89}=2)\}$
Part type 2	p_{21}	$= \{(d_{05}=14, t_{213}=10), (d_{67}=8, t_{214}=40), (d_{83}=15, t_{212}=25), (d_{41}=10, t_{211}=15), (d_{29}=5)\}$
	p_{22}	$= \{(d_{01}=2, t_{221}=22), (d_{27}=8, t_{224}=30), (d_{83}=15, t_{222}=32), (d_{49}=14)\}$
	p_{23}	$= \{(d_{05}=14, t_{233}=25), (d_{61}=15, t_{231}=18), (d_{27}=8, t_{234}=30), (d_{89}=2)\}$
	p_{24}	$= \{(d_{01}=2, t_{241}=42), (d_{27}=8, t_{244}=45), (d_{89}=2)\}$
Part type 3	p_{31}	$= \{(d_{05}=14, t_{313}=20), (d_{63}=6, t_{312}=30), (d_{41}=10, t_{311}=40), (d_{27}=8, t_{314}=15), (d_{89}=2)\}$
	p_{32}	$= \{(d_{05}=14, t_{323}=58), (d_{61}=15, t_{321}=52), (d_{29}=5)\}$
Part type 4	p_{41}	$= \{(d_{07}=5, t_{414}=18), (d_{81}=6, t_{411}=12), (d_{23}=8, t_{412}=25), (d_{49}=14)\}\}$
	p_{42}	$= \{(d_{05}=14, t_{423}=20), (d_{61}=15, t_{421}=42), (d_{29}=5)\}$
	p_{43}	$= \{(d_{05}=14, t_{433}=10), (d_{63}=6, t_{432}=18), (d_{41}=10, t_{431}=15), (d_{27}=8, t_{434}=12), (d_{89}=2)\}$

Optimization of sequenced entry and operation execution of particular parts in the manufacturing process has been achieved with partially various criteria. The problem has been solved in two distinct manners which gave different final results. The different problem solving approaches are characterized by:

Case 1. requirement for the shortest possible manufacturing cycle, assuming that the transport of the product depends only on the availability of the machine that performs the operation (transport system availability ignored).

Case 2. requirement for the shortest possible manufacturing cycle and the shortest possible waiting period of the machine which performs the operation, assuming that the transport of the product depends only on the availability of the machine that performs the operation (transport system availability ignored).

Results for individual cases have been derived by trying out different parameters of the genetic algorithm. The gained experience has shown superiority of some results. Only the best results are shown here.

4.1. Case 1.

Figure 7 shows the optimization result according to the shortest possible production cycle on FMS criterion with four different machines.

The genetic algorithm has been applied with 539 genes per chromosome, 250 chromosomes in a population (*popSize*=250), 500 generations (*maxgen*=500), stochastic replacement selection, linear scaling, uniform crossover (*pcross*=0,65), [17, 21 – 24] nearest neighbor mutation (*pmutation* =0.03).

It can be seen that the occupation time of machine 2 is fairly long (till time 5 664 when product 4 leaves the process), and its utilization is fairly small. However, only the criterion for the shortest possible manufacturing cycle has been applied here. For *case* 2, both criteria, for the shortest possible manufacturing cycle and the shortest possible waiting period of the machine which performs the operation will be used, on the same FMS.

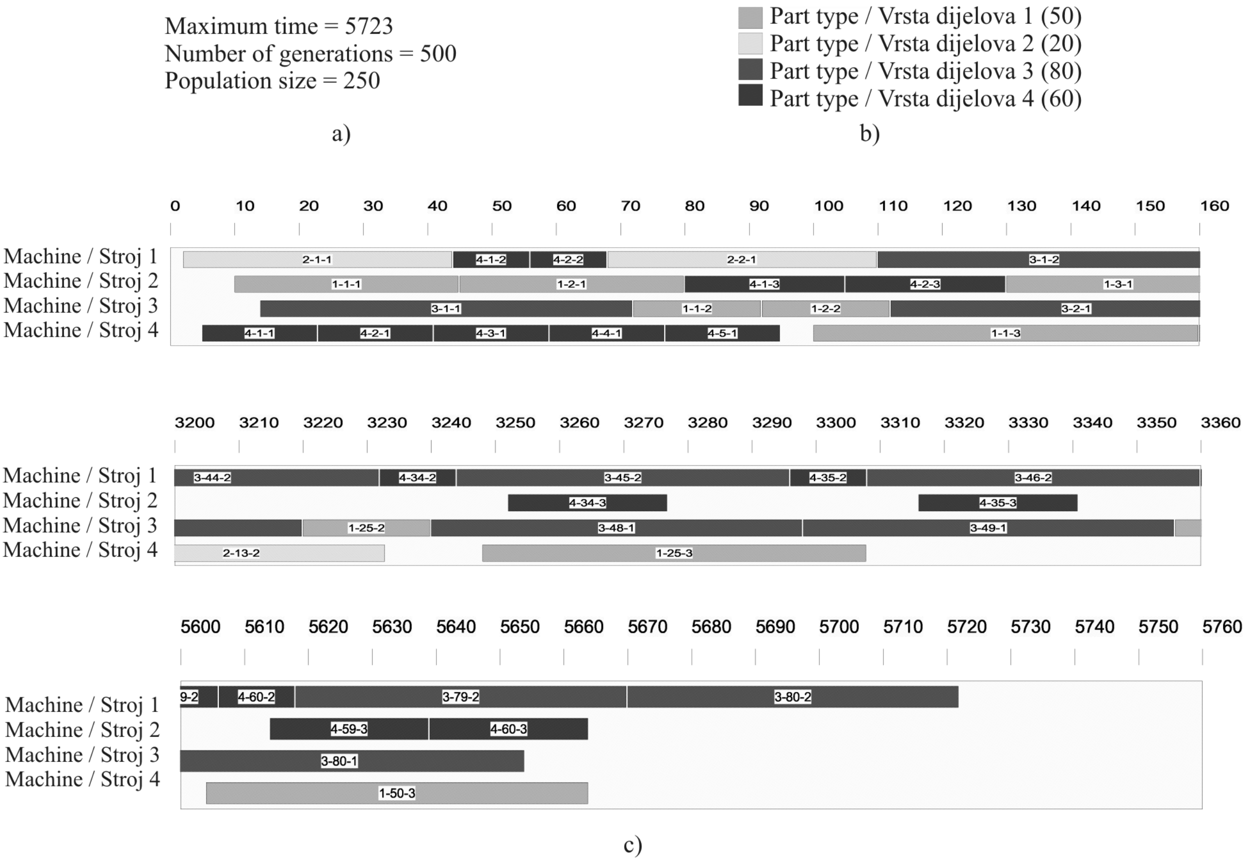
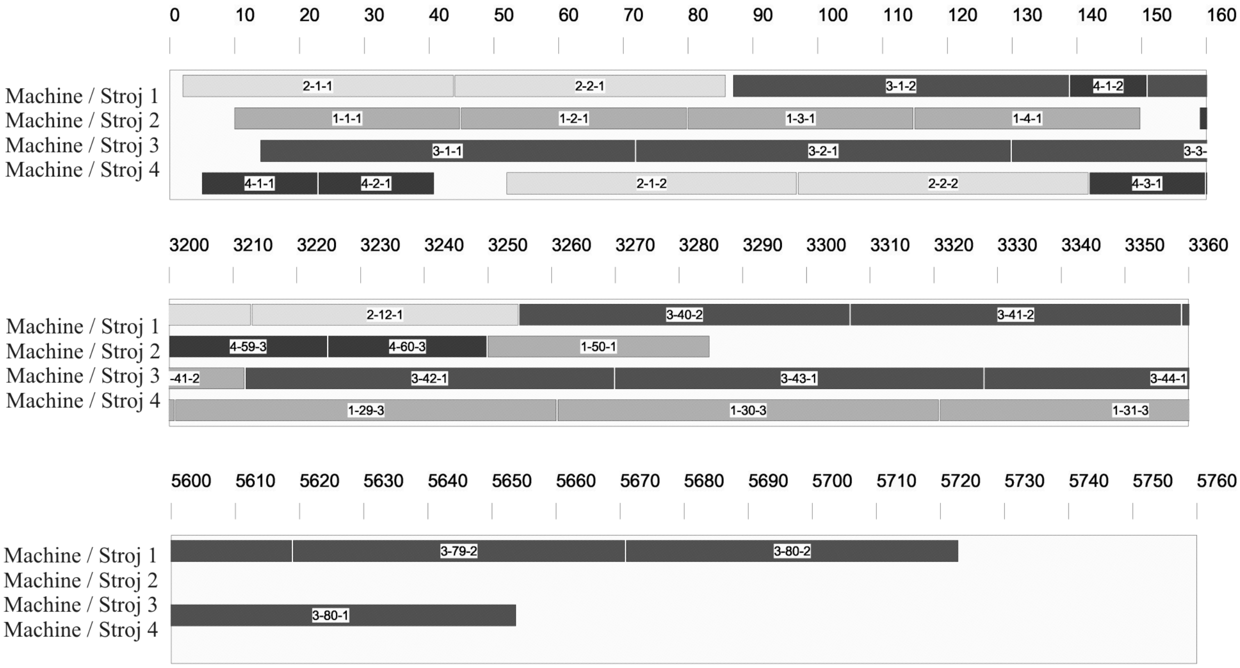


Figure 7. Partial presentation of task results for the minimum manufacturing cycle criterion – case 1 with GJOB program: a) result; b) legend; c) gantogram

Slika7. Djelomični prikaz rezultata zadatka za kriterij minimalnog ciklusa izrade – slučaj 1 programom GJOB: a) rezultat; b) legenda; c) gantogram zauzetosti strojeva

Maximum time = 5723
Sum of machine waiting periods = 88
Number of generations = 1000
Population size = 250

a)



b)

Machine 1 started 2 completed 5723 performed 5720 (99.86%)
part type 2 performed 840 (14.66%)
part types 3 performed 4160 (72.63%)
part type 4 performed 720 (12.57%)

Machine 2 started 10 completed 3285 performed 3250 (56.74%)
part type 1 performed 1750 (30.55%)
part type 4 performed 1500 (26.19%)
empty 2478 (43.26%)

Machine 3 started 14 completed 5654 performed 5640 (98.46%)
part type 1 performed 1000 (17.46%)
part type 3 performed 4640 (81.01%)
empty 88 (1.54%)

Machine 4 started 5 completed 5016 performed 4980 (86.94%)
part type 1 performed 3000 (52.37%)
part type 2 performed 900 (15.71%)
part type 4 performed 1080 (18.85%)
empty 748 (13.06%)

c)

Figure 8. Partial presentation of task results for criteria combination – case 2 with GJOB program: a) result; b) machine gantogram; c) machine statistics

Slika 8. Djelomičan prikaz rezultata zadatka za kombinaciju kriterija – slučaj 2 programom GJOB: a) resultat; b) gantogram strojeva; c) statistika strojeva

4.2. Case 2

Figure 8 shows the result of optimization using both criteria, for the shortest possible manufacturing cycle and the shortest possible waiting period of the machine which performs the operation, used on FMS with same properties as in *case* 1.

By introducing an additional criterion for the shortest possible waiting period of the machine which performs the operation, *case* 2 becomes more complex than *case* 1. Therefore, the application of the same genetic algorithm parameters does not give the best result.

By trying out different genetic algorithm parameter values, the conclusion has been reached that it is sufficient to enlarge the number of generations.

The genetic algorithm with 530 genes per chromosome, 250 chromosomes in a population (*popSize* =250), 1000 generations (*maxgen* =1000), stochastic replacement selection, linear scaling, uniform crossover (*pcross* =0,8), and nearest neighbor mutation (*pmutation* =0,03) was applied.

Figure 8 shows that combination of criteria for minimum manufacturing cycle and minimum waiting period of the machine achieves much better utilization of machine no. 2 (98,9 %), till the completion of operations. That means that machine 2 is free from the period 3285 and can be used for other purposes. Such a combination of criteria reduces time spent of the cycle for manufacturing of part 4 (time 3250 in comparison with 5665 in *case* 1).

Previous analyses were made with the assumption that transport of the product on a palette from buffer store to machine depends only on the availability of the machine which performs the operation. This means that the transporter is available at any moment which is, of course contrary to the real case.

When comparing figure 7 (*case* 1) and figure 8 (*case* 2) results, it can be seen that both cases contain a fairly large population (250 units), the cross over parameter is the same, while the mutation parameter and generation number vary depending on the complexity of the problem. Solving *case* 2 is more complex than solving *case* 1, since there is one more restriction. This restriction is the shortest possible waiting period of the machine, therefore a larger number of generations is required (1000) for achieving optimum results.

5. Conclusion

Optimizing the process flow within the work order is one of the key features of reaching adequate overall productivity and effectiveness of the complete manufacturing system. When dealing with flexible manufacturing systems, optimizing the manufacturing cycle of work order, as an indicator of temporal processing by means of simultaneous part fabrication, is of outstanding importance. It plays a great role in achieving terms for high overall efficiency of flexible manufacturing system, which is the main factor in economical justification of large investments for their development and utilization.

Forming the partial task with a convenient structure of work order is an assumption for high efficiency of the production system. Beneficial structure of work order implies a set of parts the production of which requires all available machines with similar time consumption. Required time interval should be as small as possible, and combined with good synchronization of personnel and good tool usage.

Due to the fact that the assembly plan has the primary influence on present technical and organizational solutions of manufacturing systems, the sequence of occurrence of manufacturing steps within the work order remains as the primary element which dictates the efficiency of the FMS.

This paper contributes to the solution of the problem of controlling FMS which consists of various machines, considering the realization of particular work orders, the structure of which is defined by assembly plan. This means that the structure is defined by market demands when referring to quantities and part types. Since the work order structure is not harmonized with exploitation characteristics of FMS which arise from characteristics of core system structure, we are facing a problem how to realize the work order and achieve the main goal at the same time: the least possible time occupation of the system, i.e. the shortest possible processing cycle.

The problem has been analyzed in this paper, and the conducted research has resulted in the development of an approach which is based on two problem solving phases:

first phase – selection of optimum process plan combination,

second phase – optimization of sequential process event.

Selection of one process plan combination among developed process plans is conducted within the first phase, which will ensure minimum time load of the production system of known features, by applying the simultaneous production of randomly combined parts.

The second phase requires controlling of the sequential events for particular partial task operations to lower the overall manufacturing cycle. Thus, it is necessary to optimize the entering sequence of each part into the production process as well as the operations while bearing in mind shortest possible time load of the system as a whole (work stations, automated transport systems), and equal engagement of each work station.

It was important to come up with a method which can process the input data quickly, and with a definition of optimum sequencing of performing certain operation from the wholeness of work order. This was done in order to ensure applicability of the operational controlling of FMS and to achieve the main goal.

The goal for efficient operation has been accomplished by means of a genetic algorithm approach in both control phases. Bearing in mind properties of genetic algorithm approach, it can be concluded that achieved results of optimization tasks are almost optimal. The second stage optimization, due to its complexity, could not have been solved at all by using another method, or it would have been solved less efficiently.

Valuable are not solutions to individual problems of optimal FMS controlling, but also the developed computer program which can be applied to any new problem or optimization of sequential FMS process events.

By comparing results of the two cases in this paper, a tool has been given for how to adapt population size to number of genes per chromosome or chromosome unit size. It was also shown that number of generations varies due to the complexity of the problem. Change in population and generation number calls for change in cross over parameters (*pcross*) and mutation change (*pmutation*). All results have been obtained by examining various populations, number of generations as well as various crossover and mutation parameter values. Only the best results have been shown.

It is also important to note that optimization of sequential operation, events for the particular work order was done with the basic assumption that transport of the product from buffer store to machine depends only on the availability of the machine which performs the operation. This means that the transporter is available at any moment which is, of course contrary to the real case.

Future research will try to comprise real limitations of the transport system.

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