

## Optimizacija pretoka materiala v serijski proizvodnji The Optimization of Material Flow in Serial Production

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*Spremenjenim potrebam tržišča, ki terja kakovostne izdelke in upoštevanje rokov dobave, je vse teže slediti. Eden izmed ukrepov, ki omogoča uresničitev teh zahtev, je tudi optimizacija pretoka materiala, ki jo izvedemo z analizo pretoka materiala, s katero dobimo vpogled v proizvodno organizacijo podjetja in njeno ocenitev na različnih organizacijskih ravneh. Analiza temelji na podatkih tehnološke baze podatkov in organiziranosti posameznih služb v podjetju. Omogoča analizo pretoka materiala (materialov, sestavnih delov, sestavov in izdelkov) in informacij ter analizo prostorske razmestitve oddelkov, delovnih sredstev in naprav. Rezultat analize je v racionalnejši ureditvi in zmanjšanju stroškov pretoka materiala.*

Ključne besede: proizvodnja serijska, pretok materiala, analize pretoka, diagrami potekov

*Market demands are different: they tend to require individual, customised products of high reliability and high quality, also produced at the right time. Material flow optimization is an indispensable step to be taken. The proposed optimization method is material flow analysis, which provides an insight into the production organization of a company and its evaluation at different organizational levels. The analysis is based on a technological database and on the organization of individual departments of a company. It allows for a material and information flow analysis (materials, parts, structures and products) as well as an analysis of the department layout, production means and devices. The result of the analysis is material flow rationalization, thus minimizing production costs.*

Keywords: serial production, materials flow, flow analysis, flow diagrams

### 0 UVOD

Cilj vsakega proizvodnega podjetja je povečanje gospodarnosti, kar lahko dosežemo z:

- zmanjšanjem pretočnih časov,
- zmanjšanjem odstopanja od dogovorjenih rokov,
- zmanjšanjem stanja in
- zvečanjem izkoriščenosti zmogljivosti.

Cilje gospodarne izdelave ločimo na cilje trga in cilje podjetja, kar prikazuje tudi slika 1.

Cilja podjetij sta predvsem nizko stanje in dobra izkoriščenost vseh zmogljivosti, tržišče pa zahteva kratke pretočne čase in brezpogojno izpolnjevanje dogovorjenih rokov.

Zaradi zaostrenih pogojev konkurenčnosti doma in na svetovnem trgu je v zadnjih letih prišlo do bistvenega premika od ciljev podjetja k ciljem trga. Dandanes so torej bolj pomembni kratki pretočni časi in izpolnjevanje dogovorjenih rokov kakor pa nizko stanje in dobra izkoriščenost zmogljivosti.

Podjetja doma in po svetu so pred odločilnimi potezami. Modernizacija in prestrukturiranje sedanje proizvodnje sta za vključevanje na svetovni trg nujni. Pomanjkljivost današnjih podjetij se kaže predvsem v previsoki lastni ceni izdelka, ki je po naših ugotovitvah rezultat neracionalnega pretoka materiala in predolgega zadrževanja obdelovancev v proizvodnji.

### 0 INTRODUCTION

Every production-oriented company's goal are the maximum economic assets, which can be achieved by the following measures:

- minimization of flow times,
- minimum alterations of agreed-upon terms,
- minimization of the mean-state, and
- maximization of resource efficiency.

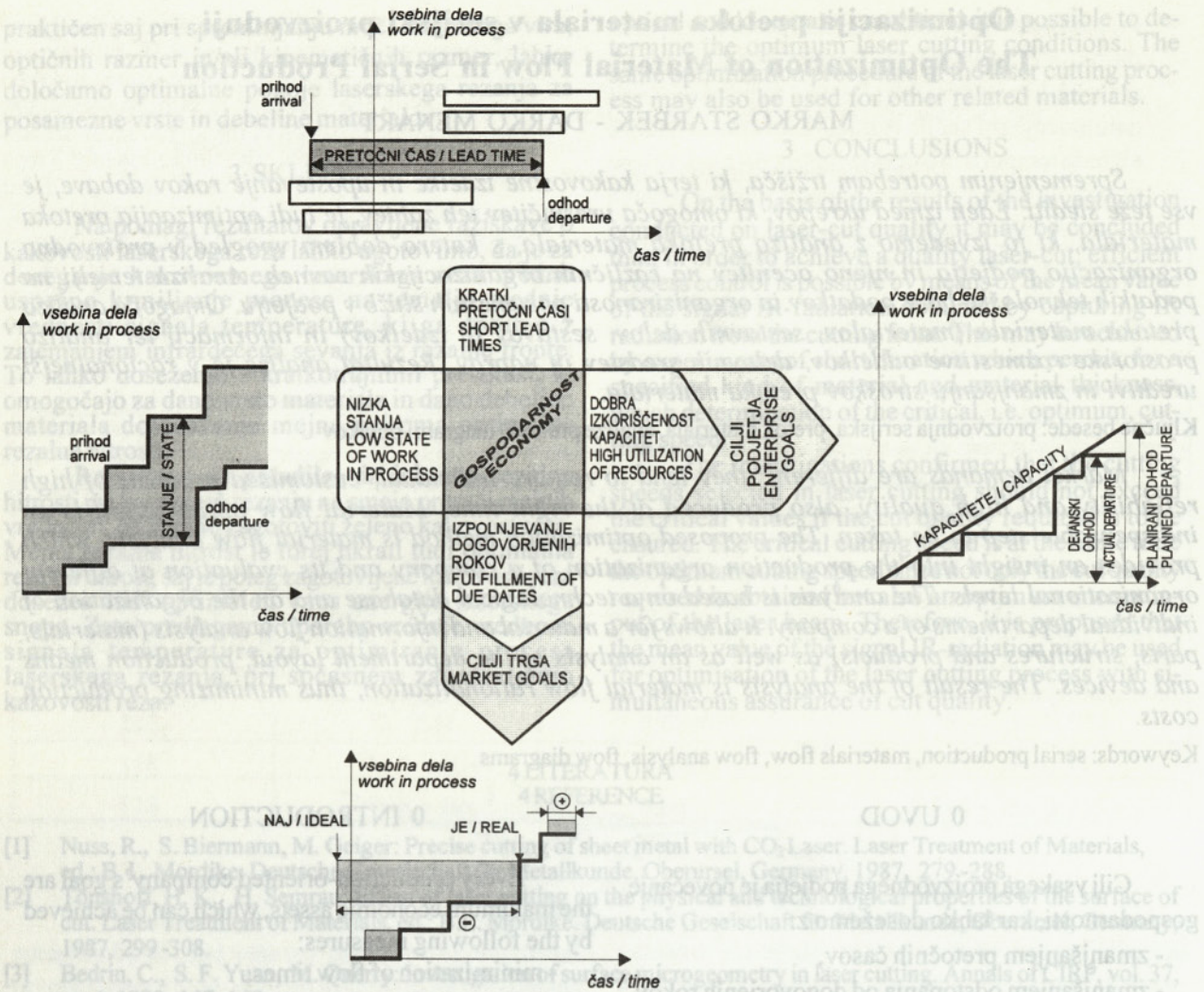
One should distinguish between the goals of the market and the goals of the company, as shown in figure 1.

The two primary goals of companies are basically a low state and good efficiency of all resources. However, the market demands short flow times and the ultimate fulfillment of agreed-upon terms.

Harsher competition on the domestic as well as on the international market has caused a considerable shift from the goals of the company to the goals of the market. Today, short flow times and the fulfillment of agreed-upon terms are far more important than a low state and good resource efficiency.

Companies all over the world now have to make some crucial moves. The modernization and restructuring of the existing production are crucial for entering the international market. Companies' main setbacks are reflected in a product's net cost that is too high, which has been found to be the result of an irrational flow of material and long production process.





Sl. 1. Cilji gospodarne izdelave

Fig. 1. The goals of economic production

Na sliki 2 je prikazan delež operacijskega časa v pretočnem času, to je v celotnem času, ko se obdelovanec zadržuje v proizvodnji. Analize so pokazale, da se za povprečen obdelovanec v proizvodnji na stroju porabi samo 5 odstotkov vsega časa, za samo obdelavo pa manj ko 30 odstotkov časa na stroju, kar pomeni, da pripada izdelavi elementa (operacijski časi) samo približno 1,5 odstotka vsega časa [3]. Rezultati kažejo, da so v proizvodnji še velike zaloge, ki jih je mogoče izrabiti.

Ugotovimo lahko, da je neracionalnost proizvodnje posledica slabe organiziranosti pretoka materiala.

Predlagamo metodo, ki z najmanjšimi investicijami in večjimi vlaganji v znanje nadomesti prevelik razkorak in predvsem dosega z boljšo organiziranostjo izdelovalnega sistema večjo izdelavo.

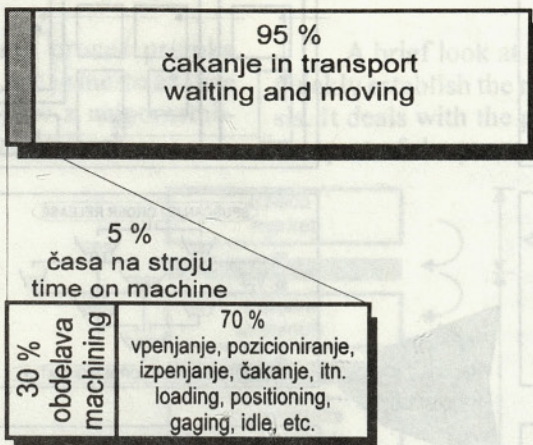
Figure 2 shows the proportion of the operational time with regard to the flow time, i.e. in the whole amount of time a workpiece spends in the process of production. According to our analyses, an average workpiece spends only 5 percent of the time in the process of machine production and less than 30 percent of the time for machining on a machine. Obviously, the manufacturing of an element (operational times) takes up only approximately 1.5 percent of all the time [3]. These results indicate major production reserves that can still be used.

The above facts indicate that irrational production is the result of poorly organized material flow.

Our proposal is based on a method which, with minimum investments and a greater emphasis on knowledge, will bridge the gap that is too big and, more importantly, - through better organization of the production system - it will result in the larger output of this system.



## čas v proizvodnji / shop-time utilization



Sl. 2. Razdelitev časa obdelovanca v proizvodnem procesu

Fig. 2. The time division of a workpiece in the production process

1 RACIONALIZACIJA PRETOKA  
MATERIALA

Racionalizacija pretoka materiala (to je smotrna ureditev pretoka materiala, vrsta ukrepov za izboljšanje, poenostavitev in pocenitev pretoka materiala, zmanjšanje stroškov pretoka materiala) zahteva izvedbo naslednjih korakov:

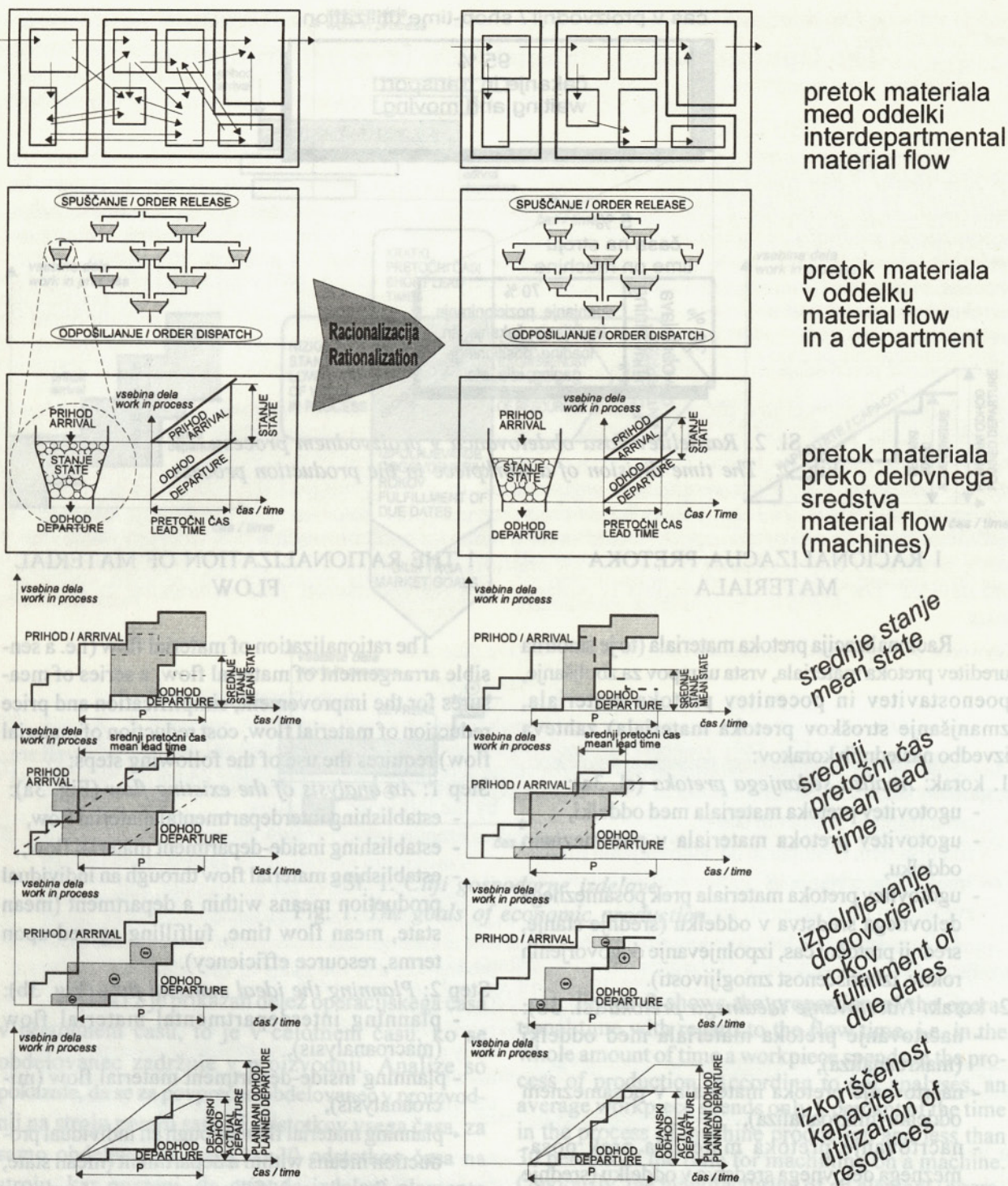
1. korak: *Analiza sedanjega pretoka* (sl. 3a):
  - ugotovitev pretoka materiala med oddelki,
  - ugotovitev pretoka materiala v posameznem oddelku,
  - ugotovitev pretoka materiala prek posameznega delovnega sredstva v oddelku (srednje stanje, srednji pretočni čas, izpolnjevanje dogovorjenih rokov, izkoriščenost zmogljivosti).
2. korak: *Načrtovanje idealnega pretoka* (sl. 3b):
  - načrtovanje pretoka materiala med oddelki (makroanaliza),
  - načrtovanje pretoka materiala v posameznem oddelku (mikroanaliza),
  - načrtovanje pretoka materiala prek posameznega delovnega sredstva v oddelku (srednje stanje, srednji pretočni čas, izpolnjevanje dogovorjenih rokov, izkoriščenost zmogljivosti).
3. korak: *Ugotovitev rezultatov racionalizacije pretoka materiala*:
  - prihranek pri stroških notranjega transporta,
  - skrajšanje srednjega stanja naročil,
  - skrajšanje rokov izpolnjevanja dogovorjenih rokov na delovnem sredstvu oziroma oddelku,
  - izboljšanje izkoriščenosti kapacitet delovnega sredstva oziroma oddelka.

1 THE RATIONALIZATION OF MATERIAL  
FLOW

The rationalization of material flow (i.e. a sensible arrangement of material flow, a series of measures for the improvement, simplification and price reduction of material flow, cost reduction of material flow) requires the use of the following steps:

- Step 1: *An analysis of the existing flow* (Fig. 3a):
  - establishing interdepartmental material flow,
  - establishing inside-department material flow,
  - establishing material flow through an individual production means within a department (mean state, mean flow time, fulfilling agreed-upon terms, resource efficiency).
- Step 2: *Planning the ideal material flow* (Fig. 3b):
  - planning interdepartmental material flow (macroanalysis),
  - planning inside-department material flow (microanalysis),
  - planning material flow through an individual production means within a department (mean state, mean flow time, fulfilling agreed-upon terms, resource efficiency).
- Step 3: Establishing the results of the rationalization of material flow:
  - lower cost of internal transport,
  - shorter mean state of orders,
  - shorter time needed to fulfill agreed-upon terms on a production means or in a department,
  - better resource efficiency of a production means or a department.





Sl. 3. Načrtovanje sedanjega in popolnega pretoka materiala  
 Fig. 3. Planning the existing and the ideal material flow

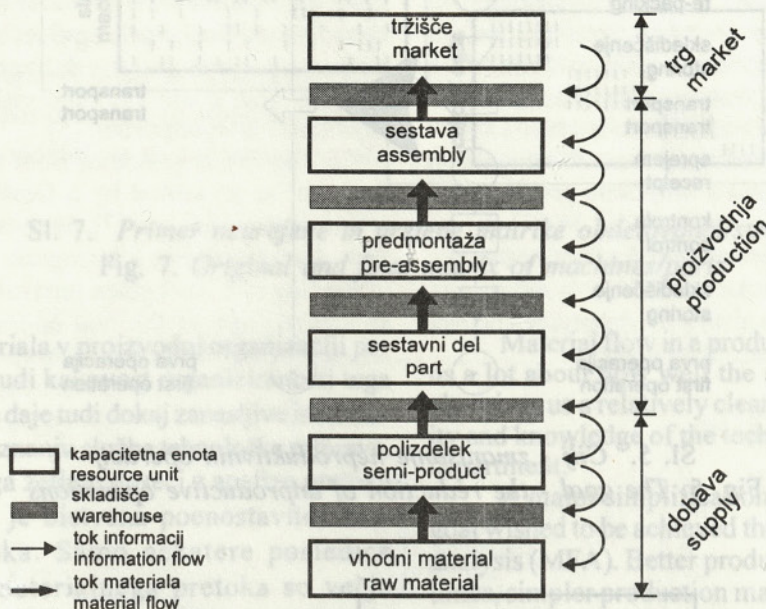


## 2 ANALIZA PRETOKA MATERIALA

Če si na kratko ogledamo proces pretoka materiala, lahko hitro določimo, kje je mesto analize pretoka materiala. Ukvarja se prav z najpomembnejšim delom procesa, to je proizvodnjo.

## 2 THE MATERIAL FLOW ANALYSIS

A brief look at the material flow process will quickly establish the role of the material flow analysis. It deals with the production as the most important part of the process.



Sl. 4. Logistična veriga med dobavo, proizvodnjo in prodajo

Fig. 4. A logistic chain between supply, production and sales

Z analizo pretoka materiala ugotovimo prostorski vzorec pretoka materiala in v tem vzorcu uveljavljanje predvsem prevladujočih poti. Tem se morajo kasneje podrediti tako organizacijske strukture kakor tudi poslovne odločitve, tehnološka priprava dela in celo konstrukcija.

Posledica urejenega pretoka materiala je tudi zmanjšanje proizvodnih netehnoloških operacij. Te dodatne operacije ne spreminjajo kakovostnih (oblikovnih, mehanskih, kemičnih, električnih itn.) lastnosti obdelovancev, občutno pa lahko prispevajo k njihovi lastni ceni. Dodatne operacije so v bistvu neproduktivne in neplačane operacije, zato jih moramo zmanjšati na najmanjšo mogoče mero. Sprememba do želenega cilja je prikazana na sliki 5.

Pretok materiala v podjetju lahko delimo na dve stopnji, imenujemo ju makroanaliza in mikroanaliza [2].

Na prvi stopnji, makroanalizi, poiščemo najpreprostejši pretok materiala na nivoju celotnega podjetja, in sicer med posameznimi vnaprej definiranimi oddelki. Preprost primer urejanja pretoka materiala in s tem doseganje standardnega pretoka materiala je prikazan na sliki 6. Iščemo torej makroskupine strojev, to je oddelke in makrodružine obdelovancev, ki so izdelane v minimalnem številu oddelkov, lahko le v enem. Obdelovanci potujejo iz oddelka v oddelek le, ko zanje predpisanih tehnoloških postopkov zaradi različnih zahtev v enem samem oddelku ni mogoče uporabljati.

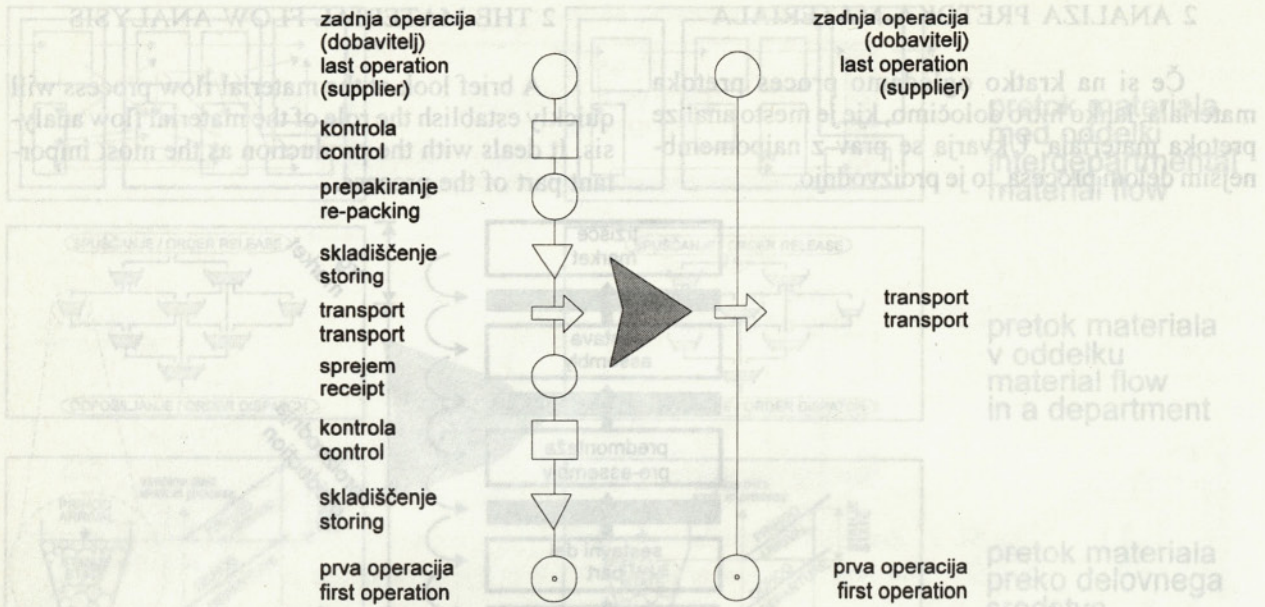
The aim of the material flow analysis is to establish the location pattern of material flow, in which it would then determine the mostly dominant ways. Later in the process, organizational structures as well as business decisions, technological preparation of work and even design would have to be subordinated to these dominant ways.

Appropriate material flow also results in less non-technological production operations. These additional operations do not alter the qualitative properties of workpieces (shape, mechanical, chemical, electric, etc.). However, they do contribute considerably to the net cost. Since these additional operations are in fact unproductive and unpaid operations, they have to be reduced to the minimum level. Figure 5 shows how this can be done.

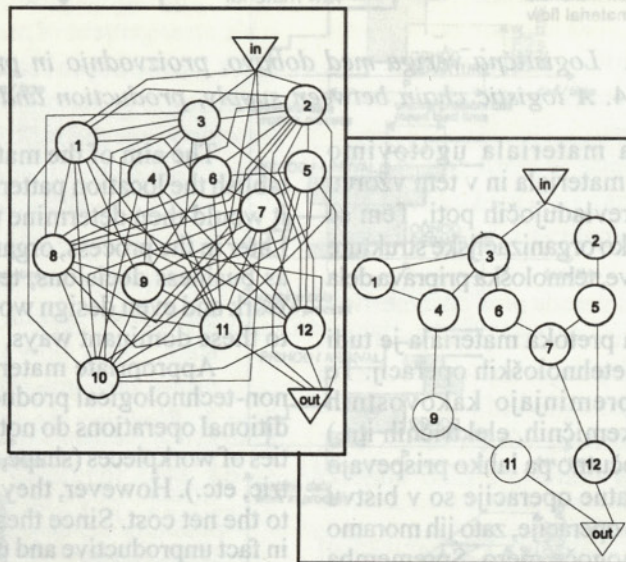
Material flow in a company has two stages: macroanalysis and microanalysis [2].

During the first stage, the macroanalysis, we wish to determine the simplest possible material flow between individual departments defined in advance. A simple case of arranging material flow with which standard material flow can be achieved is shown in figure 6. We look for macrounits of machines, i.e. departments and macrofamilies of workpieces, which are produced in the minimum number of departments, possibly in a single one. The aim is for the workpieces to travel from one department to another only in cases when the required technological procedures cannot all be performed in a single department.





Sl. 5. Cilj - zmanjšanje neproduktivnih operacij  
 Fig. 5. The goal - the reduction of unproductive operations

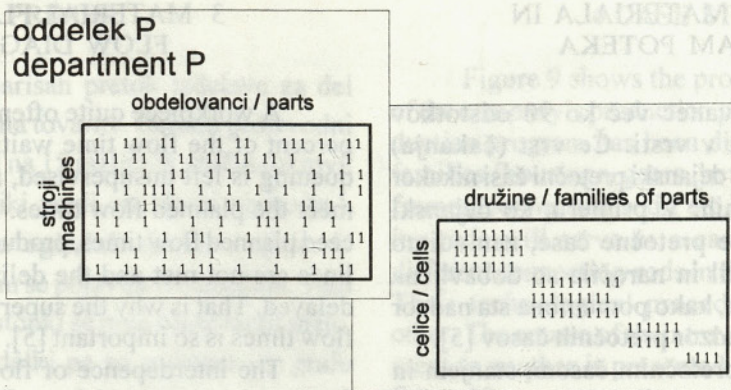


Sl. 6. Primer neurejenega in urejenega pretoka med oddelki  
 Fig. 6. Example of unarranged and arranged flow between departments

Na drugi stopnji, imenovani mikroanaliza, z analizo pretoka poskušamo razdeliti obdelovance, ki se izdelujejo v posameznih oddelkih v družine obdelovancev, stroje v posameznih oddelkih pa na skupine strojev, ali proizvodne celice [1]. To delitev opravimo tako, da so posamezne proizvodne celice zmožne v celoti izdelati njim pripadajoče družine obdelovancev. Preprost primer preoblikovanja je prikazan na sliki 7.

During the second stage, microanalysis, we try to divide the workpieces - produced in individual departments - into families of workpieces and machines from individual departments into groups of machines or production cells [1]. This division is performed in such a way that individual production cells can produce on their own the workpieces that belong to them. A simple example of such a transformation is shown in figure 7.





Sl. 7. Primer neurejene in urejene matrice obdelovanci/stroji  
Fig. 7. Original and final matrix of machines/parts

Pretok materiala v proizvodni organizaciji posredno prikazuje tudi kakovost organiziranosti tega sistema, poleg tega daje tudi dokaj zanesljive informacije o kakovosti in znanju službe tehnološke priprave.

Namen, ki ga želimo doseči z analizo pretoka materiala (ATI), je bistvena poenostavitev materialnega pretoka. Samo nekatere posledice preprostejšega materialnega pretoka so večja produktivnost, krajši pretočni časi, enostavnejše vodenje proizvodnje, manjše medfazne zaloge in zato manjša vezana sredstva.

Poleg naštetih učinkov pa naj ATI poskrbi, da bodo opravljeni popravki materialnega pretoka zagotovili, da se posamezni obdelovanci izdelajo v minimalnem številu oddelkov, po možnosti v enem samem.

Ta ukrep bo omogočil glavno nalogo ATI, to je preoblikovanje delavniškega načina proizvodnje v celični proizvodni sistem, za katerega je značilna izdelava posameznih družin obdelovancev na ustreznih skupinah strojev (celicah). Celična proizvodnja približa malo in srednjeseerijsko proizvodnjo masovni proizvodnji z bistvenim zmanjšanjem časov, ki so potrebni za začetne in končne operacije, preprostejša je za krmiljenje, poleg tega pa je prijetnejša za delavca, ker je manj enolična in ker mu ponuja odgovornost za določene izdelke in ne le za posamezne operacije.

Poleg teh, je treba omeniti še: celična proizvodnja sili posamezne organizacije v specializacijo na nivoju izdelave elementov [4]. Specializacija ima seveda za posledico izboljšavo kakovosti in nižanje stroškov, poleg tega daje realno možnost za prehod na visoko produktivne sisteme, na primer prilagodljive obdelovalne sisteme (POS), pri ugodnih tržnih pogojih.

Bistvena ekonomska pridobitev je zmanjšanje pretočnih časov, ki imajo neposredni učinek na zmanjšanje vezave kapitala v zaloge, kar je mogoče zmanjšati še s krajšanjem pripravljalnih časov.

Material flow in a production organization tells us a lot about how well the system is organized. It also gives us a relatively clear picture about the quality and knowledge of the technological preparations department.

A major simplification of material flow is the goal wished to be achieved through the material flow analysis (MFA). Better productiveness, shorter flow times, simpler production management, lower inter-phase supplies - and consequently lower deposits - are only some advantages of a simplified material flow.

In addition to the effects mentioned above, MFA should see to it that the implemented corrections of material flow ensure that individual workpieces are produced in the minimum number of departments, if possible in a single one.

This measure will enable the implementation of the chief task of MFA - the transformation from the workshop production into the cell production system. The cell production system is known for its production of individual families of workpieces on proper groups of machines (cells). Cell production brings small- and medium-scale production to large-scale production with a considerable shortening of the time necessary for setup operations. It is also easier to control and more pleasant for workers, as it is less monotonous and makes workers feel responsible not just for individual operations, but also for particular products as a whole.

It should be noted that these advantages are not the only good points. Cell production forces individual organizations into specialization at the element production level [4]. The ultimate consequence is higher quality, cost reduction as well as a real opportunity for transition onto highly productive systems, such as flexible machining systems (FMS), provided the market conditions are also good.

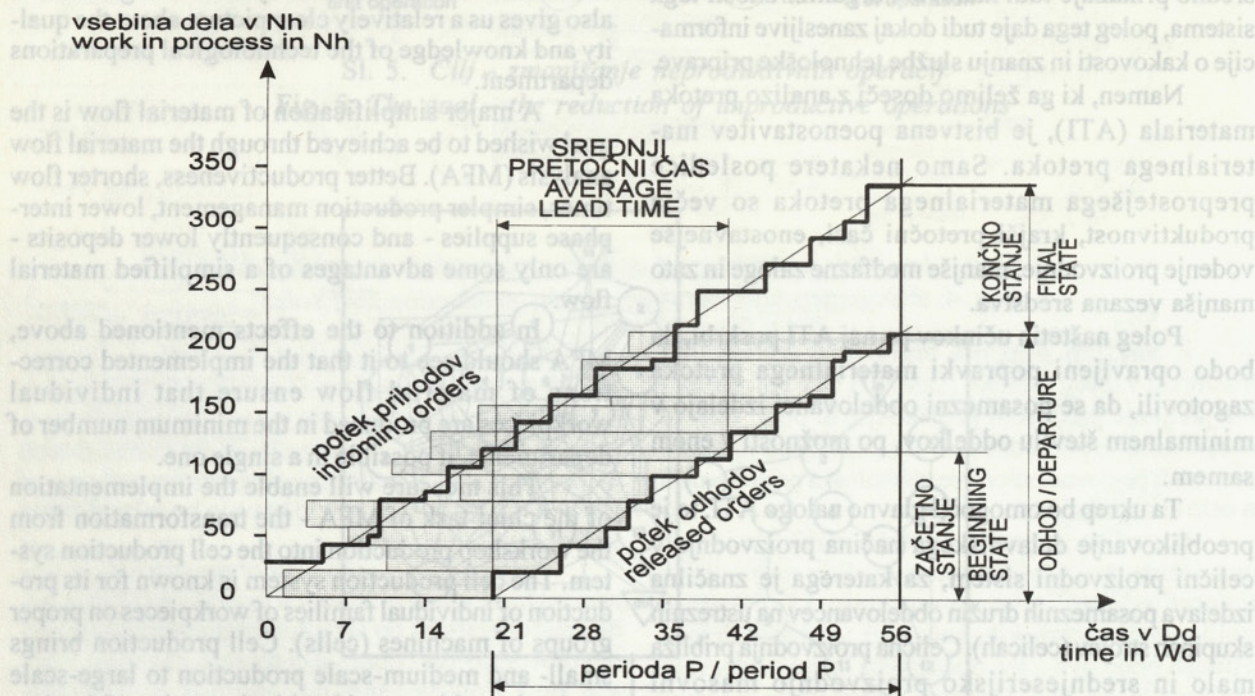
The main economic gain is in reduction of flow times, which have a direct effect on lower capital deposits, which can be further reduced by the reduction of setup times.



### 3 PRETOK MATERIALA IN DIAGRAM POTEKA

Pogosto obdelovanec več ko 90 odstotkov pretočnega časa čaka v vrsti. Če vrst (čakanja) nimamo pod nadzorom, dejanski pretočni časi nikakor ne dosežejo načrtovanih. V primeru, ko dejanski prekoračijo načrtovane pretočne čase, zamudimo čase izgotovitve naročil in naročila so dobavljena prepozno. Tako vidimo, kako pomembna sta nadzor čakanja in prav tako nadzor pretočnih časov [5].

Odvisnost med pretočnim časom, stanjem in učinkom lahko prikažemo v diagramu pretoka ali v diagramu obremenitev - učinek [6] in [7], ki ga prikazuje slika 8. V diagramu pretoka je prikazan histogram dejanskega poteka obremenitve delovnega mesta (prihod naročil) in histogram dejanskega poteka učinka delovnega mesta (odhod naročil).



Sl. 8. Diagram pretoka (obremenitev - učinek) diagram  
Fig. 8. Flow diagram (load-effect) diagram

Naloga načrtovanja in krmiljenja proizvodnje je, da preprečuje preveliko čakanje naročil, ki prihajajo na delovna mesta in s tem predolge pretočne čase ter premajhno stanje, ki bi lahko povzročilo nedelo zaradi pomanjkanja naročil. Pri določanju zaporedja obdelav moramo upoštevati prioriteta pravila, s katerimi naj bi sestavljali zaporedje naročil, ki bi zagotavljalo enakomeren pretok in doseganje terminov.

### 3 MATERIAL FLOW AND FLOW DIAGRAM

A workpiece quite often spends more than 90 percent of the flow time waiting in a queue. If the queuing is left unsupervised, real flow times never meet the planned flow times. If real flow times exceed planned flow times, production is delayed, deadlines are not met and the delivery of goods is also delayed. That is why the supervision of queuing and flow times is so important [5].

The interdependence of flow time, state and effect can be presented by a flow diagram or load-effect diagram [6] and [7], as shown in figure 8. The flow diagram shows a histogram of the real course of loading of a workplace (arrival of orders) as well as a histogram of the real course of effect of the workplace (departure of orders).

The role of the production planning and control is, on the one hand, to prevent too many orders at a time, which can cause too long flow times; on the other hand the production control must prevent a shortage of orders, which would consequently cause a lack of work. When setting the order of machining, priority rules must be considered. These priority rules are supposed to help us to assign the orders in such a way that they would come in an even flow, which would enable an even fulfillment of orders and terms.



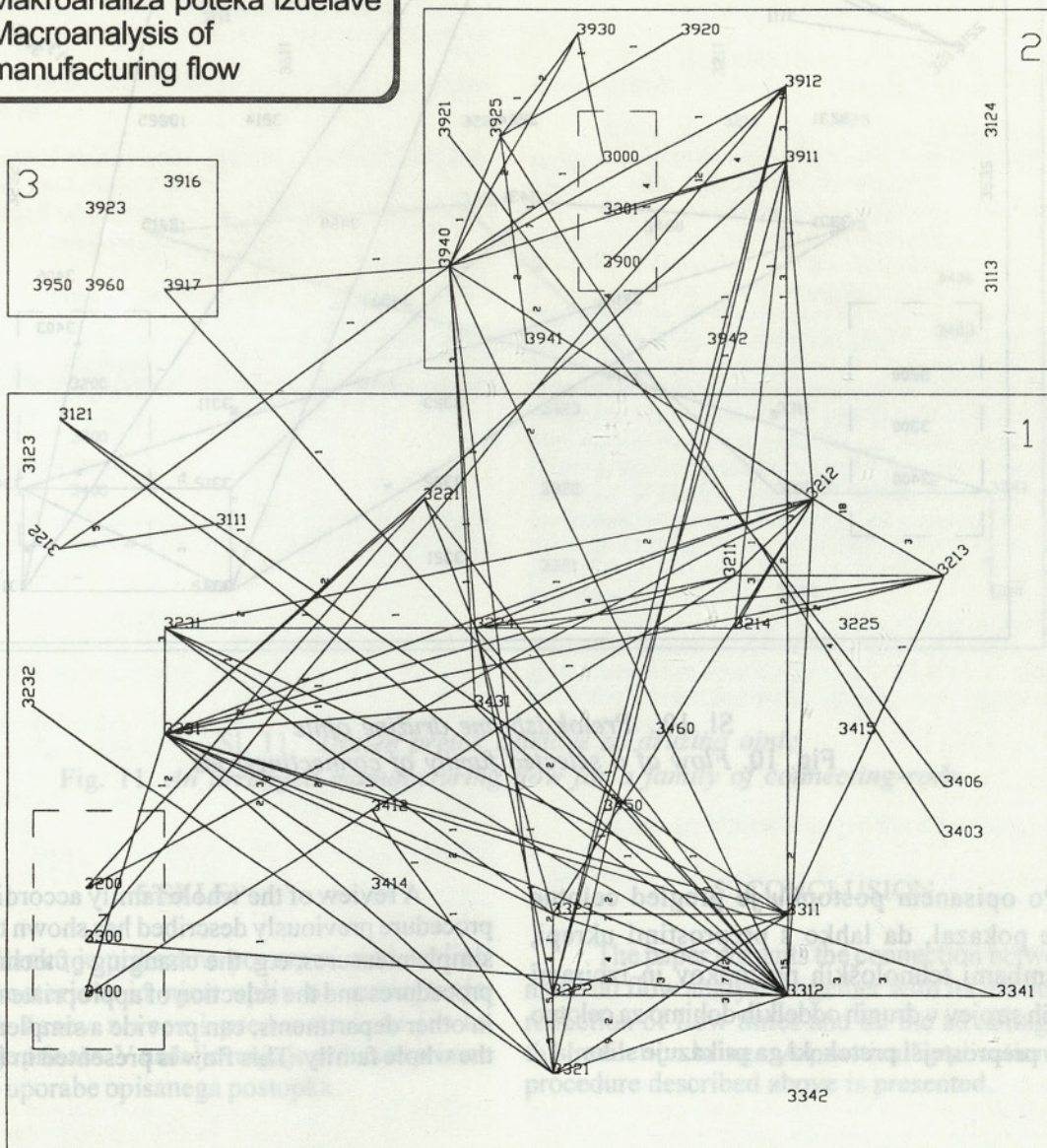
## 4 PRIMER

Na sliki 9 je narisan pretok izdelave za del proizvodnega programa tovarne. Celotni proizvodni program smo razdelili na 15 različnih družin (okrovi, zobniki, stožčasti zobniki, gredi, osi, okviri, ojnice itn.). Kot primer si bomo ogledali družino ojníc. V proizvodnem programu se pojavlja 12 različnih. Tudi njihovi tehnološki postopki se med seboj razlikujejo, njihove poti med oddelki pa so prikazane v grafu pretokov na sliki 10.

## 4 CASE STUDY

Figure 9 shows the production flow for a part of the company's production program. The whole production program has been divided into 15 different families ( housings, gears, bevel gears, shafts, axles, frames, connecting rods, etc.). A family of connecting-rods will serve as a case study. There are 12 different connecting-rods in the production program. Their technological procedures differ from each other. The course of their travelling from one department to another is presented in the flow diagram in figure 10.

Makroanaliza poteka izdelave  
Macroanalysis of  
manufacturing flow



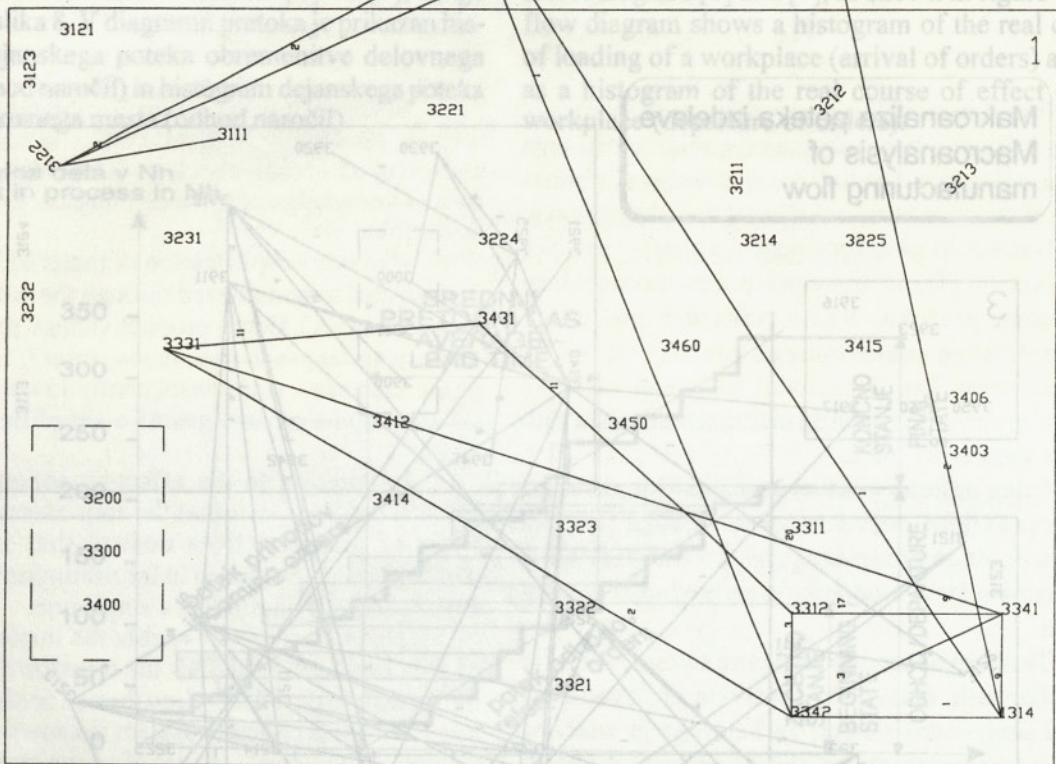
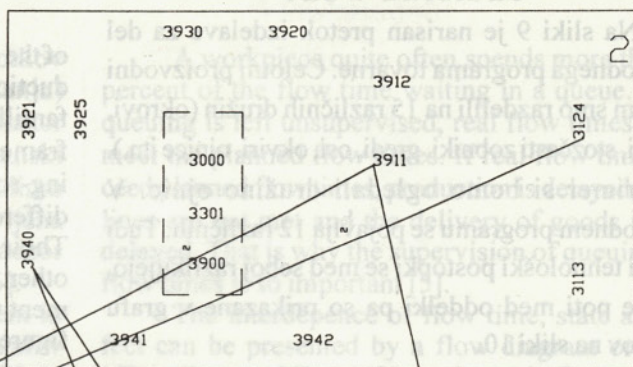
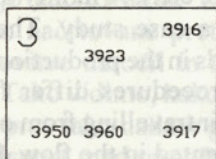
Sl. 9. Povezave med oddelki za del proizvodnega programa podjetja

Fig. 9. Connections between departments for a part of the company's production program



**Makroanaliza poteka izdelave**  
**Macroanalysis of**  
**manufacturing flow**

stara stanje / previous state



Sl. 10. Pretok izbrane družine ojníc  
 Fig. 10. Flow of a selected family of connecting-rods

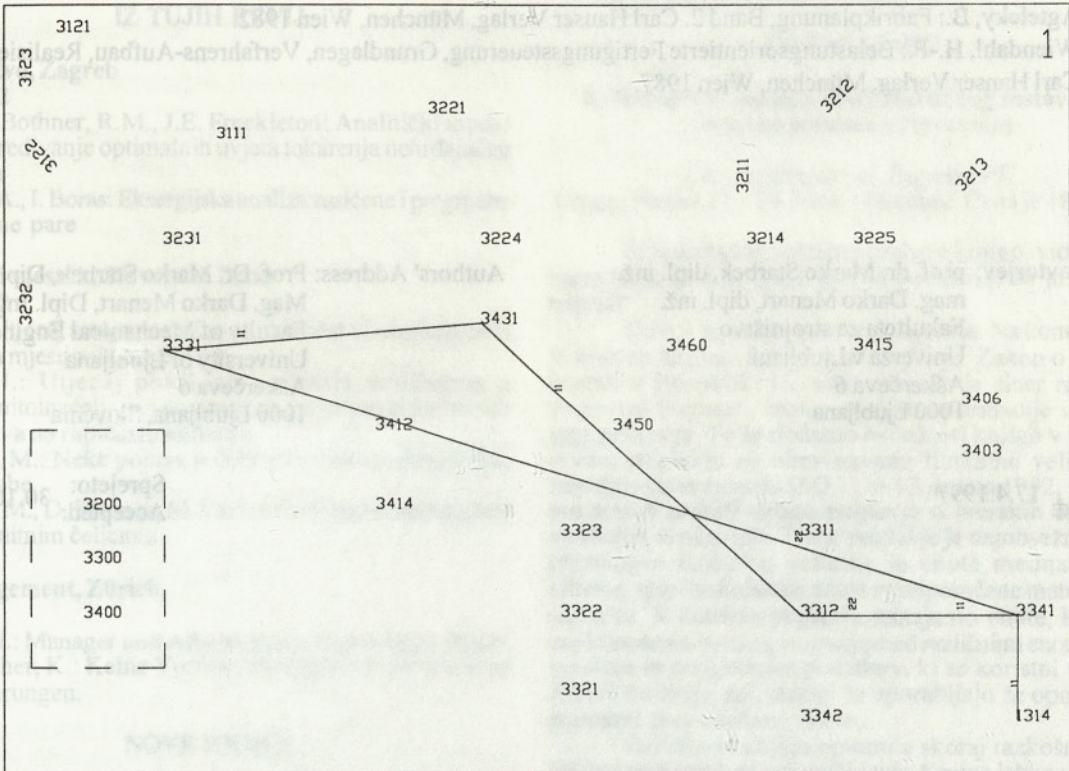
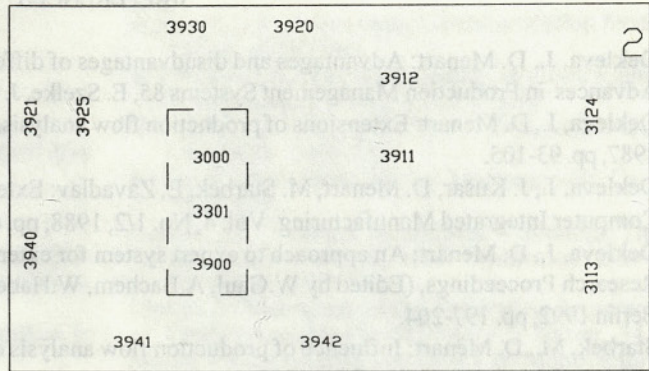
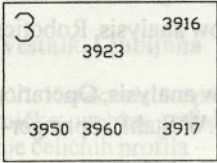
Po opisanem postopku je pregled celotne družine pokazal, da lahko s preprostimi ukrepi, spremembami tehnoloških postopkov in izbirami ustreznih strojev v drugih oddelkih dobimo za celotno družino preprostejši pretok, ki ga prikazuje slika 11.

A review of the whole family according to the procedure previously described has shown that some simple measures, e.g. the changing of technological procedures and the selection of appropriate machines in other departments, can provide a simpler flow for the whole family. This flow is presented in figure 11.



**Makroanaliza poteka izdelave**  
**Macroanalysis of**  
**manufacturing flow**

novo stanje / new state



Sl. 11. *Urejen pretok izdelave za družino ojníc*  
 Fig. 11. *An arranged manufacturing flow for a family of connecting-rods*

5 SKLEP

V članku je prikazana povezava med analizo pretoka materiala in njen vpliv na zmanjšanje pretočnih časov z vsemi prednostmi, ki jih to zmanjšanje prinaša. V nadaljevanju je prikazan primer praktične uporabe opisanega postopka.

5 CONCLUSION

The paper presents the connection between the material flow analysis together with its influence on reduction of flow times and all the advantages that this reduction brings. A practical application of the procedure described above is presented.



6 LITERATURA  
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