FACTA UNIVERSITATIS
Series: **Economics and Organization** Vol. 7, No 3, 2010, pp. 349 - 360

ANALYSIS OF PROCESS DURATION AND PROCESS CAPACITY AS A BASE FOR PROCESS TIME MANAGEMENT

UDC 005.962.11

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Abstract. *Processes represent the basis for the analysis and improvement of business operations. Their efficiency influences the efficiency of an enterprise as a whole, but also customers' and other stakeholders' satisfaction. Therefore continuous improvement of business processes can be considered as managers' and employees' everyday task. In this paper the focus is on exploring some possibilities for process improvement concerning process duration and capacity. Considering the fact that on-time delivery and product availability are significant factors of an enterprise's competitiveness, process time analysis, based on analysis of process duration and capacity, represents an important source of information, especially for the operational managers.*

Key Words: *process management, process duration, process capacity, time management*

INTRODUCTION

Processes represent the enterprises' bloodstream. Problems that occur inside processes produce consequences that affect the health of an entire enterprise. For that reason processes have to be managed, or even better, an enterprise should be managed through process management. Process approach involves identification, measurement and analysis of their performance, as well as continuous improvement and monitoring of the implementation of the improvement. Process identification can be described as determination of the start and the end point of the process, sequence and content of the activities it includes, as well as points of connection with the other processes. Measurement provides data on processes' performances, which is, during the analysis, transformed into information important for discovering the link between inputs and processes, on the one side, and the results of processes, on the other. This information is important for proposing the possible solutions, and for choosing the best of them for process improvement.

Received November 11, 2010

When making decisions about process improvement, managers must have in mind the necessity to fulfil three most important customers' demands. Those demands concern quality, time and price (costs). This means that they have to integrate quality management, time management and cost management. Time management represents some kind of a connector between quality management and cost management (quality of processing affects process lead time, and this, consequently, affects process costs). Generally, there are two ways for providing information for better time management, and they are: process duration analysis and process capacity analysis.

ANALYSIS OF PROCESS DURATION

An important instrument of process analysis in terms of lead time or duration is a flow chart. This diagram shows the sequence (and sometimes duration) of each activity of the process. From the flow chart diagram one can find out why there are problems and delays in the process realization or why the process duration is longer than the sum of the activities' (which it consists of) duration [1]. The most common reasons are: repetition of activities for error correction, the multiplication of activities, and sequential execution of activities rather than parallel or vice versa [6].

1. In modern conditions, self-control by employees performing specific activities, usually in form of process control, is often suggested. However, considering that perfect performing is still not characteristic of processes for the most of the enterprises, in addition to process control, there is usually necessity for control of process outputs. Control activities assume verification of outputs based on certain criteria, which after control become accepted or rejected. Rejected outputs are those that have certain defects. However, the defects of some of these outputs can be corrected, but they need to go back to further processing or for repeating of some of the activities previously performed, but this time properly. Repetition of the activities is reflected in the average duration of the process [7, p. 146-151], or precisely contributes to extending of the lead time. When during process performing defects or errors appear, and therefore it contains "error loop", then the number of units inside the process or its capacity depends on the percentage of non-accepted outputs or outputs with defects [5].

Figure 1 represents an example of a process, which consists of four activities: the first one concerns preparation, the other two concern production and the fourth control. As it can be seen from the figure, if there are no errors, the process lead time will be 34 minutes, or TP = 10 + 10 + 10 + 4 = 34 minutes.

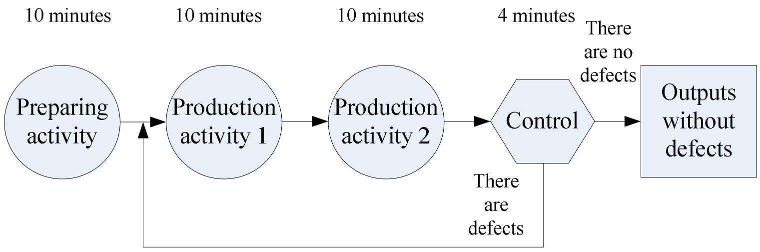

Fig. 1 Flow diagram for the process "X"

However, as some outputs have to be returned for further processing, process duration is prolonged. In this example, if every fourth unit has some kind of defect, which can be repaired, the process will last 40 minutes, or TP = 10 + 1.25 (10 + 10 + 4) = 40 minutes. If the percentage of rejected units is marked "r", the sum of all activities that are repeated due to errors correction or further processing as "T", and the sum of all activities that do not need to be repeated as "To", the duration of the process can be determined as follows:

$$TP = To + (1 + r) * T \tag{1}$$

This formula is valid when it is assumed that the probability that an error will occur again equals zero. However, assuming that the probability for errors after control (after additional processing for correction of defects originally created) is always the same, and then the process lead time can be determined as follows:

$$TP = To + \frac{T}{(1 - r)} \tag{2}$$

In this example, the percentage of outputs with some kind of error is 25%, which means that "r" equals 0.25. If one assumes that 25% of the outputs that are returned for correction will also have some kind of defect, the duration of the process will be longer than in the previous case. The following calculation confirms this:

$$TP = To + \frac{T}{(1 - r)} = 10 + \frac{10 + 10 + 4}{(1 - 0.25)} = 42 \text{ minutes} \tag{3}$$

2. Multiplied activities occur inside processes in which, after performing a certain number of activities, one or more activities have to be separated into two or more activities. When one activity is separated into two or more activities, their content is very similar but still different, usually concerning the duration, due to the fact that the outputs of these activities are assigned to different customer categories.

The number of units in each sub-process depends on the frequency of their choice by customers/clients [3]. Total number of products or services has to be equal to the number of units that have entered the process. The number of clients (services) on certain path is calculated by multiplying the total number of units with the probability that it will be chosen.

For example, in a bank there is an employee who works at the info desk and calls upon all customers and directs them to the designated counter. Figure 2 shows an example where there are three different counters, for three types of services. This figure also shows the probability that clients will choose some kind of services, as well as the time necessary for providing those services. If it is supposed that "m" represents the types of clients, "p" represents the probability of arrival of the client "i", "T" duration of the activity-serving the client, "To" the first activity (which is common to all types of clients) duration, and "Tk" the last activity (which is common to all types of clients) duration, then the duration of the process can be determined as follows [7]:

$$TP = To + \Sigma\, p_i * Ti + Tk, \tag{4}$$

where i = 1, 2, 3, 4, ... m.

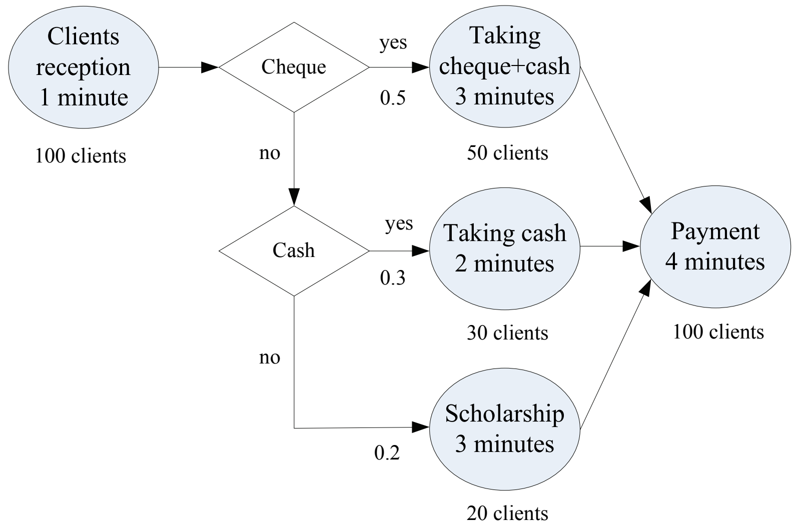

Fig. 2 Flow diagram for process with multiplied activities

For three types of clients, the process duration can be calculated in the following way:

$$TP = T_O + p_1 * T_1 + p_2 * T_2 + p_3 * T_3 + Tk. \quad (5)$$

For the data from Figure 2, process duration will equal 7.7 minutes or TP = 1 + 0.5 * 3 + 0.3 * 2 + 0.2 * 3 + 4 = 7.7 minutes. If this process is seen as a set of three processes or sub processes, which have common first and last activity, then it is possible and necessary to determine the duration of each of them, or duration of the process for each type of client.

3. Parallel activities. When a process includes few activities, which can be performed parallel, then the number of units at each activity is the same as the number of units that have entered the process. This means that capacities of resources, necessary for performing of activities, should be balanced or at the same level [11].

An example of the parallel course of action may be a process for reviewing applications for loans in a bank or an enterprise. If a customer requires deferred payments and has not cooperated with the enterprise, his request has to be processed in order to check its credit history and references and finally make a correct decision. This process is shown in Figure 3.

The duration of this process, besides the duration of the first and final activity, depends on the duration of an activity that has the longest duration, from those activities that come along. Therefore, duration of the process can be calculated as follows:

$$TP = To + \max (T_i) + Tk. \quad (6)$$

In the specific example, the process duration will be 40 minutes or TP = 5 + max (10, 20, 18) + 15 = 5 + 20 + 15 = 40 minutes.

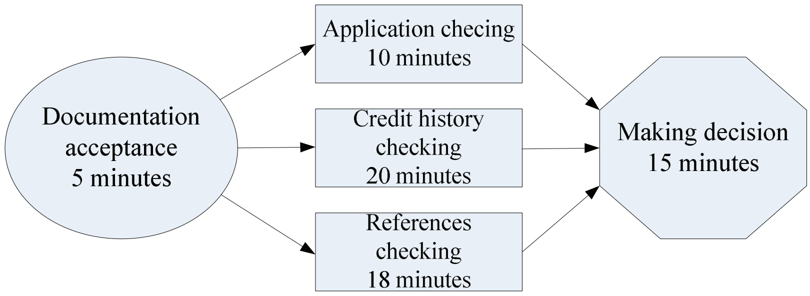

Fig. 3 Flow diagram for the process that contains parallel activities

4. The entire analysis of the process is focused on increasing process efficiency. In this sense, after determining process lead time, it is necessary to determine its efficiency. Process efficiency (PE) is ratio between theoretical and actual process duration [12], where actual duration is usually longer than theoretical, due to waiting time and some unexpected events. Figure 4 represents the process which includes all three previously mentioned possibilities.

While Figure 4 shows the process, the duration of which is subject to analysis, in Table 1 there is the list of all activities of this process, with their processing and waiting time. It is assumed that the process contains multiplied and parallel activities, as well as that part of the outputs, after control has to be returned for further processing and correcting the errors.

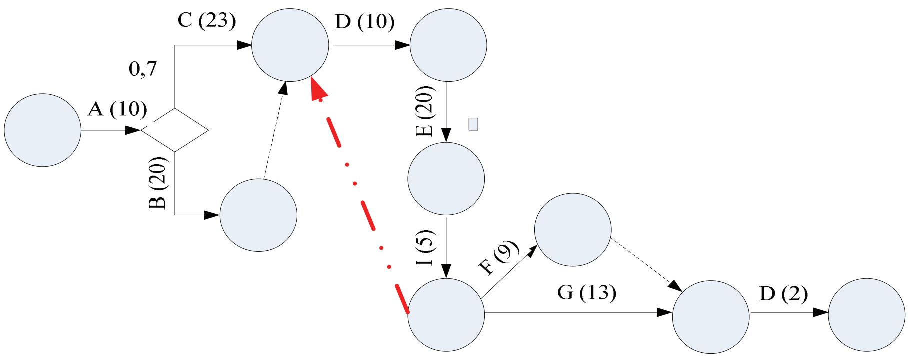

Fig. 4 Flow diagram for the complex process

In this example, the actual process duration (APD) equals 85.6 minutes or

$$APD = 10+0.3*20+0.7*23+1.1*(10+20+5) + \max (9, 13) + 2 = 85.6 \quad (7)$$

Theoretical duration of the process (TPD) can be calculated based on the time of processing for each of the featured activities, or the time from the second column in Table 1.

Table 1 Duration of activities as parts of the process [7]

Activities	Processing time	Waiting time	Total duration
A	2	8	10
B	5	15	20
C	8	15	23
D	3	7	10
E	4	16	20
I (Control)	4	1	5
F	2	7	9
G	4	9	13
H	2	0	2

In this case, process duration is 27.2 minutes, or

$$TPD = 2 + 0.3*5 + 0.7*8 + 1.1*(3 + 4 + 4) + \max(2, 4) + 2 = 27.2 \quad (8)$$

The data about theoretical and actual process duration can be used for process efficiency calculation, which in this case equals 32%, or

$$PE = \frac{TPD}{APD} * 100 = \frac{9.6}{92.5} * 100 = 32\% \quad (9)$$

Efficiency of 32% indicates that almost two-thirds of the process is wasted in waiting, while the rest of the time is spent on actual processing. Process efficiency can be increased through elimination or reduction of:

1. Waiting time,
2. Time of realization of activities with greater probability to be chosen by customers (clients),
3. Number of outputs with defects (greater control inside "error loop"),
4. Duration of the long lasting activities, from the group of activities that are performed parallel, etc.

PROCESS CAPACITY ANALYSIS

Besides lead time analysis, process flow chart facilitates the analysis of its capacity. These two aspects of process analysis are interrelated. Process capacity analysis involves detecting the number of units that pass through each activity, or the number of units that occur as a result of the process realization. It is usually assumed that the capacities of resources, with which activities inside process are performed, have to be balanced [2]. However, this is one huge mistake that managers usually make, because the capacities of resources are not the ones that should be balanced, but the flow of work in process with the demand. Therefore, the process efficiency growth assumes the compliance of process workflow. This shows that it is necessary to determine the real capacity of each resource or the activities that are performed with them, and the capacity of the process as a whole. The number of units that pass through the process is determined by the process design [8], which, as in the case of the process duration analysis, often includes repetition of the activities due to errors correction, multiplied activities and parallel activities.

1. The long term objective of process improvement is providing zero-defects. However, all processes produce defects, to some extent. For example, process "X" contains four activities. Three of them (the second, the third and the fourth) are inside the "error loop". If the percentage of defective outputs is 25%, then activities inside "error loop" must have additional capacity (for processing of the additional 25% of units due to the necessity for defects elimination). If the capacity of the resource for the first activity is 100 units per day, then the capacity of the resources for the other activities (inside the "error loop") has to be 25% greater or it must be equal to 125 units per day (Figure 5).

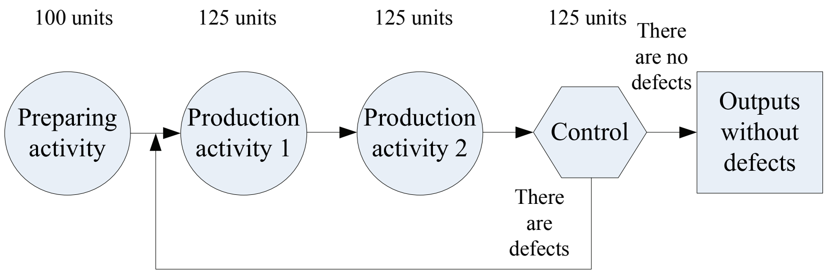

Fig. 5 Flow diagram for process "X" with "error loop"

This will be true with the assumption that all 25% of units returned for processing, after error correction will be without defects. In this case, capacity of the resources for the activities inside "error loop" (RCi) can be calculated in the following way:

$$RCi = (1 + r) * n, \tag{10}$$

where n represents the number of units that enter the process. If, however, the assumption that all defective outputs, returned into the "error loop" will be corrected successfully, can not be accepted, then one has to change the assumption in the following way: each time the process is repeated for the certain number of units, it will produce the same number of defects. This means that coefficient "r" has a constant, stabile value. In this case, in order to determine the capacity of the resources for activities inside the "error loop" (RCic), one can use the following formula:

$$RCic = \frac{n}{1 - r} \tag{11}$$

In this specific example, in case that the assumption about constant value of coefficient "r" is accepted, or if each time 25% of units are returned for errors correction, capacity of resources for activities inside the "error loop" has to be equal to 133 units, or:

$$RCic = \frac{100}{1 - 0.25} = 133.33$$

The data about needed capacity of resources for the activities inside the "error loop" is very important from customers' point of view. If customers expect to receive 100 units and due to defects and errors they can receive only 75 units in the promised period of time and the rest 25 units with certain delay, then they will not be satisfied. They will not recommend the enterprise's products and they may even change the provider of the specific products or services [10]. In order to prevent customers' dissatisfaction, the process owner has to bear in mind possibilities for errors and defects and, therefore, try to increase the capacity of the resources for activities inside the "error loop". This confirms the Goldratt's basic principle [4] that one should balance the flow, and not the capacity.

2. As it is already mentioned, sometimes the process has multiplied activities, which represent the activities that are quite similar, but the process efficiency demands their separation. In that case, the process is divided into sub-processes or it is performed through few paths [9]. Figure 6 shows the needed capacity for resources on each path, depending on the probability of certain groups of clients.

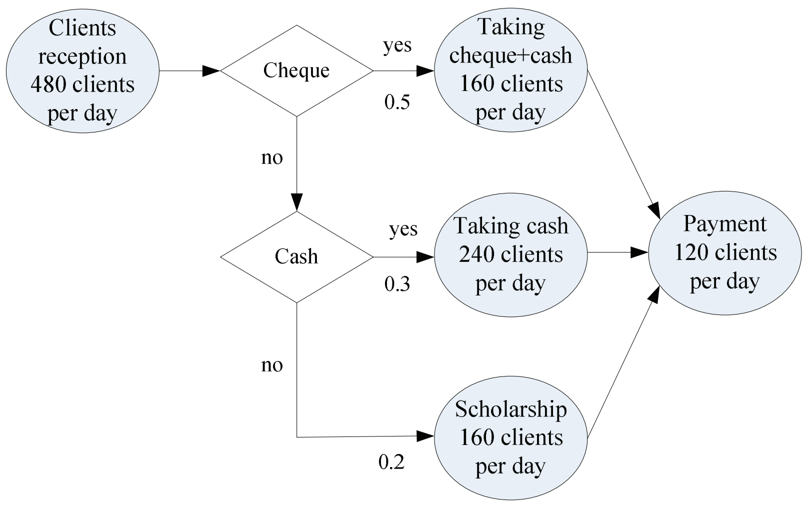

Fig. 6 Flow diagram with multiplied activities

The flow diagram, presented in Figure 6, can help managers to identify process bottleneck. Likewise, the flow diagram can point out possibilities for transferring work from activities performed by the bottleneck to activities performed by resource which has unused capacity.

3. Since processing time for parallel activities is usually not the same, managers should increase the capacity of resources for the activity that has the longest duration (processing time). The resource that is used for realization of this activity usually represents the bottleneck. In order to avoid bottleneck appearance, managers have at least two possibilities. They can:

- Switch from parallel to sequential realization of activities or
- Increase the capacity of resource that is used for the longest activity realization.

Figure 7 shows that the longest activity and, therefore the activity which resource represents the bottleneck is the second parallel activity. This activity can serve only 24 clients per day. Considering this, in one day this process can be performed only 24 times or in one day 24 services can be provided. If, in some cases, the process can be restructured and the whole process performed by one person, the process capacity will be equal to 30 services. The number of services is calculated in the following way: the one person will perform all three activities, for which he or she will need 48 minutes, which means that he or she will be able to serve 10 clients per day (8 hours * 60 minutes / 48 minutes); considering that there are three employees for these activities performing, the total number of services per day will equal 30 (3 employees * 10 clients per day). The other solution concerns increasing the capacity of the second activity resource, which can be provided through training of employees or by additional employee engagement or by additional physical resource.

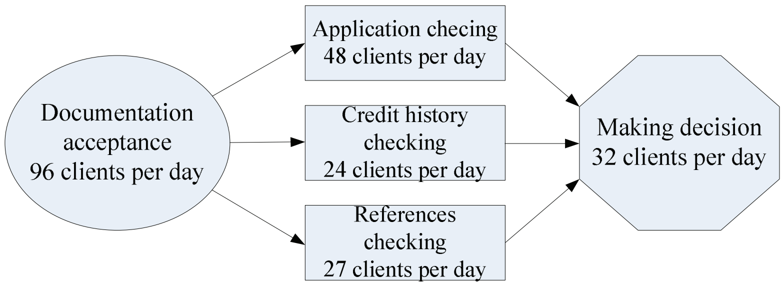

Fig. 7 Flow diagram for process which contains parallel activities

4. The next step assumes determination of capacity of each resource, necessary for process performing. For each activity, inside the process, beside the processing time and number of units that have been passing through the process, one has to know which resources are needed (qualitatively and quantitatively). Therefore, the assumption is that each activity inside the process is performed with a certain resource. Some activities can be performed with the same resource. The following example shows how managers can calculate the level of process capacity usage. The data necessary for calculation the process capacity and its usage are given in Table 2.

For the process realization there are available three units of resource R1, two units of resource R2 and one unit of resource R3. Resource capacity can be expressed as reciprocal value of time necessary for performing of activities, which need the specific resource. This indicator shows the number of units in process, which one unit of resource can perform in a certain time period [7]. The resources capacity is presented below:

- For the resource R1, capacity equals 1/12. However, since the process has three available units of this resource, the resource capacity is 3/12 or 1/4 or 0.25;
- For the resource R2, capacity equals 1/12. However, since the process has two available units of this resource, the resource capacity is 2/12 or 1/6 or 0.167;
- For the resource R3, capacity equals 1/10 or 0.1 (there is only one unit of this resource available for the process performing).

Table 2 Data for calculating the resources' capacity

Activities	Processing time	Necessary resources	Number of resources' units
A	3	R1	1
B	6	R1	0.5
C	2	R2	2
D	4	R2	2
E	6	R1	1
F	6	R3	1
G	4	R3	1

Based on the previous data, one can come to the conclusion that the resource R3 represent bottleneck of this process, since it has the lowest capacity level or can perform the least number of units in certain period of time. Precisely, the capacity of this resource is 0.1 units per minute or 6 units per hour. It is very important that one realizes that bottleneck concerns the specific resource, and not activity. This means that capacity is connected to resources, and not to activities. When there is a resource which represents the bottleneck, the capacity of the whole process is equal to the capacity of that resource.

Previously shown calculation of capacity is based on processing time, but not operation time of activities. Since processing time does not include waiting time (pauses), calculated resources' capacity can be concerned as theoretical. However, real capacity usually differs from theoretical. Real capacity can be expressed as the number of units that are finished in a certain period of time (e.g. one hour). When real capacity is compared to theoretical, one can determine the level of resources' capacity usage (Cu).

Capacity usage is a very important indicator for each resource in a certain process, but its importance is the greatest for the resource that represents bottleneck. In this case, the third resource represents the bottleneck, and therefore the level of capacity usage should be calculated for this resource. If the real capacity is 4 units per hour, the calculation shows that the bottleneck is used 66.67% or

$$Cu = \frac{\text{Real capacity}}{\text{Theoretical capacity}} * 100 = \frac{4}{6} * 100 = 66.67\%. \quad (12)$$

Calculation of bottleneck capacity usage is very important, since the bottleneck capacity determines the process capacity. Therefore, every moment wasted on bottleneck (every moment the bottleneck is not used) represents the waste for the whole process. For that reason process manager or process owner has to determine the capacity for each resource, then capacity usage for the resource that represents bottleneck, and finally to focus on the improvement of the level of capacity usage for this resource.

CONCLUSION

In modern conditions, when barriers between organizational units can represent causes of inefficiency, process management represents the only true choice. Process lead time and capacity analysis represents the part of process management. Process mapping and flow diagrams show the process structure and can help in discovering the unnecessary activities, as well as activities that have to be repeated or can be more efficient.

Process analysis can discover possibilities for efficiency improvement or for capacity rising. From the time viewpoint, process analysis helps managers to discover the real operating time, considering different breaks and necessity for error correction. This analysis is in function of better response to customer demands concerning delivery time, because managers can make realistic plans for responding to customer demands. On the other side, capacity analysis is used for determining the capacity of resources in order to provide continual flow of units through the process, but also in order to prevent bottlenecks, on one hand, and inventory, on the other.

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ANALIZA TRAJANJA I KAPACITETA PROCESA KAO OSNOVA ZA UPRAVLJANJE VREMENOM REALIZACIJE PROCESA

Marija Andjelković Pešić, Vladimir Zlatić, Bruno Bojić

Procesi su, u savremenim uslovima, polazna osnova za analizu i unapredjenje poslovanja preduzeća. Njihova efikasnost direktno se odražava na efikasnost poslovanja preduzeća kao celine, ali i zadovoljstvo potrošača i ostalih stakeholdera preduzeća. Značajna poboljšanja moguće je ostvariti korišćenjem informacija koje se dobijaju na osnovu analize trajanja i kapaciteta procesa. S obzirom da je pravovremena isporuka i raspoloživost proizvoda značajan faktor konkurentnosti preduzeća, analiza vremena realizacije procesa, koja počiva na analizi trajanja i kapaciteta procesa, morala bi biti značajan izvor informacija operativnim menadžerima.

Ključne reči: *upravljanje procesima, trajanje procesa, kapacitet procesa, upravljanje vremenom.*