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MODEL FOR PERFORMANCE EVALUATION OF A FLEXIBLE PRODUCTION SYSTEM

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ABSTRACT

The evolution of production systems was motivated by two important factors, increasing productivity on one hand and increasing the number of types of products that can be made in the system, on the other hand. When seeking a higher level of automation in the manufacture of products for small and medium series it should be a balance between the two conflicting goals, high flexibility and productivity of machinery. A compromise solution offers the concept of a flexible manufacturing system, receiving partial flexible automation. When implementing a FMS the configuration must satisfy both requirements: economic and technical. When implementing a FMS the configuration must satisfy both requirements: economic and technical. The research is oriented towards the study and analysis of these systems in order to know the behavior and performance and possible, as well as possible, even before the physical realization. Before evaluating the performance of a flexible production system and deciding to implement it, are analyzed the specific technical aspects of design, dimensioning and configuration. This paper proposes to develop the analytical models for evaluation their performance. Flexible production system is represented as a system of network of queues. It can thus calculate, key performance parameters of flexible production system.

KEYWORDS: production systems, modeling, flexibility, optimization

INTRODUCTION

Production systems are currently in a permanent change, with an upward trend. With the globalization of the economy, companies are faced with a large number of competitors, each can bring to market new products or services. Systems that meet the new requirements are advanced manufacturing systems with two main characteristics - flexibility and adaptability. The notion of flexible manufacturing system is linked to the new concept in production, including the integration of computer components and flexible manufacturing.

From the point of view of global caracteristics the flexible production systems are superior to systems they replace.

The sharp rise in competition, especially at international level, external environment changes, reduced life cycle of products and their increasing complexity and diversification, represents several reasons that have led to increased interest in implementing advanced production systems.

The concept of advanced production involves fundamental changes that will affect both technical basis and the methods and techniques of management and organization, production scheduling, system quality assurance methods for improving the workforce, the system of production and logistics system [1]. The degree of automation, robotics and computerization will be high, which will allow the development of manufacturing processes in which the human operator intervention will be minimal. Advanced production system will be the "factory of the future", "fully automated factory" [2, 3, 4].

The implementation of advanced manufacturing systems can only be achieved through an overall strategy, of long term (8-10 years), which has the basic components of a CIM (ComIuter Integrated Manufacturing) strategy, one of a FMS (Flexible Manufacturing Systems), and a JIT (Just in Time) strategy, to continuously improve the production process and workforce. Flexible manufacturing system, is a complex whole, that raises certain problems in terms of configuration and dimensioning, as well as in the conditions of implementation. Flexible manufacturing systems require such a synthesis approach, and thus appropriate specialist, the design of these systems assuming high knowledge on components of systems and interdependencies between them, and the relationships between the system and the environment.

Compared with classic design manufacturing systems, flexible manufacturing systems design requires a greater conception effort of 6-10 times, interdisciplinary groups of specialists and new design methods.

Another major problem in researching and achieving flexible manufacturing systems is the efficiency. These systems raise more important economic efficiency problems than any of the known production systems, because flexible manufacturing systems require large investment costs to be recovered in a short time by the advantages in exploitation and use. Because some of these systems did not prove economic success, there are some reservations in the design and implementation of flexible manufacturing systems.

Another impediment in flexible manufacturing systems design is the fact that till now there is no formal method, a design methodology universal acceptable to form a FMS. This conclusion is found frequently in the literature [5, 6].

Systems flexibility and adaptability

In the current context of products diversification , two issues will preoccupy managers in the near future: în the first place quality care, secondly the concern to reduce costs and increase efficiency. Since flexible production systems are the only ones that does not fail to respond in terms of flexibility - adaptability - productivity, by implementing flexible automation, both objectives will be achieved simultaneously although in conventional production they were considered conflicting. Low volume productions and low costs also seemed irreconcilable elements.

In most of the literature, "flexibility" is used more as a "generic phrase" and to a small extent as a "complex concept". It makes a huge number of works "flexibility" to be treated partially superficial, confusing and sometimes incorrect. The number of factors / parameters to which the current definitions of "flexibility" is very high. Thus, in [2], during the years 1991 there have been inventoried over 55 definitions of flexibility, selected from a large number of works in the fields of technical, economic, managerial, etc. papers and expressing different interests. In [7] by “flexibility” in a general sense, manufacturing system capability to adapt quickly to market demands, by executing variable production tasks in a short time with minimum expenditure and structural changes and to operate profitably on a long interval, is meaned.

In a general sense, „flexibility” is the system's ability to respond technical - economically effectively to changing conditions:

- Technological: changes in the type and order of operations, in chip removing regime, technological routes diversity and variable manufacturing series;
- Functional: changing transportation routes, restructuring the machinery / equipment, need for a variable number of tools, various, bigger loading degrees;
- Economics: cost as little as possible, negotiated delivery time, quality required.

The capacity of adaptability is a new concept of automated manufacturing and has an technical economic particularly important impact, maintaining high productivity in terms of product diversification, at relatively low cost. Flexible manufacturing systems are the only allowing production adjustment. Adaptability must be ensured from the earliest stages of conception, decision assisted and computer-aided design, prior verification assisted by simulation, so that the designed system, so complex and high value will be subsequently functionaly and efficiencent validated.

Adapting through flexibility has advantages in terms of economic and technical issues, to a certain class of products, products with similar technology in general. Switching from a type of product to another is expensive if the production system was not designed and built as a flexible system.

PERFORMANCES OF FMS

Before evaluating the performance of a flexible production system and deciding to implement it, we have to analyze specific technical aspects of design, dimension and configuration. When implementing a FMS the configuration must satisfy both requirements: economic and technical. The research is oriented towards the study and analysis of these systems in order to know the behavior and performance and possible, as well as possible, even before the physical realization.

The impementaion of a FMS in an integrated production system, it is an important result, which leads to the optimization of the material and information flow of the entire company. Forecast of the savings in production costs can always refer only to individual cases and requires a precise calculation of comparison. Taking as a basis their use of time it can be determined relatively precisely cost reduction of machined parts on a FMS standard, in relation to a group of individual machines. They are heavily dependent on the number of integrated mashines since the volume of expenses for system peripherals and computer management at all levels of construction are almost equal. These facilities to introduction and benefits allowus to expect widespread future flexible manufacturing systems.

The evolution of production systems was motivated by two important factors: increasing productivity on one hand and increasing the number of types of products that can be made in the system, on the other hand. When seeking a higher level of automation in the manufacture of products for small and medium series it should be a balance between the two conflicting goals: high flexibility and productivity of machinery. A compromise solution offers the concept of a flexible manufacturing system, receiving partial flexible automation, [8, 9].

By introducing flexible production systems for cylindrical parts process there can be obtained important advantages concerning the functioning of the organization and other economic advantages concerning: the possibility to change the reference (a new system adaptation) almost without losing time, for new equipment and disconnecting the attendance staff reported to the work pace of the machine, lead to an important increase of the use degree of the machine; fabrication in batches sizes, according to the necessary amount and at the time required by mounting (the possibility to deliver the pieces manufactured "Just in Time"), make possible an important decrease of the pieces volume in the workshop and warehouses (production decrease in processing and stocks, with a rate of 50-60 %) and it has influence upon a quick reaction capacity towards the market requirements oscillations, at the reference change; manufacturing time decrease, often with more than 50%, leads to delivery time decrease and thus to creating decisive competition advantages; improving quality by strictly respecting the stages of the production process; realizing a production process easily to be controlled in its essential points; work force qualification increase by its movement towards preponderantly intellectual activities; better use of the capital by its distribution between the buildings and the equipment of the process. By the possibility of the optimal use both of the systems capacity and the staff and their high availability, which can be reached today, of machines and plants, on the one hand and of almost unlimited enlargement, replacement and change flexibility, on the other hand, result important productivity increase on long terms of systems use (8-10 times reported to classical systems).

To implement a flexible manufacturing system a configuration must be found to satisfy both economic and performance requirements of the system. These requirements are associated with inputs (operating costs and capital expenditure) and outputs (amount of production) of a flexible manufacturing system. The configuration that best meet the objectives of introducing a flexible manufacturing system must be searched în the set of defined and evaluated alternatives.

MODELS PERFORMANCE EVALUATION OF A FMS

The models of performance evaluation of a flexible manufacturing system (Figure 1) can be grouped as follows: static allocation models, analytical models based on queuing systems theory and simulation models phenomena that occur in FMS; it identifies the bottleneck in the system, and the performance of the other components of the system result from its limited performance. Both models the queuing system, and the simulation models are analyzed in the standby dynamic relationship that occurs between the workpiece and the flexible manufacturing system resources, [10]. The models that are based on queuing theory allow calculation in a finite number of steps of the key parameters needed to assess the performance of a flexible production system. This process is based on the theory of *Closed Queueing Networks* (CQN). Queueing models are distinguished by the level of detail that is used to describe the characteristics belonging to a given flexible manufacturing system. At the basis of these models is the classical model of closed queuing networks model (CQN Model). This model takes into account various assumptions allowing not to take into account the concrete, current operating mode of a FMS in the industrial environment. As long as the assumption that processing time has an exponential distribution remains true, than this does not raise difficult issues but that of the existence of storage units with limited capacities puts. Various other theories of queuing networks systems take into account the blocking factors and lack of food. There is also research that take into account the existence of a separate supply system tools.

Simulation models show a more detailed description of the alternative of flexible manufacturing systems considered to mimic an restore the dynamic performance of the system. Relevant assessment criteria (the average waiting time of parts in the system, the probability distribution of queue length) is then deducted from these dynamic observations. Research on simulation of an FMS can be performed using simulation language, or FMS simulators, [11].

While simulation languages allow the user to build an unlimited number of different models for FMS, simulators are programs specifically designed for simulation of flexible manufacturing systems.

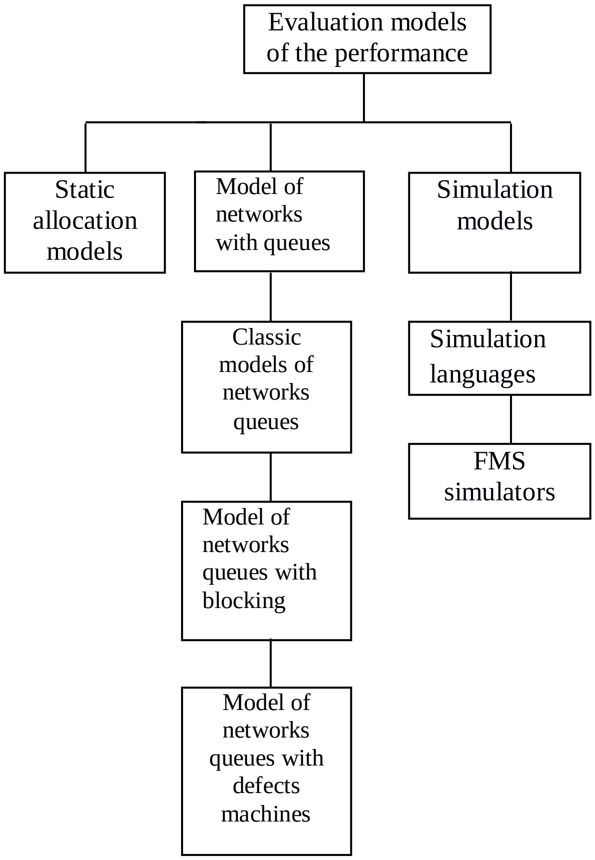

Fig. 1 Models for step of performance evaluation of an FMS

If whether it is used a mathematical optimization model or an expert system or other system for dimensioning and configuration of the flexible manufacturing systems looking towards an optimal aims, same requirement exists, namely we should evaluate quickly and accurate the alternatives that satisfy and withheld relevant performance criteria. Rapid analytical models used to estimate the performance of a system enable more accurate assessment of them.

At the end of the evaluation it is recommended to use a simulation model as a tool for investigations, detailing a flexible manufacturing system configurations. At first you can use performance evaluation procedures that quickly creates a rough estimate of the performance of a flexible manufacturing system.

Thus, it is possible to eliminate a large number of alternative configurations earlier and with a lower calculation effort. The investigation process continues progressively until only some configurations of FMS remain, that will be studied in detail by means of simulation models.

The graphical model of networks with queues

Queuing theory is commonly used for modeling the functioning of Flexible Manufacturing Sytems (FMS).

Flexible Manufacturing Systems is considered as a network of queuing systems, each system mode is assimilated to a queuing system. Modeling the network with queues apply in the following circumstances: manufacturing by technology group, automated handling and transport in the FMS, the logistic industrial variable (reconfigurable) subsystem structure and material flows (semi-finished parts, tools).

In developing the model using the following key concepts:

- Route inside FMS (semi-finished parts, tools) is its itinerary required by the process.
- The queue or waiting lines or associated with a workstation, as a number of pieces ordered that respects the rule of serving, waiting for processing.
- The branch is the place (point) for selecting route criteria loading machine and the processing workstation compatibility.
- Service time is the time in wich a workstation is served with semi-finished parts for processing. Since it has provided a continuous process, the limit is equal to operational time.

A queuing system consists of the following elements (Figure 2):

- the source from where the parts arrive;
- the queue or waiting lines;
- the server systems that include one or more service stations.

The requests in FMS are pallets that are fixed parts. Service stations are machines, from loading / unloading stations and other workstations.

The waiting interval between the moments occurs when arrivals are stochastic or deterministic when arrival times are, but vary significantly for different parts.

A queuing system components can take various forms. Source for example can be limited or unlimited depending on the characteristics of requests, incoming requests can be made individually or in group behavior can be influenced arrivals or interval between arrival - deterministic or stochastic.

The model of networks are designed to calculate key parameters of the queuing system: arrival time, service time, the number of service workstations, usually serving the maximum number of requests in the system (in serving and waiting) and number of applications retained.

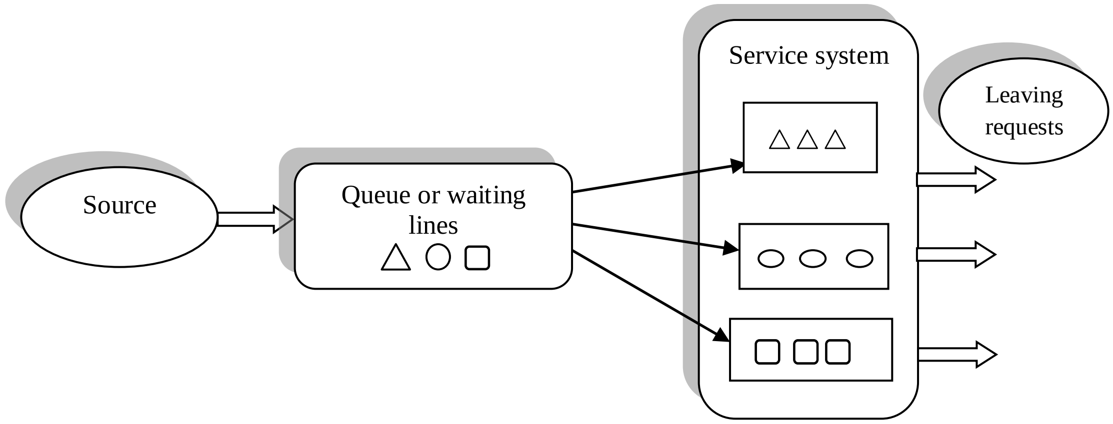

Fig. 2. Items network model with queues

Flexible production system is represented as a system of network of queues (model CQN – Closed Queue Network). This classic model with queues was developed first by Solberg [12]. The CQN is a FMS performance evaluation model based on queuing systems theory. To resolve it can be done relatively well-developed software products for computing systems.

In the literature [13, 14] are presented theoretical considerations (hypotheses, restrictions, rules), the algorithms used and the results obtained in flexible manufacturing systems modeling.

The model was developed for a flexible manufacturing system for processing six items families circular parts (P_1, ..., P_6) by technological operations (TO_1, TO_2, ..., TO_n) like in Figure 3.

Following the heuristic model establishment for determining of the affinity, consistency and differentiation grades resulting the composing scheme for the material flow in the analyzed system.

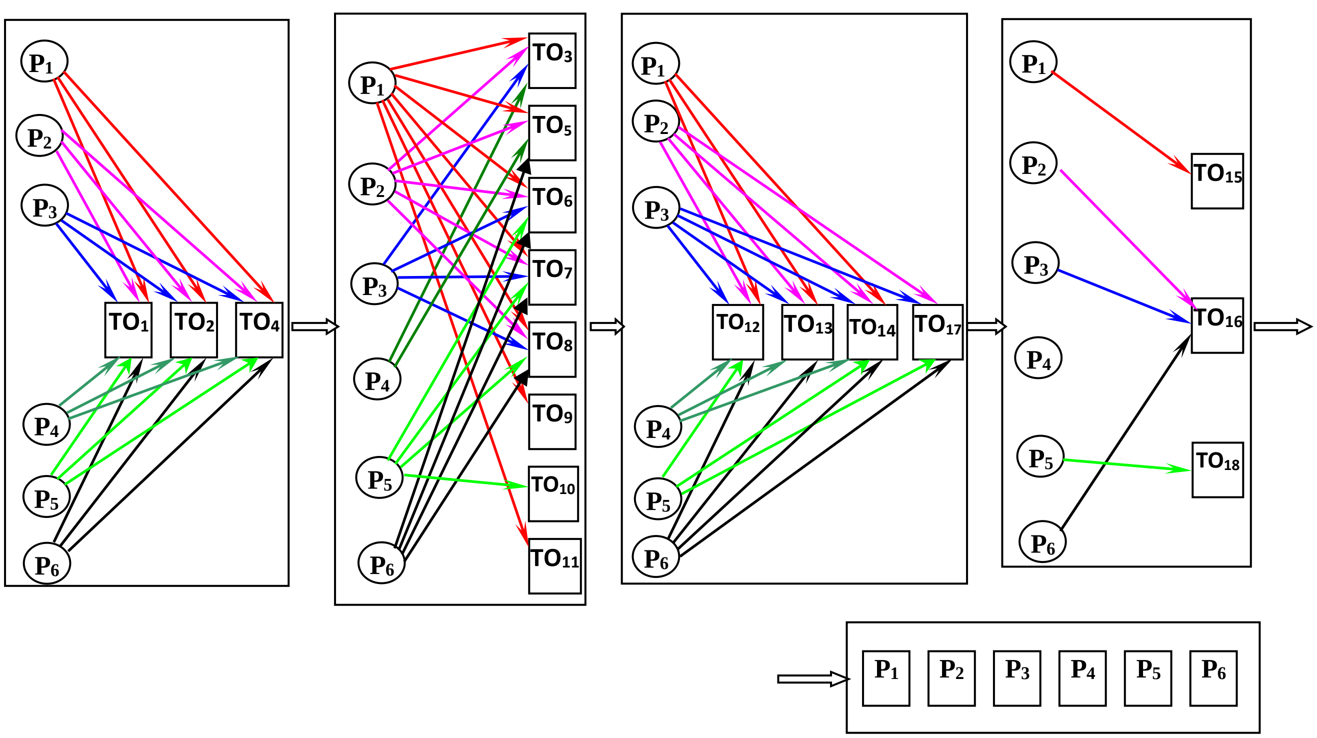

Fig. 3. Material flow in the designed FMS

The analytical model of networks with queues

It is considered a flexible production representing cylindrical parts as a queuing system. A FMS is modeled, such as a set of interconnected calling systems (stations). One station includes one or more service stations (machine tools, from loading / unloading, measuring devices / control systems for transport logistics / handling, and other).

For developing analytical model based on data input system analyzed the load of production, representative of the full diversity landmark typology, manufacturing technology and generalized production plan previously established design FMS.

The data for these stages with the objective of evaluating the performance of the analyzed system are:

- The average time for processing a workpiece at the workstation q, technological operation:

$$\bar{t}_p = \frac{1}{n_q}\left(\sum_{i=1}^{k} \propto_i \cdot n_{iq} \cdot t_{iq}\right), q = \overline{1, Q-1} \quad (1)$$

- The average number of technological operations at the station q:

$$n_q = \sum_{i=1}^{k} \propto_i \cdot n_{iq} \quad (2)$$

- The relative frequency of arrival of parts to the station q:

$$p_q = \frac{n_q}{\sum_{i=1}^{Q-1} n_i} \quad (3)$$

The amount (p_q) can be interpreted as the probability that a date range or a track to be transported to the q after he left any other station in the system.

- Average loading station q:

$$s_q = p_q \cdot t_p \quad (4)$$

- Average load transport system:

$$s_T = p_T \cdot t_T \quad (5)$$

in which: $p_T = 1$, t_T is the average transport.

Probability distribution in stationary applications stations (nodes) in calling systems [12], $P(n)$ can be represented by the product of the individual probabilities status values $P_Q(n_Q)$; Q - index stations:

$$P\{n\} = P\{n_1, n_2, \dots, n_Q\} = P_1\{n_1\} \cdot \dots \cdot P_Q\{n_Q\} \quad (6)$$

Considering the theory of networks systems with queues, probability distribution of applications in nodes can be described through product specific factors fq (NQ), where $q = 1 \dots Q$ and is calculated based on the average loadind station, the number of parts the station and the number of machines that are powered from the same common queue from the state.

As long as the number of requests (N) is constant in the system, individual factors are bound together by an integral amount, called normalization constant g (N, Q). Normalization constant probability ensure that the sum of the number of existing tracks in the nodes to be equal to 1.

$$P\{n\} = P\{n_1, n_2, \dots, n_Q\} = \frac{1}{g(N,Q)} f_1\{n_1\} \cdot \dots \cdot f_Q\{n_Q\} \quad (7)$$

Normalization constant is defined by the equation:

$$g(N,Q) = \sum_{n \in S(R,Q)} \prod_{q=1}^{Q} \cdot f_Q\{n_Q\} \quad (8)$$

where: S (N, Q) represents the state space model CQN possible, depending on the number of stations and the number of blades Q (R) system.

In the paper [12] is presented the procedure of the Buzen's algorithm [13] of the normalization constant. According to him, the networks with queues was developed by introducing a central server that piece has to pass through the system always moving.

Entries material flow FM (handling time) have a Poisson distribution and the outputs (time serving stations) have exponential distribution - negative. Both conditions must be met. Entries are variable over time random typological diversity both as benchmarks and as input for determining the flow of inputs (λ), size of lot (n_L) as order input FIFO, LIFO, and so on.

$$f(x) = \frac{\lambda^x}{x!} e^{-\lambda}, x \in \aleph \quad (9)$$

Flow output depends on service time and varies with the benchmark (P_k) and mahine (m_i) cycle time (T_{ci}) is the random variable in the system, with negative exponential probability density:

$$f(T_{cik}) = \mu \cdot e^{-\mu \cdot T_{cik}} \quad (10)$$

in wich μ it is the average number of outputs, individual / u.t.

Traffic intensity (the rate of traffic or service factor) is given by:

$$\rho = \frac{\lambda}{\mu} = \frac{(\lambda^x / x!)e^{-\lambda}}{\mu \cdot e^{-\mu \cdot T_c}} \quad (11)$$

After the input data were synthesized, all embedded in a landmark pieces representative pallets are moved using universal FMS (N).

It can thus calculate, key performance parameters FMS: productivity, average waiting time at each station of the piece, the average waiting time of the song in the whole system, queue length parameters workstations, etc.

Performance evaluation. Results

The elements needed for performance evaluation such as average number of technological operations at stations (q) the system average load stations (s_q) and the relative frequency of arrival of parts at each station (p_q) were determined using the relationships (1) ... (5) of the previous model and are summarized in Table 1.

Table 1. Items for evaluating FMS

q	n_q	s_q	p_q
1	3.97	4,50	0,4
2	2.25	6,32	0,22
3	1	1,72	0,1
4	1	0,83	0,1
5	0.76	3,84	0,05
6	0,42	5	0,03
7	1	2,57	0,1
Total	10,4		1,0

By applying analytical model above - relations (6), (7), (8) were obtained some results on the probability distribution of this parts stations loading / unloading or cylindrical parts processing (by technological operations (TO_1, TO_2 ...TO_n - turning, drilling, milling, grinding, etc.).

In table 2 are given as examples some results, for the circulation of a number of $N = 6$ pallets in the system.

Table 2. Probability distribution / station St_{LU}

N	P{n}	
Loading / unloading Station(St_{LU})		
0	$P\{n_0\}$	0,697
1	$P\{n_1\}$	0,329
2	$P\{n_2\}$	0,155
3	$P\{n3\}$	0,081
4	$P\{n_4\}$	0,046
5	$P\{n_5\}$	0,007
6	$P\{n_6\}$	0,003

Table 3. Probability distribution / station St_T

N	P{n}	
Turning Station (St_T)		
0	$P\{n_0\}$	0,285
1	$P\{n_1\}$	0,197
2	$P\{n_2\}$	0,168
3	$P\{n3\}$	0,124
4	$P\{n_4\}$	0,097
5	$P\{n_5\}$	0,053
6	$P\{n_6\}$	0,031

Table 4. Probability distribution / station St_G

N	P{n}	
Grinding Station (St_r)		
0	$P\{n_0\}$	0,832
1	$P\{n_1\}$	0,534
2	$P\{n_2\}$	0,375
3	$P\{n3\}$	0,093
4	$P\{n_4\}$	0,032
5	$P\{n_5\}$	0,008
6	$P\{n_6\}$	0,003

Graphical representations of the probability distribution of the number of parts on workstations and transport subsystems can be seen in Figures 4 and 5.

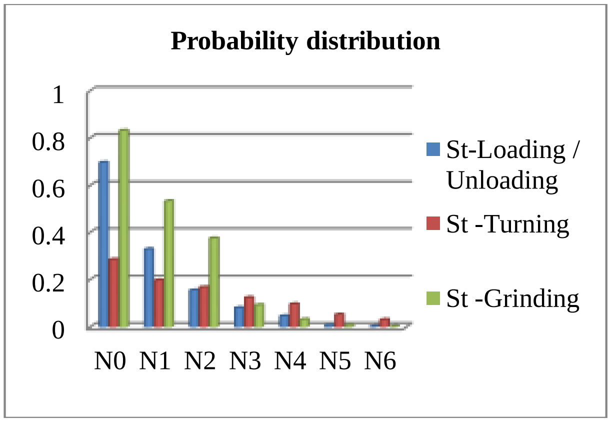

Fig. 4 Probability distribution / stations

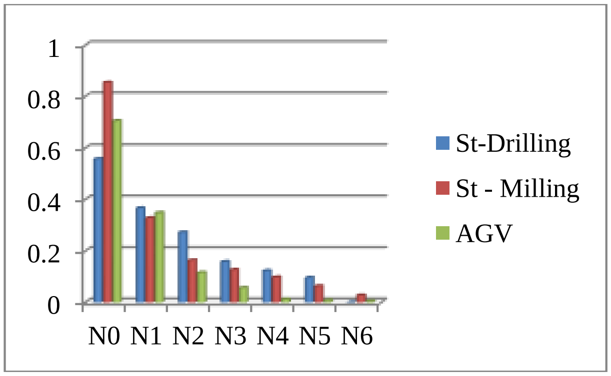

Fig. 5 Probability distribution / stations

CONCLUSION

Advanced manufacturing systems offer currently high competitiveness can not be achieved in other ways. The advantage of these systems lies in near total adaptability to changes in the economic environment that works.

Using modeling techniques and simulation to optimize the structure and behavior of systems is now widespread, as determined by current conditions on management systems, the systems of international business, which tend to become more complex, influenced by a large number the internal and external factors. The models used in flexible production systems are based on technical aspects of designing and dimensioning their performance evaluation systems and flexible production decision on their implementation and exploitation in real conditions. Rapid analytical models used to estimate performance assessment increasingly allow their more precise. In the final assessment it is recommended to use a simulation model tool for investigations detailing a flexible production system configurations. The model developed in this work it aimed to achieve favorable solutions for the simplest models. On the basis of these models is the classical model of closed networks queuing systems (CQN model). Queuing theory is commonly used for modeling SFF the functioning of, considered as a network of queuing systems, each system mode is assimilated to a queuing system. Thus, they considered various assumptions allow not take into account the current operating mode of the FMS in the concrete industry.

Were determined key parameters of the queuing system: the arrival time distribution, the distribution of service time, the number of service stations, discipline serving, the maximum number of requests in the system. The model developed, integrated into a software program used to study the behavior stationary the networks with queues in a flexible production system.

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