Simulation Tool for Assessing the Performance of a Flexible Manufacturing System

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Abstract. The flexible manufacturing system (FMS) is as complex whole, raises concerns regarding the configuration and dimensioning, as well as on the conditions for implementation. The scientific researches in this paper, are directed towards the study and analysis of flexible manufacturing systems, in order to know their behaviour and performances as well, and if possible, even before their physical realization, and to establish the scientific basis for sizing, configuration and simulation patterns of flexible manufacturing systems. The ARENA simulation software can describe the complex interactions between resources and processes that take place within a FMS, a system of discrete events. In the simulation phase, evaluation of performance criteria allows the introduction of planning strategies in the use of system resources. After developing these models the verification and validation of the models, confirms their validity. The researches will be also extended in the domain of flexible manufacturing systems management and control in real and virtual environment.

Keywords. manufacturing systems; modeling; simulation, Arena software

1. Introduction

Development of advanced manufacturing systems involve profound changes in manufacturing processes by increasing automation, robotics and information technology, and the application of methods and techniques of management, organization and quality assurance. These systems, which ensure continuous production, respond to the current need for competitiveness, the main advantage being the almost total flexibility and adaptability to changes in the economic environment, in terms of efficiency and minimum response time, [1]. In this context, flexible production systems are superior to the systems they replace, especially in terms of technical and economic performance. Optimal use of system capacity, staff, and high technical availability and flexibility of replacement and change, results in significant increases in productivity over long periods of system use (8-10 times the classic system). The Flexible Manufacturing System (FMS) is defined as an integrated complex, composed of a set of computer-controlled machining centers and containing automatic handling, material transfer / transfer devices. FMS is designed to achieve the cost-efficient production key as it is a good combination of diversity and productivity [2].

The introduction of an FMS into an integrated manufacturing system is an important result, which leads to the optimization of the entire material and information flow of the enterprise. Given the complexity of these systems, the difficulties in designing and implementing them require intensive design, planning and management. Flexible Manufacturing Systems thus require a synthesis approach
and, by implication, the appropriate specialist, designing these systems with deep knowledge of the
system components and the interdependencies between them, as well as the relationships between the
system and the environment. The theoretical and practical knowledge base, the newest approaches in
the automation of production systems [1, 3], and the practical examples [2, 4, 5] refer to the
application of modern concepts of integrated management of production systems, as well as to the
analysis and evaluation of their performance.

Implementation and entry into service of a flexible manufacturing system involves a lot of expenses
and the expected economic effect is hard to determine. For this reason, both during the design and the
operation of the FMS, modeling and simulation technique has been used [6, 7]. With regard to
Flexible Manufacturing Systems modeling operation, there are still several attempts, some recent, [8]
to define and analyze the performance indicators of the system.

In many of current simulation approaches, despite the existence of well-developed tools, it is often
difficult to transform system requirements into the simulation program and the whole implementation
process is still carried in an intuitive manner [3].

The objective of this paper is to study and evaluate the flexible manufacturing system through
modeling and simulation. Thus, one can develop a decision support tool for assessing the performance
of a flexible production system that is available to companies interested in the production. Using
simulation we intend to clarify some issues regarding the description of system operation,
development of theories and hypotheses based on previous operation, using the model to predict future
operation or establish the effects of changes in the system.

Modeling and simulation technique allows, through a computer model to make predictions on various
aspects of the operation of dynamic Flexible Manufacturing System, existing or future, in order to
respond best to the problems involved in its operation.

The aim of the paper is to increase the technical and economic performance of these systems by
optimizing the processes based on the new knowledge in the field and the authors' previous research
[10, 11].

2. Modeling FMS. case study

2.1 Presentation of the analyzed system

The study was conducted on a flexible manufacturing of cylindrical parts, designed and developed
physically, according to stand in Figure 1, existing in research laboratory and the applicative character
of the research theme is demonstrated.

![Figure 1. Sequence of Flexible Manufacturing System – FMS01](image)

The production flow consists of the operations required for the machining of the cylindrical parts on
drilling / boring-milling, turning and control stations. The system is managed by a PLC and includes
stations supply / exhaust parts and equipment logistics conveyor type transport.

In a first step, a simulation program was developed and implemented using SCADA's Cx-Supervisor
Developer programming environment to monitor and run the process in real time (Figure 2).
Operational parameters for the existing flow were also estimated using the ARENA software, the results being presented in paper [10].

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The results have led to the need to optimize and extend the system by introducing some industrial robot industrial logistics elements. In the present simulation study, we aimed at balancing the production line, minimizing the asynchronous occurring in the system and ensuring a continuous flow, considering the increase of the production capacity.

The evolution in time of the system state was described by algorithms or complex procedures that better express its actual functioning. Verification and validation of models will be performed on the existing system.

2.2 Technical and economic parameters of the model

To achieve a mathematical model to be used in the design and performance analysis of the manufacturing system there are a number of necessary input data, shown in Figure 3: MF - material flow, IF - informational flow, EF - energy flow, time and space. The models must contain a number of parameters and optimization criteria, objective function, performance indicators, optimal synthesis in real time and environment.

In modeling a FMS it must respond to major issues concerning: determining resources and their characteristics that most affect system performance, formulating a model or a description, representing
these resources and the relationships between them and determining values for the performance in conditions of known scenarios.

To study and analyse the performance of a cylindrical parts processing FMS, [11] will consider the following initial data of entry into model:

Current part in manufacturing \((P_k, 1 \leq k \leq p)\), \(p\) - number of types parts from typological diversified manufacturing task;

The processing of parts: \(P_r(k, k = ct)\).

The crowd parts involving crowd of the manufacturing processes:

\[
\{P_k\} \rightarrow \{P_r(P_k), k = var\} \tag{1}
\]

Manufacturing task:

\[
MT \rightarrow \{P_k, P_r(P_k), 1 \leq k \leq p\} \tag{2}
\]

Manufacturing task is obtained on output from the system and is carried through the manufacturing system, as a means, defined as the set of workstations:

\[
MS \rightarrow \{WS_{ij}, 1 \leq i \leq q, 1 \leq i \leq n\} \tag{3}
\]

where: \(WS_{ij}\) represents workstations, machinery from the system that directly contribute to the transformation of material flow in the finished piece.

It considers serial production, manufacture executing on the size batches of the size of \(n_b[pcs/batch]\), for \(\forall P_k \in FP_k, k \in N, k = [1, r]\) with the frequency of occurrence of the lot \(v_{bk}[no.\ batch/\tau]\). Any model is developed on a time interval \(\tau\) (week, month, and year).

Performance analysis simulation system will be made in relation to a number of parameters listed below. The duration of manufacturing \((T_m)\) is the total time that is needed to completely process all identical parts \((P_k)\) from one batch and is expressed by equation (4), in which \((i)\) is the index of the technological operation and \((q)\) - the number of machines, workstations through which the semi-finished goes successively, ordered for the purpose of processing the finished piece:

\[
T_{mk} = \sum_{i=1}^{q}(t_{opk} \cdot n_b + t_{a} + t_{ad})[t.u] \tag{4}
\]

Knowing the average operative time \((\bar{t}_{op})\), auxiliaries times \((t_a)\) and adaptation times \((t_{ad})\) and handling times \((t_h)\) it can be calculated the average manufacturing duration \((\bar{T}_{mk})\) of a part on the whole system of machines, according to relationship (5), where \(t_h\) is the handling time (transport/transfer) of the part along the entire process of processing parts, on the entire manufacturing system:

\[
\bar{T}_{mk} = q_k \cdot n_b \cdot \bar{t}_{op} + \frac{t_{h} + t_{ad}}{n_b}[t.u/batch, syst.] \tag{5}
\]

The production rate \((R_p)\) on the part, on the machine \((m)\) is calculated using equation (6) and expressed in \([pcs / t.u, m_i]\), in which \((T_c)\) is the period of the machine cycle:

\[
R_p = \frac{1}{T_c} \tag{6}
\]

Production capacity is available or necessary means of production required for production plan and expresses the relationship (7), where \(n_p\) is number of productive units, \(n_c\) - shifts number / u.t., \(h\) - hours number / shift, \(R_p\) production rate:

\[
Q_p = n_{up} \cdot n_c \cdot h \cdot R_p \tag{7}
\]

Average unit through production time - \(\bar{T}_{m,u}[h/pcs]::

\[
\bar{T}_{m,u} = \frac{\bar{t}_m}{n_{PIx\cdot n_{LK}}} \tag{8}
\]
The period of the machine cycle \( T_c \) [min/pcs]:
\[
T_c = t_{op} + t_{aux} + t_h
\]  
(9)

The degrees of utilization in time for workstation \( (\eta_{tu}) \) and in days \( (\eta_{du}) \):
\[
\eta_{tu} = \frac{r_m}{F_{rt}}
\]  
(10)
\[
\eta_{du} = \frac{n_{wbk}}{R_p \cdot T_m}
\]  
(11)

Production in processing \( (P_p) \), the number of semifinished or their percentage of the total number of parts to be processed, where \( z_p \) is machined number of the parts, \( z_{w} \) - waiting number of the parts and \( z_t \) - total number of the parts:
\[
P_p = \frac{z_p + z_w}{z_t} \%
\]  
(12)

Optimization of these indicators aims to reduce the auxiliary time that can be achieved by automating activities and transferring human resources to intellectual activities.

The parameters and performance indicators will be set in order to optimize the synthesis of the system in real-time environment. The developed model aims to know the system behaviour as well as its performance, and if possible, even before their physical realization.

3. Simulation of FMS

3.1 Simulation tools

The use of simulation techniques in large systems is now widespread. Thus, the Flexible Manufacturing System is decomposed, its internal structure detailed, so that the processes of operation of all its component subsystems can be algorithmized and implemented step-by-step into the computer, while respecting the accuracy and taking into account the interaction with the external environment.

Simulation is one of the most powerful means of analysis used to design complex systems for planning / scheduling and control. The current trend is, simulation to become a next-generation tool for analyzing computer systems. It is now possible to provide for the complete integration of simulation with other software packages that collect, store and analyze system data [4].

For the case study analysed, ARENA Simulation Software version 15.00.00001 (Arena Trial version) built on SIMAN language was used [12]. This software can be used to describe complex interactions between resources and processes occurring within FMS, considered a discrete event system [4, 13]. In Arena Software, the basic process offers the highest level of modeling to allow rapid, easy and flexible creation of models in most systems (Kelton et al., 2010). SIMAN, simulation language from ARENA allows the dynamic deployment in time of the system. It describes and reproduces the dynamic structure of the system, the interdependencies within the system.

ARENA offers high capacity simulation of advanced manufacturing systems, relatively easy to use. With this software can be described complex interactions between resources and processes occurring within FMS considered discrete event systems. Arena is an easy-to-use, powerful modeling and simulation software tool that allows the user to construct a simulation model and run experiments on the model.

ARENA is a software for dynamic simulation of discrete technical systems that includes FMS and uses terms like: \textit{entity} that is a part of the system which constitutes a subsystem; \textit{attributes} that are characteristics of the entities; \textit{activities} than are dynamic processes that lead to modification of attribute values; \textit{event} that changes the value of an attribute. ARENA requires knowledge of random distributions, probability, and statistics.

3.2 Developing the simulation model. Results
After collecting all necessary information to implement the study ARENA simulation model using modular flow (flowchart) and data modules will be build. With the graphics animation module that allows you to view the simulation behaviour on the display screen, errors can be determined and the model can be redesigned. After creating the complete logic model, it will be checked whether the model resulting from the computer simulation corresponds to the conceptual model. Validation will show that the model behaves just like the real system.

A manufacturing model has been developed using ARENA simulation software, a simulation sequence being shown in Figure 4. In Arena, modules are basic building blocks basic (or objects) that consist of Arena models. There are tow types of modules: flowchart modules and data modules. The flowchart modules are used to describe the flow of entities and placed in the flowchart view of the model window, [12]

![Figure 4. The flowchart of the FMS model. Simulation sequence.](image)

Measurements, analytical models and simulation models are alternative performance analysis techniques. The models based on the simulation are preferable because they allow to obtain accurate results for complex and larger calculations, with fewer assumptions [10].

The model has been designed according to the events and processes taking place in the system. The model created evaluated the dynamic process flows, including technology manufacturing operations, but also the handling and the transferring of the blanks. It performed a simulation of the simultaneous processing of three parts, which typically occurs in the real environments. In the system the three processed pieces each have their own technological route, with different phases.

Complete description of system operation is achieved by specifying the various interactions between processes. In Flexible Manufacturing Systems, the parts interact, in general, all other processes, which express their movement into the system. The simulation is done by describing the movement of the parts through different processes, corresponding to the machine tools, the means of transport and the means of handling.

As a first result obtained by evaluating the flow of parts on machine and processing stations and examining conflicts regarding the application of limited resources, it could be evaluated and optimized the system layout, the selection of equipment and industrial logistic subsystem, as well as the operating procedures. It will explore in real environment and real-time, without interruption of the running operations new operating procedures.
The conducted simulations allowed to define some aspects of production management, to detect “narrow places” that slow the production flow and to study the impact of failures on the manufacturing process (Figure 5).

![Figure 5. The simulation sequence and bottlenecks in the production process](image)

After running of the simulation model, the result of throughput analysis such as average, minimum and maximum times for production, work in process – WIP are shown (Fig.6 and Fig.7).

| Entity   | Time          | Average | Half Width | Minimum Value | Maximum Value |
|----------|---------------|---------|------------|---------------|---------------|
| VA Time  |               | 8.2585  | (Insufficient) | 5.1106       | 12.2576       |
| NVA Time |               |         |            |               |               |

![Figure 6. Category overview time in FMS](image)
2nd International Conference on Manufacturing Technologies (ICMT 2018)  
IOP Conf. Series: Materials Science and Engineering 398 (2018) 012023  
doi:10.1088/1757-899X/398/1/012023

Another important indicator for performance evaluation is the degree of loading of workstations in the system. Figure 8 shows the resources report of the FMS model, after the simulation run. The resource (Machine 1, Machine 2, for example) utilization was 86.96% and 97.70% (average) and 100% (maximum).

Figure 7. Work in process (WIP)

Figure 8. The Resources report of the FMS model

4. Conclusions
The purpose of this simulation study is to provide a decision support tool in the evaluation of FMS. The simulation will help assess the impact of production rates, resource use, operating time, and buffer stock levels in different scenarios. After comparing the results, we suggest the best solution for the newly designed manufacturing system. It was developed a production model for the study of cylindrical parts processing, using simulation software Arena. The following indicators of performance evaluation of the analyzed system have been optimized: real time manufacturing, the pace of manufacturing, the workload of the machines, and the blocking time in the production process. Increasing the performance of the system was achieved by introducing an industrial robot that reduces handling times, operational time, manufacturing time and waiting time. This work identified opportunities to shape the research and the application in industry.
4.1 Acknowledgments
This work was supported by a mobility grant of the Romanian Ministry of Research and Innovation, CNCS-UEFISCDI, Project number 253/8.12.2017, code PN-III-P1-1.1-MC-2017-1155.

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