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Performance Analysis of a Flexible Manufacturing System (FMS)

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Abstract

The performance of a flexible manufacturing system (FMS) has a great impact on a manufacturing firm success and the analysis of FMS justifies the high investment cost behind it. As the competition in the global market is growing, manufacturing companies compete not only on product cost and quality but also in time to market. FMS as a highly automated system typically comprised of a set of processing workstations allowing in an integrated manner to react rapidly and economically to production-oriented aspects of an enterprise in order to cope significant changes in its operating environment. This paper analysed the performance of a FMS through manufacturing process modelling and simulation. The modelling of a manufacturing system enables to grasp quickly how the current system is working and to evaluate the proposed process changes before actual decision making, on the other hand, the simulation of the system supports the idea of virtual manufacturing and gives prompt response to the decision maker. Moreover, integration of system dynamic analysis with reliability estimation methods enable engineers to find the most unreliable places in a production process and supports the decision making for reliability improvement of a production system. In this paper elaboration of the graphic simulation model of FMS operation has been described, FMS model parameters have been estimated, and criteria have been defined based on requirements regarding system reliability.

Keywords: Performance evaluation, FMS Modelling and Simulation, Reliability analysis

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1. Introduction

Extreme competition in domestic and international markets of manufacturing sector constantly appeals firms to deal with rapid technology change, more demanding and emphatic customers, and shortening product life cycle. The flexibility of a manufacturing firm is necessary in order to be competitive. A manufacturing system should be flexible to accommodate instable demands, varying product mixes, effective launching of new products in the market. Flexible Manufacturing Systems (FMS) serves these capabilities by engaging programmable automation for machining and material handling. Moreover, proper functioning of such system like successful management of the product changes and adaptation to demand situation need to be assured. It leads to the optimal performance, for example: improved equipment utilization, reduced setup time and work-in-process (WIP), considerably reduced throughput and lead times. Therefore, assessment of FMS and the factors evaluating its performance should be defined and analysed to get the optimal value of throughput time and equipment utilization.

2. Literature Review

A flexible manufacturing system usually consists of computer numeric control (CNC) machine tools, interconnected by automated material handling and storage systems, and control by an integrated computer system. Such systems are capable of processing a variety of different product families with the help of CNC machine tool(s), which are loaded and unloaded by industrial robot(s) [1, 2].

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2.1 Manufacturing System Flexibility

FMS aims to manage change and adjust to desired situation, in order to be flexible; a manufacturing system must hold the following capabilities: the ability to identify and differentiate the different incoming parts or products styles; agile configuration of operating instruction; and quick changeover of physical setup [3]. Manufacturing system flexibility consists of four classified types [4]:

- New product flexibility: The capability to introduce and manufacture novel products or to modify existing ones.
- Mix flexibility: The ability to change the range of products prepared by the manufacturing system within a specified period.
- Volume flexibility: The capacity to change the level of accumulated output.
- Delivery flexibility: The ability to change planned or expected delivery dates.

This flexibility in manufacturing system improves manufacturing performance and consequently increases competitiveness.

2.2 Applications of FMS

FMS technology is most broadly applied in machining process. Furthermore, it is applicable in metal press working, forging, and assembly, mostly used in mid-volume and mid-variety production [5, 6]. From the applications of FMS certain number of benefits can be derived such as: higher machine utilization, fewer machines (less resources), reduced factory floor space, increased responsiveness to changes, reduction in inventory requirements, shortened manufacturing lead times, curtailed direct labour requirements and greater labour productivity, and possibility for unattended production [4, 7].

2.3 Manufacturing Process Simulation

Manufacturing process simulation is a useful computer technology in a system modelling, design, and operation [8, 9]. One of the purpose of simulation is to present and animate the construction of a manufacturing system along with collects the statistics on performance and cost dimensions. A simulation is not supposed to run only one time. Because in order to get the optimum (more accurate) results of performance, the certain model should be simulated more than once. Furthermore, the same basic model supposed to execute number of times for experimental analysis with manipulating a variable every time. Simulation analysis may include the following objectives [10]:

- Evaluating machine resource level (loading of a machine)
- Definition of process bottlenecks (queues)
- Determining the impact machine downtime
- Process efficiency

In current paper the authors have constructed and simulated an FMS model in a software named – *Enterprise Dynamics* to analyze the features and variables of a system. It enables to evaluate the time performance level of a FMS.

2.4 System Modelling and Reliability

The activity analysis and activity modelling are an essential components of a system study. It is usually difficult to understand and remember all information which should be known about systems because the amount of data is large, complex and confusing. Integrated DEFinition (IDEF) is a graphical approach to system description, on the other hand, IDEF0 is a diagramming technique that shows component parts, inter-relationships between them and how they fit into a hierarchical structure. IDEF0 is used to apply structured methods to better understand how to improve manufacturing productivity [11]. An IDEF0 model can provide a method for capturing, organizing and documenting system information.

Due to increasing complexity of modern engineering systems, the concept of reliability has become a very important factor in the overall system design [12, 13]. Authors have considered the possibility to define the reliability of a manufacturing systems by fault tree analysis (FTA) [14] from a process model, and an integrated methodology for estimation of a manufacturing system.

The novelties of an integrated system rationalization tools introduced in the paper are: system modelling, simulation, and reliability estimation. All the analyses are implemented based on of IDEF0 modelling. In this study, the selected FMS was model through IDEF0 technique, followed by AS-IS simulation analysis to find out the bottleneck and utilization of the FMS process and components respectively. Moreover, TO-BE simulation analysis was performed to identify the impact of modifications and in the end reliability analysis was carried out to check the stability of FMS.

3. Methodology

This paper proposes a technique that generates fault tree from process model. It is possible, because both methods IDEF0 and FTA have the same hierarchy structure. The defined mechanism of the system performs each activity of a process by IDEF0 method [11].

Models can be enriched with information about probability of faults for each mechanism of a system, which participates in the process. The information may be entered at the stage of definition of parameters of a system. Every change of working parameters of a system aimed to change its performance can be followed by unpredictable faults. Thus, the reliability of a system should be evaluated after every change.

Every bottom level event must have a probability associated with it. It enables to calculate the probability of the top-level event occurrence. According to the axioms of probability, the probability of a high-level event occurrence can be determined as follows:

For AND events: $P(A \cap B) = P(A) \times P(B)$ (1)

For OR events: $P(A \cup B) = P(A) + P(B)$ (2)

The overall model for the analysis of a flexible manufacturing system is shown in Fig. 1. The authors follow the same modelling schema, starting from process model, followed by process simulation and reliability analysis. Authors have evaluated the parameters through simulation and discuss the improvement recommendations in the following sections.

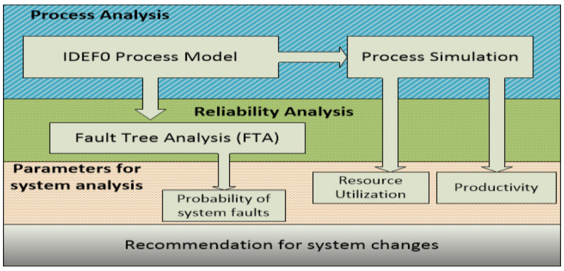

Fig. 1. Main scheme of analysis

4. Analysis of FMS processes

Usually, there are two types of problems or challenges that need an attention during the analysis of a FMS. First, design challenges that deals with the selection of FMS components and second, operational problems deal with the utilization aspects of a FMS. This study focuses on the operational study of a FMS, process simulation was performed to estimate the performance of suggested changes and their impact on other parameters. Meanwhile, it also identifies the bottleneck point in the FMS.

4.1. Configuration of the system

There are many different configurations of FMS, however authors focus on an exemplary FMS consisting of a CNC milling machine, two conveyors and two robotic arms. Such configuration can be found in various cases of automated production industry [15]. This kind of configuration simplifies material-handling control, better understanding of operations, enhanced strategic focus and flexibility. In general, it leads to simplified operations and simplified scheduling logic in particular [16].

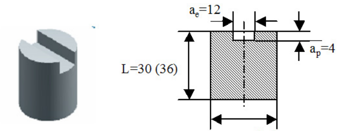

Fig. 2. Machined part parameters

The general view of a machined part and its parameters are shown in Fig. 2. In current example machine system can machine four types of part with different length (L) and diameter (D). Work part material is steel C35 (HB=150).

The layout of current FMS with its main components is shown in Fig. 3. Conveyors are equipped with sensors, which secure the positions of moving work part. FMS consists of interdependent parts that work together to perform a required functions.

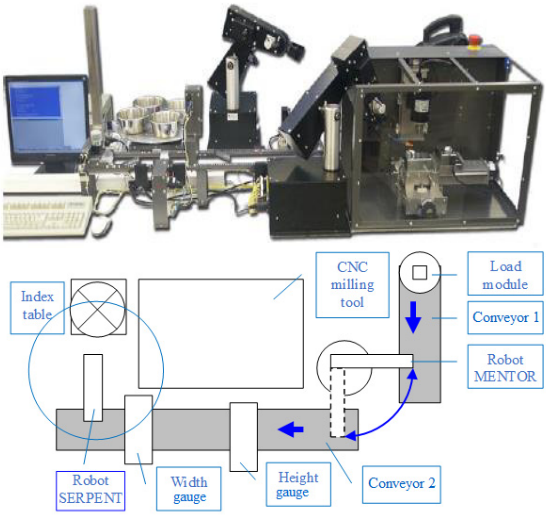

Fig. 3. General view and main scheme of FMS

4.2. Modelling of the process

The model introduced in current work describes selected FMS process flow, how it is controlled, what are the work tasks and functions it performs, and what outputs it produces. The current model is developed for process analysis, improvements, and update or replacement of the manufacturing system.

In current research work authors have used IDEF0 modelling method to describe the manufacturing system. The top level diagram of current process with mechanisms involved is introduced in Fig. 4.

The Node Tree Diagram (NTD) for the whole process is introduced in Fig. 5. The processes are numbered, and the leaf activities (prefix A) of the processes are provided together with duration logic (DL) and deviations, given by normal distribution (N): DL=N (duration in seconds, deviation in seconds).

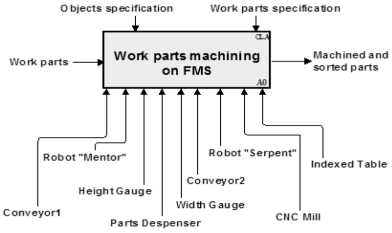

Fig. 4. Top-level diagram

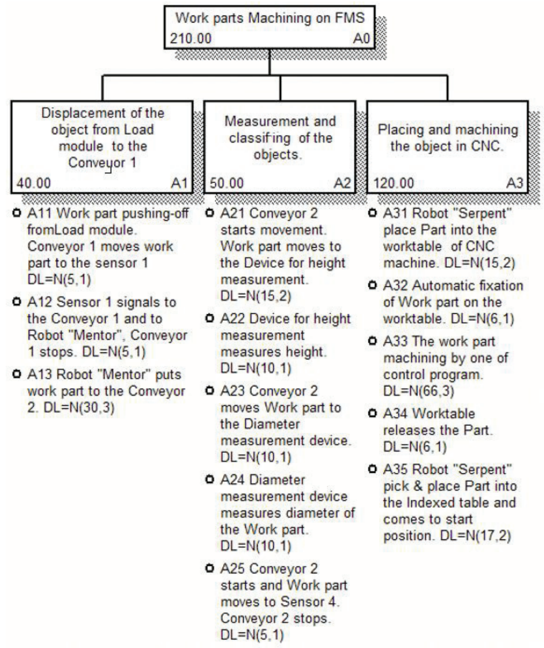

Fig. 5. Common process Node Tree Diagram

Process time of all the activities were not changed for the several types of work parts, except the machining time. The machining time is different as for A33 activity i.e., machining time of products with diameter (D) = 25 mm and D = 28 mm were not same. The longest machining time was used by the machining of D = 28 mm for process analysis. The working cycle of the system and the time graph of the process are presented in Fig. 6.

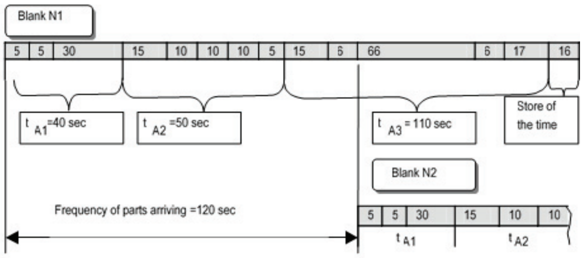

Fig. 6 Time graph of process

The cycle time of moving and machining of part t_{A0} can be calculated as:

$$t_{A0}=\sum t_{Amn}=\sum t_{A1n}+\sum t_{A2n}+\sum t_{A3n}+\sum \Delta t_{Amn} \tag{3}$$

The bottleneck of the manufacturing system is maximum time t_{A3}. For cycle time reduction, it is necessary to reduce the time of process A3 (Module A3) - t_{A3}. Module A3 includes three objects: Robot “Serpent” (works at maximum speed); Index table (works with defined speed); milling tool (allows to change cutting rates and to reduce t_{A3}).

4.3. Simulation of the process

The main goal of process change is to increase FMS productivity by decreasing the cycle time of the process. The aim of simulation is to depict the impact of changes and to validate the current study scenario. The simulation results provide useful information about the operation of studied FMS in general, and for CNC milling machine in particular. In this work only the mechanical parts of FMS were considered. The dynamic analysis of the process allows determining the behaviour of the system under different initial inputs by performing the repeated experiments within the process. Previous study concluded that the main benefit of using the simulation for manufacturing system allows manager and engineer to obtain a system-wide view of the effect of local changes in the manufacturing system. The modelling of a system enables to grasp quickly how a current system is working and to evaluate the proposed process changes before decision-making [17]. Simulation conditions for the FMS study are as follows:

- Run time for study – 20 minutes
- Normal distribution

Time allocation for each function is shown in the simulation results graph, see Fig. 7. The chart shows that function A_{33} (work part machining time proportion) should be decreased for more efficient FMS operation and productivity increment.

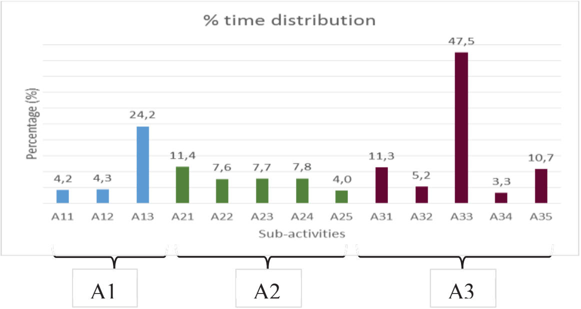

Fig. 7. Process time distribution

The summary report of the simulation shows that 9 parts were produced during 20 minutes of operation, Fig. 8 demonstrates the utilization of FMS objects (components).

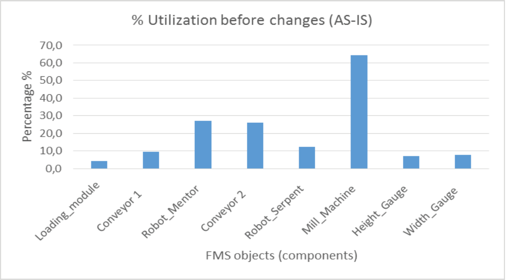

Fig. 8. Loading (utilization) of FMS objects

The analysis has shown that the “bottleneck” of system was the work part machining process and it should be reviewed. Authors have tried to change the parameters of the cutting process to achieve the better throughput of the process.

5. Enhancing FMS productivity

After studied current (AS-IS) model scenario, simulation on existing parameters, authors have discovered the parameters that should be changed to achieve higher throughput of FMS. The experiments were carried out on the same base model, thus each time only one argument of the system varied.

5.1. Modification in cutting conditions

This section compares the conditions of cutting for three different material of end milling cutters ∅12. The comparison of the machining time within the acceptable limits of the machine tool are introduced in Table 1.

- End mills from high speed steel S18 (used in AS-IS simulation model)
- End mills from hard alloy NI45, MS45
- End mills with inserts from hard alloy S6

Table 1. Machining time for different tools/materials for D=28mm

NI45 (Solid End mills)	8.9 sec
MS45 (Solid End mills)	4.6 sec
S6 (Insert. Uncoated)	8.6 sec
High-speed steel (**S18-0-1**)	27 sec

Minimal cutting time for D=28 mm during the run time (20 minutes) by using High-speed steel (S18-0-1) was 27 seconds (sec). For using end mill from hard alloy NI45 was 8.9 sec, difference was 18 sec. and for MS45 the difference was 22.4 sec. respectively.

5.2. Results after modification

From the Table 2 it is noticeable that the machining of same length with different types of end mill resulted in reduction of machine processing time. Reduction in the machining time with the changes of cutting tool also changed the cycle time of the whole process. The changes were taken into the account in simulation model as well and the following results were obtained in *20 minutes'* time duration. The results of simulation are shown in Fig. 9 and the timing of respective components of the FMS also effected by different tools as shown in Fig. 10.

- High-speed steel S18-0, *9 parts produced*
- Inserts from hard alloy S6, *11 parts produced*
- End mills, hard alloy MS45 & NI45, *12 parts produced*

On the basis of the results it can be determined that the usage of the hard-alloy cutting tool considerably increases the capacity of studied FMS.

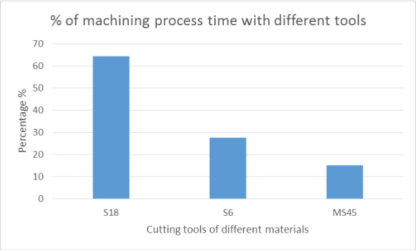

Fig. 9. Comparison of simulation results: altered types of cutting tools

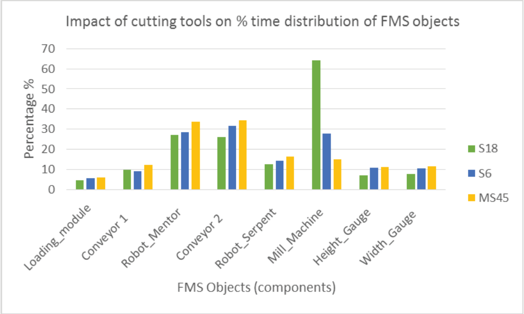

Fig. 10. Impact of cutting tools on the whole FMS components

Table 2. Comparison of AS-IS and TO-BE results

Parameters	*AS-IS (S18)*	*TO-BE (MS45)*
Cycle time (sec)	120	100
Release blank from load module	12	16
Collect part to indexed table	9	12
Usage of FMS objects (%) for interval 20 minutes		
CNC Milling tool	64.3	15.1
Robot «Mentor»	27.1	33.6
Robot «Serpent»	12.4	16.2
Conveyor 1	9.6	12.0
Conveyor 2	26.2	34.2
High measurement device	7.0	11.2
Diameter measurement device	7.6	11.4
Load module	4.4	5.8
% change of the cycle time = 16.6 (% reduction in time)		
Cutting tool (min)		
Stability of tool	20	45
Lead time division (%)		
Operation time	36.56	35.16
Moving time	62.77	60.90
Waiting time	0.65	3.92

The % change in reduction of cycle time is 16.6 % and there is an overall improvement in the FMS components utilization, due to the modification the FMS is balanced. It is possible to substitute devices in FMS or to set-up a new one. Hence, by using simulation software on the computer to manipulate all these alternatives can be cheaper and faster, than in real life.

6. Reliability model of the FMS

Fault Tree Analysis (FTA) was used for the estimation of the work reliability of FMS. The probability of occurrence of the top event (P_{AO}) for the IDEF0 methodology defined as:

$$P_{A0}=P_{A1}(\Sigma P_{A1i}) \cup P_{A2}(\Sigma P_{A2i}) \cup P_{A3}(\Sigma P_{A3i}) \qquad (4)$$

P_{A1i}, P_{A2i}, P_{A3i} are the probabilities of the faults related to lower-level activities *A1, A2* and *A3,* respectively. An example of Fault Tree Analysis of studied FMS for reliability purpose is depicted in Fig. 11.

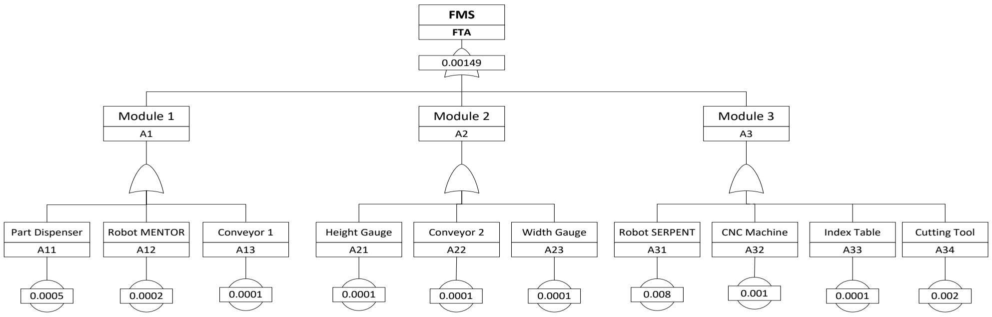

Fig. 11. Fault Tree Analysis of FMS

Successful results for the calculation of probability of faults can be achieved if all the mechanisms of a model have the same structure which was used in the FTA, in chosen modelling mechanism structure and FTA have resemblance. In the proposed automated technique to generate fault trees have been used capabilities of a modelling system. Models are enriched with information about probability of faults for every mechanism of a system, which took part in the process. The information can be entered to leaf level of diagram (A11-A34 see Table 3) at the stage of definition of parameters of the system. Probability of fault in high level could be defined by FTA calculation mechanism.

Table 3 Probability of faults definition for process elements

Mechanism	Level	Activity	Probability of fault
FMS	A-0	A0	$149\text{x}10^{-5}$
Module1	A0	A1	$85\text{x}10^{-5}$
Module2	A0	A2	$45\text{x}10^{-5}$
Module3	A0	A3	$11.1\text{x}10^{-5}$
Parts Dispenser	A1	A11	0.0005
Conveyer 1	A1	A12	0.0001
Robot Mentor	A1	A13	0.0002
Conveyer 2	A2	A21	0.0001
Height Gauge	A2	A22	0.0001
Width Gauge	A2	A23	0.0001
Robot Serpent	A3	A31	0.008
Cutting tool	A3	A32	0.002
CNC Mill	A3	A33	0.001
Indexed Table	A3	A34	0.0001

7. Conclusion

In this study, the performance of a FMS was evaluated with the help of the IDEF0 modelling technique and the manufacturing simulation. The bottlenecks were found out, corresponding changes were proposed for the improvement in throughput time and the changes were simulated for comparison. The current process of FMS was improved by considering an efficient cutting tool that leads to the reduction in throughput time and increment of productivity. Furthermore, the paper was presented a generic model for conducting the overall process analysis of a system and also described how the reliability analysis of a FMS could be carried out. A procedure was suggested to generate the fault trees commonly used for the reliability analysis, which is supported by IDFE0 technique. The suggested techniques can be applied in the manufacturing industry to enhance the performance of a FMS.

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