FMS, subsystem of objects ordering, Enterprise Dynamics, computer simulations

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A METHOD FOR MODELLING THE FLOW OF OBJECTS TO BE MACHINED IN FMS USING ENTERPRISE DYNAMICS

Abstract

Owing to the complexity of technical and organizational problems that manufacturing enterprises are faced with, there is a growing interest in methods and tools that aid design of manufacturing systems. These methods and tools can be applied both to reorganize the existing manufacturing systems and to design new ones. For this reason, computer simulations are widely used in production engineering. This paper presents the application of computer simulations when designing the subsystem known as ordering of objects in a flexible manufacturing system. The simulations were performed using the comprehensive simulation software Enterprise Dynamics.

1. INTRODUCTION

Simulations of manufacturing process allow us to examine models to be applied in practice with regard to such factors as time, cost, efficiency and resource utilization [1]. Enterprises can take advantage of a number of process modeling tools to either design a new manufacturing system or reorganize the existing one. These tools particularly allow comparison of alternative process models and – following experimental tests – selection of the best solution. Generally, experimental simulations do not include initial state estimation, so as to provide a basis for middle- and long-term analysis [15]. Also, they serve as a starting point for estimating potential of the system being tested [2,16]. This contrasts with the requi-rements of supporting decision-making operations which are aimed at estimating the possibility of introducing short-term changes to the process to

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enable better performance of the system in case of unforeseen circumstances [17]. The estimation of the current state of the system and history of events allows us to gain insight into short-term effects of changes introduced to the designed system [3].

Computer simulations are used to design highly complex objects, including flexible manufacturing systems (FMS) [4]. These systems – combined in various configurations – are the fastest developing form of production organization [5]. The term "flexible manufacturing system" is generally used to describe systems based on the use of so-called means of flexible automation, i.e. computer-controlled manufacturing devices that are highly universal and easy to retool. System flexibility is one of the most desired features that can be obtained in various ways, starting from product range, selection of machinery and production equipment, organizational structure, systems of production control and cooperation between employees, to establishing proper connections between the FMS and its surrounding environment [6]. The use of flexible manufacturing systems leads to higher production efficiency due to the integration of manufacturing processes, lower costs of starting a new order and shorter time of fulfilling it, less capital to be invested and – at the same time – higher turnover of this capital. The introduction of FMSs based on the use of microsystem electronics, IT and electrical engineering has therefore led to a significant technological and organizational progress. In the literature, the FMS is defined as a *computer-integrated complex of machines and technological devices characterized by high flexibility, automation and integration of its constituent elements* [7,8]. The application of numerical control in this system ensures considerable efficiency, practically no manual operation, and a short time of retooling. Another advantage of the FMS is that – given the potential of an enterprise – it can be used to produce any product depending on a demand [9].

2. DESIGN OF FMS SUBSYSTEMS

Flexible Manufacturing Systems (FMS) are highly complicated systems, which means that it is necessary to split an individual FMS into its constituent parts, or subsystems [10]. The FMS structure (Fig. 1) is made up of a network of connections (existing and observable relationships) between individual elements which help carry out the manufacturing process. Two systems can be distinguished: static (made up of a stock of machine tools and auxiliary devices) and dynamic (form of the process). When building the system, it is difficult to create a physical environment of the process, as this is either very expensive or – in many cases – simply impossible to do. To prevent this, systems are often virtually mapped, including the parameters of machinery and devices during machining and transport [11,14].

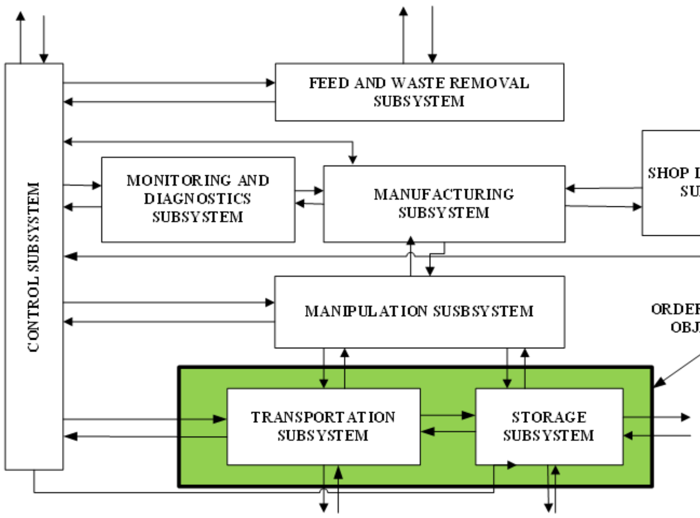

Fig. 1. FMS structure [12]

When designing flexible manufacturing systems, it is difficult to design the flow of objects in the storage and transportation subsystems [13]. The correct design of the flow of objects depends on both the financial aspect and the way in which the flow is intended to function. The design involves considering not only the size, type and arrangement of stores, but also their dimensions and capacity. The examination of individual factors according to different criteria ensures that the structure is designed correctly and, hence, it will function correctly, too.

A suitable selection of storage and transport devices responsible for the flow of materials (the subsystem known as ordering of objects) is an essential element in manufacturing system structure design, as it ensures that the manufacturing process will run smoothly. Its main task is to ensure that the machines work in an uninterrupted manner, which means that once a given operation is over another workpiece is immediately mounted on the machine tool.

3. DECISION-MAKING PROCESS AND CHARACTERISTICS OF THE FLEXIBLE MANUFACTURING SYSTEM

The complexity of modeling flexible manufacturing systems becomes clear when one examines the major aspects of designing such systems. The FMS is modeled using a closed queuing network. It is assumed that every single time a part leaves the system through the unloading station, it is immediately replaced with a new workpiece installed by the loading station. The production task is to select the parameters of material flow such that all machine tools in the system are under a uniform load.

The decision-making problem can be stated in the following way: An enterprise specializing in the machining of bodies wants to implement a flexible manufacturing system to improve both the flexibility of its manufacturing processes and its own competitiveness. First, using multi-criteria analysis methods, we selected the quantity of machine tools for the machining of the defined class of parts [18]. Then, we selected and deployed stores in the system [19]. Another stage involved enhancing the subsystem of objects ordering in such way that both the time of retooling and the queuing time are as short as possible, while load distribution is uniform.

In terms of quality and quantity, the workpieces (bodies) are sent to production at random, yet in compliance with the expected demand. The mean annual production rate of representatives of particular parts is as follows: Body_1 – 3950 pcs, Body_2 – 5435 pcs., Body_3 – 3160 pcs. These parts are machined using CNC machines selected at the stage of the flexible manufacturing system: MCX900 – 3 pcs., TOStec PRIMA – 3 pcs., MCFV1680 – 3 pcs.

The parts were machined in compliance with the process route shown in Fig. 2. The times marked in the chart with the names of machine tools denote the times of travel of parts in a given machine tool during subsequent operations (including the time of retooling).

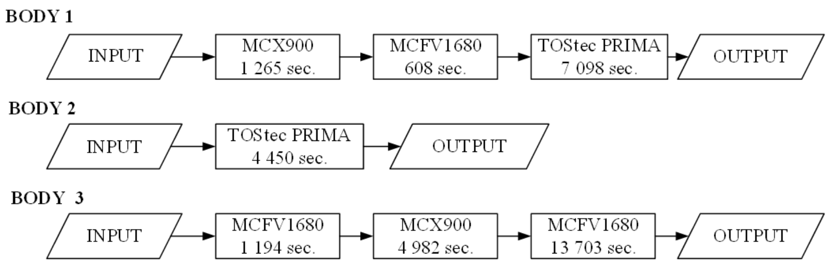

Fig. 2. Routes of parts in the manufacturing process [source: own study]

The selection of parameters and devices for the ordering of objects is aimed to improve the flow of manufactured parts by eliminating production bottlenecks and by reducing costs caused by incorrect selection of storage capacity and store types. Also, this will ensure effective management of the premises of an enterprise, hence making this enterprise more competitive.

4. MODELING OF THE MANUFACTURING PROCESS USING ENTERPRISE DYNAMICS

The model of the manufacturing system is designed using the Enteprise Dynamics simulation software manufactured by Incontrol. The designed model was used numerically simulated and the results obtained were then examined. The tested system was assumed to work 365 days a year, including 15 days for standstills due to inspections, repairs and maintenance of the devices. We allowed additional 3% of time for unexpected standstills of the system. 10% of the system operation time was assigned for conveyance operations. The work was to be conducted in a triple-shift system. Having calculated the above, we obtained the simulation time which was 7333 hours and 12 minutes – the amount of time corresponds to the annual work period of the system. The use of Enterprise Dynamics enables application of the incremental method tailored to conditions of the task with a graphical user interface; it also ensures experiment control via an interpretable language (e.g. 4DScript).

The objects flow system in the designed model (Fig. 3 and 4) consists of the following:

- 3 central stores responsible for the maintenance of the manufacturing department, additionally equipped with storage and retrieval machines located in the store,
- 7 changers, i.e. autonomous loading and unloading devices,
- 2 technical stores for "re-routing" products according to the "process route"; these stores do not, however, have any effect on the design process,
- conveyor belts made up of at least three layers: two protective screens (running and carrying screens) and a core, each belt having a speed of 1 m/s and a capacity of 1 piece [6].

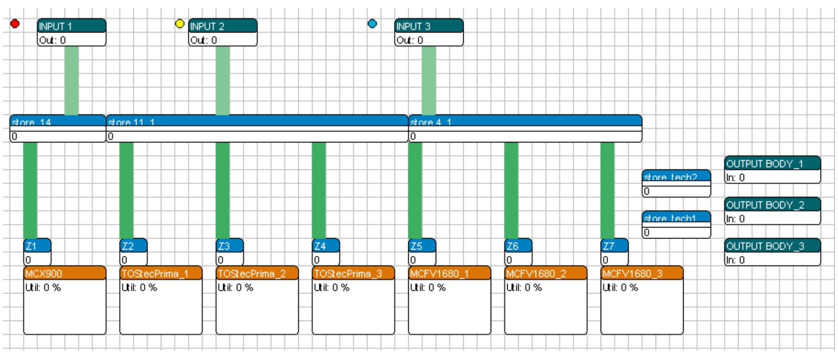

Fig. 3. FMS model [source: own study]

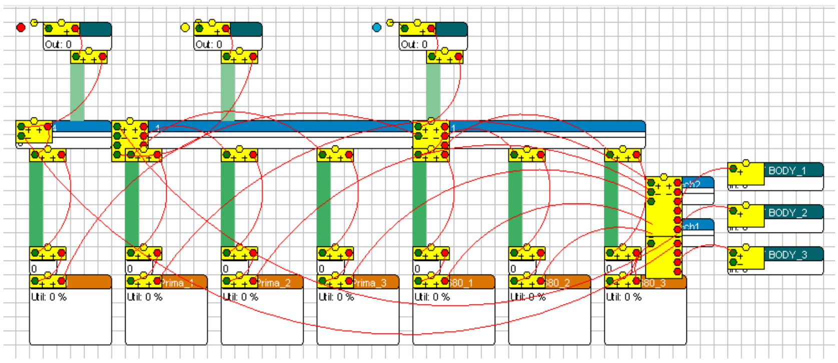

Fig. 4. FMS model showing connections between atoms [source: own study]

The tested model is used to manufacture three products: Body_1, Body_2, Body_3. Once all parts have entered the system as scheduled in the production plan, the input channel is blocked. The products are sent at random times, defined by inter arrival time. The flow of parts in the designed model is compatible with the real process route defined by a production engineer. At the end of the process, the products are sent to specified output channels (output channels are defined individually for each product). This operation is possible owing to selecting suitable parameters of the flow channel (individual atoms in the model are labeled).

The cycle time of particular operations performed on different machining stations is given in the 4DScript programming language. The application of 4DScript enabled us to create scripts that control the process according to the defined parameters of products; also, it allowed us to devise process routes showing which model of machine tool a product must be sent to as well as to transfer the finished product from one store to another. In effect, the machining of parts could be performed in accordance with the scheduled time of operation. The parts are sent in the system using the FIFO configuration. If several machine tools of the same type are occupied at the same moment, the workpiece is transmitted to the first free machine tool in the queue. If several work stations are free at a given moment, we use the following function: *Send to: A random open channel: choose a random channel from all the open output channel*, which results in sending the product to a machine tool selected at random. In the course of the simulations, we did not introduce any changes to the tested machine tools subsystem in the flexible manufacturing system for producing parts (bodies) according to the above process routes (see eg. Fig. 5).

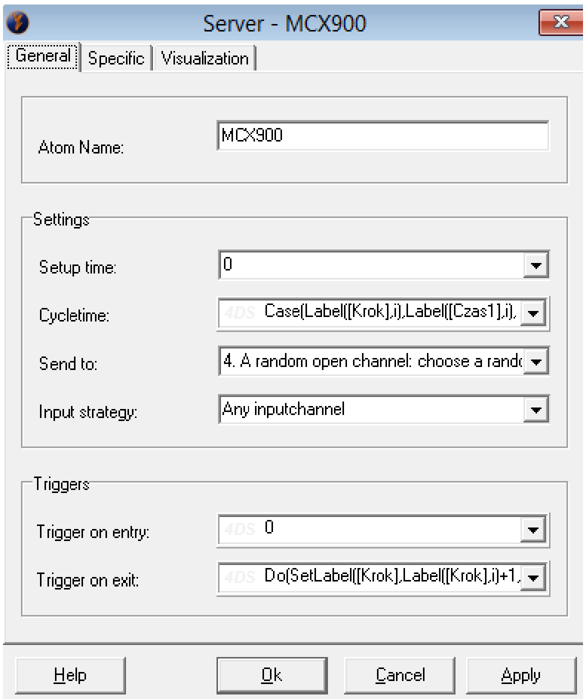

Fig. 5. Parameters MCX900 machine [source: own study]

5. COMPUTER SIMULATION AND DISCUSSION OF THE RESULTS

Based on the above assumptions, we built a model that was used in twenty simulations of the flow of objects. In the simulations, we examined the following parameters:

- mean load of the machining tool in the simulation (in %),
- maximum quantity of products stored (in pcs.),
- storage occupancy during the whole process (in %),
- mean quantity of products stored (in %),
- mean queuing time (in secs.).

The above factors were analyzed to select a suitable configuration of objects flow. The use of computer simulations both aids and ensures the building of a high quality system.

We conducted 20 simulations (Table 1), which confirmed that the stores had been selected correctly. The following had central stores: Store_14, Store4_1, Store1_1. We mounted changers at machine tools with a capacity of 2 pieces. They were located next to these machine tools and labeled as Z1, Z2, Z3, Z4, Z5, Z6, Z7. The results demonstrate that the above quantity is adequate and the mean occupancy does not exceed unity. The longest queuing time was recorded for changer Z1, which results from the fact that the changer is mounted at the MCX900 machine (Fig. 6) – the only machine of this type in the system. This machine tool is characterized by a short machining time, and the simulation results demonstrate that it was utilized in 78.564 %. The percentage is correct and it does not disturb system operation. The load applied to individual machine tools is similar (Fig. 7), which is proves that the system's random demand for specific parts was designed correctly. What is more, the entire system functions correctly, parts do not get stuck when entering the system, and the production plan is implemented. No disturbances to the system were recorded. We did not identify the occurrence of bottlenecks that could have a negative effect on flow capacity of the system.

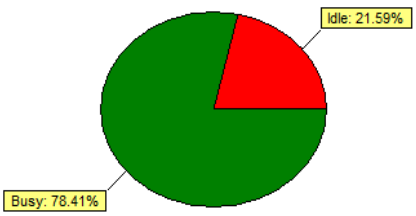

Fig. 6. Machine MCX900 usage [source: own study]

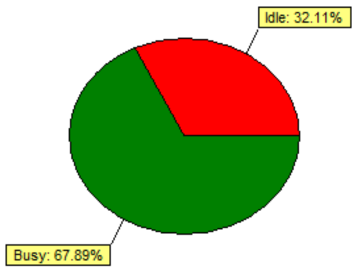

Fig. 7. Machine TOStecPrima usage [source: own study]

Table. 1. Mean results of the stores and machine tools

Storage parameters	Store_1 4	Store 4_1	Store 11_1	Z1	Z2	Z3	Z4	Z5	Z6	Z7
Capacity [pcs.]	10	10	10	2	2	2	2	2	2	2
Mean occupancy [pc.]	0.117	0.089	0.012	0.844	0.414	0.442	0.432	0.648	0.601	0.673
Maximum quantity in store [pc.]	4	3	3	2	2	2	2	2	2	2
Queuing time [s]	434.52	0.364	0.000	3133.2	3486.9	3735.6	3646.9	5115.0	4509.7	5214.7

Machine tools parameters	MCX900	MCFV16 80_1	MCFV16 80_2	MCFV16 80_3	TOStec Prima_1	TOStec Prima_2	TOStec Prima_3
Mean load of machining tools [%]	78.564	62.548	62.528	62.252	66.838	66.088	65.872
Mean time of machining [s]	2916.980	4647.750	4875.945	5563.071	5586.512	5543.647	4925.809

It is estimated that a system built in compliance with the designed model will ensure a smooth flow of materials in the system. When designing a subsystem of objects ordering, we examine individual parameters that affect a given subsystem in order to arrive at the optimum solution. With the system built thereby, it is possible to save space (not only the storage space) owing to better use of both the central store and the entire system. Although the application of conveyor belts and their developed spatial structure hinders access to work stations in cases of emergency, conveyor belts (Fig. 9) are nonetheless often used in this type of system configuration. They are structures suitable for products of varying sizes.

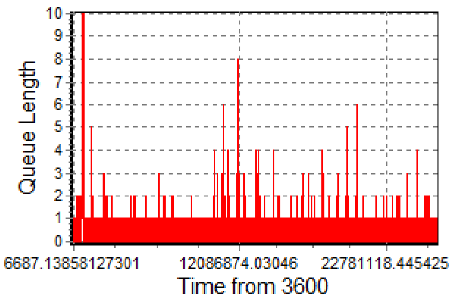

Fig. 8. Storage_14 occupancy [source: own study]

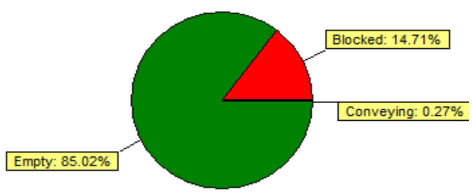

Fig. 9. Conveyor belts usage [source: own study]

In the system designed thereby, the main storage unit is defined by central store. In addition, parts can queue to be processed on conveyor belts, therefore they are not sent to the central store. The results of the performed 20 simulations show that the scheduled production plan has been implemented, even though it was burdened with uncertainty due to the random input time and random product selection when entering the system. Parts to be manufactured queue in the vicinity of the machine tools, which ensures that a workpiece is mounted on the machine tool immediately after the previous process performed by this machine tool is over.

Computer-aided simulations allow us to use manufacturing cells in a more effective way – delivery ineffectiveness can be eliminated if the flows of parts, tools and workpieces are combined. In fact, this confirms the thesis that an optimally working manufacturing cell will not ensure process continuity unless it is equipped with correctly functioning coupled subsystems.

6. CONCLUSION

Given the tendency of keeping investment outlays to the minimum while at the same time attempting to improve manufacturing efficiency and product quality, the realization of manufacturing processes involves dealing with unexpected challenges. Since the manufacturing system of an enterprise cannot function well without a well-organized internal logistics, the use of computer simulations can considerably optimize the flow of raw materials, components or finished products. Internal logistics has a significant effect on the organization of individual processes, as it ensures correct flow and transport of all components and products in successive manufacturing stages as well as the supply of fini-shed products to the store.

Due to their simple design, high reliability and relatively low energy consumption, conveyor belt systems are the basic means of transportation. Installed in an FMS, they can provide additional buffer storage. A buffer storage is used when we want to give up on large storage capacity and limit the usable area to the changers that operate the machine tools. Recently, we are witnessing a growing interest in belt conveyor systems. The only problem connected with the maintenance of conveyor belts is that after unloading plastic strain (elongation) tends to remain or they rapidly build up at the beginning of working life of new belts and set permanently after a certain period of time [2]. Nonetheless, conveyor belts are still the most widely used conveyor systems in flexible manufacturing systems.

The experimental results demonstrate that the proposed transportation system was designed correctly and the destinations of parts in the stores were set correctly, too. When using conveyors belts, however, it must be remembered that they are most suitable for circulating systems and that the route of materials flow depends on the design of a given conveyor belt. On the one hand, conveyor belts prevent easy access to work stations. On the other, the cost of mounting them is low due to a vast number of specialized transport services that are available on the market. Also, conveyor belts can be custom-designed for a specific manufacturing system. The experimental results demonstrate the potential of using computer simulations as a method for solving highly complicated problems, particularly for investigating decision-making problems that cannot be solved by traditional methods.

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