Arkadiusz Gola[1], Antoni Świć[2]

DESIGN OF STORAGE SUBSYSTEM OF FLEXIBLE MANUFACTURING SYSTEM USING THE COMPUTER SIMULATION METHOD

Complexity of problem of modern manufacturing systems design and the lack of possibility for obtained solutions verification cause that indispensable tools in this area become the methods of computer modeling and simulation. This article presents the possibility for utilization of computer simulation methods (on the example of Enterprise Dynamics program) in the problem of design of storage subsystem of flexible manufacturing system. In particular, the sequence and solutions in selection of both types of stores and economic design of their capacity in FMS for the specific research task was shown.

Keywords: *flexible manufacturing system, storage subsystem, computer simulation, Enterprise Dynamics.*

Аркадиуш Гола, Антони Свіць

ПРОЕКТУВАННЯ ПІДСИСТЕМИ СКЛАДУВАННЯ ГНУЧКОЇ ВИРОБНИЧОЇ СИСТЕМИ З ВИКОРИСТАННЯМ МЕТОДІВ КОМП'ЮТЕРНОГО МОДЕЛЮВАННЯ

У статті подано можливість використання комп'ютерного моделювання (на прикладі програми Enterprise Dynamics) для проектування підсистеми складування у гнучкій виробничій програмі. Зокрема, представлено перебіг і результати процесу вибору типу складів, а також економічного проектування їхньої місткості в ГВС для конкретного дослідного завдання. Описано складність проблеми проектування сучасних виробничих систем, а також відсутність можливості перевірки отриманих розв'язків на реальній моделі.

Ключові слова: *гнучка виробнича система, підсистема складування, комп'ютерне моделювання, Enterprise Dynamics.*

Аркадиуш Гола, Антони Свиць

ПРОЕКТИРОВАНИЕ СКЛАДСКОЙ ПОДСИСТЕМЫ ГИБКОГО АВТОМАТИЗИРОВАННОГО ПРОИЗВОДСТВА С ПРИМЕНЕНИЕМ МЕТОДОВ КОМПЬЮТЕРНОГО МОДЕЛИРОВАНИЯ

В статье показана возможность использования методов компьютерного моделирования (на примере программы Enterprise Dynamics) при проектировании складской подсистемы гибкого автоматизированного производства (ГАП). В особенности, на примере исследуемой задачи, представлен порядок, а также результаты процесса подбора типов складов и экономически оправданного проектирования их емкости в ГАП. Описана сложность проблемы проектирования современных производственных систем, а также невозможность верификации полученных решений на действительной модели.

[1] PhD, Assistant Professor, Department of Enterprise Organization, Faculty of Management, Lublin University of Technology, Poland.
[2] PhD, Associate Professor, Institute of Technological Systems of Information, Lublin University of Technology, Poland.

Ключевые слова: *гибкое автоматизированное производство, складская подсистема, компьютерная имитация, Enterprise Dynamics.*

Determination of the problem in its relation to key scientific and practical tasks. Speedy development of the global manufacturing market implies a need for rapid product change, high product variety, customized products and low production cost [5;12;14]. In consequence, companies to cope with thes challenges have to design manufacturing systems which simultaneously combine 2 main features: high efficiency and variety of manufactured product range. The system which meets these conditions is a flexible manufacturing system (FMS) [13]. FMS allows producing parts in a cost effective way reaching an optimum level at each stage of the design process [6, 20].

Flexible manufacturing system design is a complex and multistage process. The process of designing an FMS is a sequence of actions leading to the design of all functional subsystems of the FMS, with simultaneous design of material, energy and information flow streams (Fig. 1) [15]. After selection machine tools for production defined set of parts the key problem is to design the storage subsystem optimal both in qualitative (type of stores) and quantitative way (capacity of stores). The key problem is to design the FMS storage subsystem to allow fluent manufacturing process be economically justified from the minimal investment costs viewpoint.

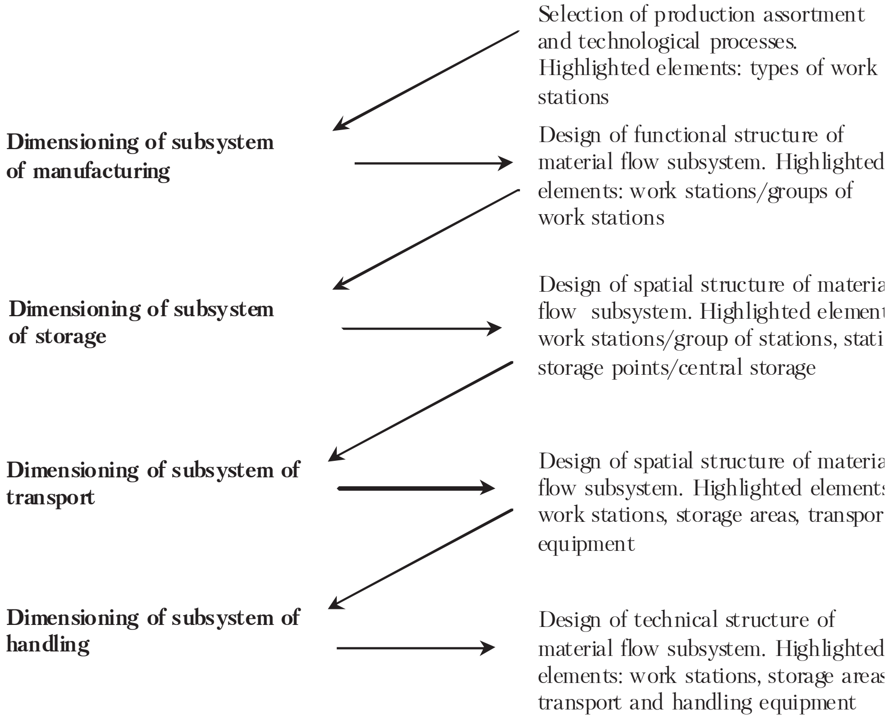

Figure 1. **The process of designing the material flow stream subsystems in FMS [15]**

Review of the literature on the problem. The problem of optimal manufacturing systems design was reached by many researchers during last decades. It is rather frequent to find in literature the description of general methodology of flexible manufacturing system [1; 2; 8; 15; 20]. There are also many publications presenting theoretical mathematical models of solving both general and detailed problems in the process of FMS design [3; 11; 16]. However, it is difficult to find complex solutions which present the way of design of storage subsystem and verification of the obtained solutions [19].

Up to now elementary problems of FMS storage subsystem design can be found in the works by Warnecke [21], Harmonovsky [8], Banaszak and Jampolski [1], Lis, Santarek and Strzelczak [15], Borenstein, Becker and Santos [2], Dorf and Kusiak [4], Harczenko [10], Mohanty [16] and Zawadzka [22]. Unfortunately, the solutions presented in those publications are still very general and the methodology of flexible manufacturing systems design is still at the stage of working out [17; 22].

Definition of the target problem for the analysis. The key problem is the optimal design of storage subsystem for the FMS designed to machining casing-class parts. Due to specified conditions, the FMS must be able to machine a set of parts, for which the representative parts are 3 parts with average annual production volume of respectively: 3950, 5435 and 3160 pieces.

At the first stage of the design process, the selection of machine tools using the multi-criteria analysis methods was conducted [7; 18]. As a result, the machine tools presented in Table 1 were selected.

Table 1. **The results of machine-tool selection process [7]**

Type of machine tool	Number of machines
MCFV1680	3
MCX900	3
TOStec PRIMA	1

The next problem is to define the structure of storage subsystem, where the key issues are:

- defining what types of stores should be used in system (central independent store, machine tool stores);
- definition of the needed and economically justified capacity for each store in the system.

The proper design of storage subsystem should secure both constant fluency of manufacturing process (without the work stoppage) and minimization of investment costs (eliminating the situation of stores with excessive capacity).

Presentation of the research material, including methodology description and key results of the research. To solve the presented above problem the computer simulation method was used. In particular the simulation model was build and analyzed in the Enterprise Dynamics program (ED). During the modeling process it was assumed the FMS works 365 days a year, where 15 days are the planned stoppage necessary for maintenance activities. Moreover, the 3% rate of the possible unplanned stoppage was taken into account. The transport time in the FMS was accepted on the level of 10% of the system work time. Finally, calculated time of designed system's work time (mirrored in the developed model) equals 7 333 hours and 12 minutes.

The analyzed model, presented in Fig. 2, includes:

- 3 central independent stores — Store_14, Store_4, Store_11 (with changeable capacity during the time of experiment),
- 7 machine-tool stores — M1, M2, M3, M4, M5, M6, M7 (with changeable capacity during the time of experiment),
- 2 technical stores (with zero capacity — which are necessary to direct machined parts in accordance with the technological routes).

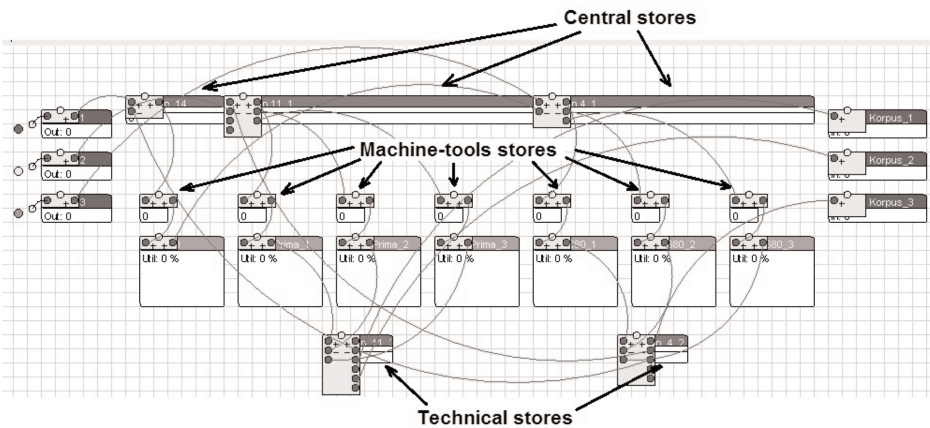

Figure 2. **The model of the designed FMS in Enterprise Dynamics**

In each experiment the machined parts are input to the system randomly using the function Inter arrival time (Table 2).

Table 2. **Input of the parts into the system — the structure of scripts**

Product	Number of parts	Defining of the randomness in ED program	Limitation the number of product ED program
Part_1	3950	*Uniform (0,Mins(219))*	*Generate maximum 3950 products*
Part_2	5435	*Uniform (0,Mins(219))*	*Generate maximum 5435 products*
Part_3	3160	*Uniform (0,Mins(219))*	*Generate maximum 3160 products*

The machined parts in the modeled system are directly in accordance with the technological routes by parameterization the flow routes using the programming language 4DScript. The command entered into the field Trigger on exit directs the product according with the label defined for the specific part. The cycle time (processing time) of the part was defined for each machine tool also using the 4DScript language. The parts in the system are passing on according to the FIFO (First In — First Out) principle. If some of machine tools are busy in a specific moment of time the part will go to this one, which finished its work. If there are some free machine tools in specific moment of time — the defined function Send to: A random open channel: choose a random channel from all the open output channels) directs the part to randomly selected machine tool. The developed model is invariable during the conducted analyzes. One variable which changes during the experiment is the capacity of each store.

On the basis of the defined parameters 3 possible variants were analyzed (Tab. 3).

Table 3. **Parameters of the analyzed variants**

Variant	Defined/analyzed parameter	Store_14	Store_4	Store_11	M1	M2	M3	M4	M5	M6	M7
Variant_1	Maximum capacity	10	10	10	2	2	2	2	2	2	2
	Average capacity	8,64	3,6	2,56	2	2	2	2	2	2	2
	Maximum number of parts in the store	10	7	4	2	2	2	2	2	2	2
	Type of the store	Central store			Machine-tool store						
Variant_2	Maximum capacity	10	10	10	2	5	5	5	7	7	7
	Average capacity	8,84	1	1	2	5	5	5	7	7	7
	Maximum number of parts in the store	10	1	1	2	5	5	5	7	7	7
	Type of the store	Central store			Machine-tool store						
Variant_3	Maximum capacity	10	1	1	7	7	7	7	7	7	7
	Average capacity	3,32	1	1	7	6,84	6,92	7	7	7	7
	Maximum number of parts in the store	6	1	1	7	7	7	7	7	7	7
	Type of the store	Central store			Machine-tool store						

Because of the random characteristics of the manufacturing process the experiment was repeated 25 times for each variants. During the process the following parameters were analyzed:

- average workload of machine tools during the simulation process — to show the manufacturing process is continuous (without stoppage);
- maximum number of parts in the store during the simulation process;
- average workload of the stores during the simulation process;
- average stay time of the part in the store;
- queue history of the store;
- average number of parts in the store during the simulation process;
- average part's wait time for machining.

Finally, the gathered data allow evaluating the analyzed variants. One of the key parameter was the workload of the store (Fig. 3). It shows that in the case of variant 3 there is a situation where the central store is not needed and the machine tools stores with defined capacity allows continuous work flow in the system (without the situation of excessive capacity). Therefore, the best solution for the analyzed task is to install only 7 machine tool stores with the capacity of 7 pieces each.

Conclusions and further studies prospectives. The process of manufacturing systems design requires both development of a theoretical model and its verification to check if the obtained solution on each stage of the process is appropriate. Unfortunately, in such research area it is impossible to verify the model on real system. Therefore, the tool applicable in that area is computer simulation method.

Figure 3. **Average workload of the stores for analyzed variants**

This article presents the possibility for application the Enterprise Dynamics program to design the storage subsystem of the flexible manufacturing systems. It allows both finding the proper solution in selecting the best type of store and determining adequate capacity of the store (or stores). In the problem of FMS store subsystem design, the key problem is to select the best type of store and its capacity which will be able to realize production task without stoppage of the system. What is also very important — the stores should characterize the less possible cost of investments. Studies in the area of FMS store subsystem design were undertaken in response to the needs of companies which are looking for a tool that will help in design of storage subsystem of the manufacturing system taking into account real plants' constraints. The authors of the methodology decided to develop a proper solution oriented at flexible manufacturing systems which are in the group of the fastest developing manufacturing systems in the world. However, this research can be expanded also for different types of manufacturing system. Further studies will be conducted in the following areas:

- design of storage subsystem for cellular manufacturing systems, focused flexibility manufacturing systems and reconfigurable manufacturing systems;
- possibility of application of computer simulation method to optimal facilities selection for transport, manipulation, tools management, discards delivering and removal subsystems;
- optimal layout of stores and other facilities in manufacturing systems.

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