# MODELS OF MANUFACTURING SYSTEMS – CLASSIFICATION FRAMEWORK

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**Abstract** The following paper is to introduce models of production systems presented and discussed in the literature. The models most often used are briefly described and characterized, as well as classified into two groups: in the first one manufacturing system's model is based on mathematical description of relations between parameters of the system and includes f.ex. production function and Leontief's formulas, while in the second models reflect system's structure and relations between its elements and includes f.ex. industrial dynamics model. The classification developed is useful for manufacturing systems analysis and description providing some formal background, especially when using informal, descrptive approach.

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## 1. INTRODUCTION

Analysis of entities realizing production processes usually includes the term *system*. System is an entity which proves it existence by synergetic cooperation of elements (Bellinger G., 2002); (Cempel Cz., 2005). The term *production system* (or *system of production*) is used and referred to an entity realizing production processes and logistic processes because of its complexity, however its use is not entirely correct. Production systems and logistics systems are real but description or analysis of production systems is usually focused on some of their aspects which means only system models are analysed [*A model* – is a simplified representation of a part of reality in which features, relations or other elements important for the predefined goal (Encyklopedia Gazety Wyborczej, p. 110)].

In the literature on the subject numerous models of production system are introduced. The authors of the paper decided to identify the models the most often used and classify them using their characteristics. The basis for classification was the classification of models introduced by J. W. Forrester (Forrester J. W., 1965, p. 49).

## 2. MODELS OF PRODUCTION SYSTEMS

Chronologically, the earliest model introduced is referred to as *production function* (de Neufville R. and Stafford J., 1971). In its simplest form it is a representation relation between production volume and the size of resources available. Production function is a set of points representing all the combinations of resources efficient from production volume maximization point of view. The function is presented in numerous variants, among which the most often cited in the literature are Cobb-Douglas function and CES production function (Theil H., 1979, pp. 23, 177, 289).

As mentioned above, the production function models the relation between production volume and resources size. It is not related with any predefined size of production system but it usually used in macro-economic approach.

The approach developed on the most detailed level are *Gutenberg's formulas* (Glaser H., 1975, pp. 19- 31), which present relations at the workstation level between:

- production volume
- resources use
- workload for each workstation
- operating time for each workstation
- production costs.

Gutenberg's formulas are linear functions presenting relations between variables presented above. If one of them is assumed a given data, the others can be calculated.

Another point of view is represented by *Leontief's formulas* (Glaser H., 1975, pp. 37-49). They are used to analyse the relations between *inputs* to a production system and *outputs* from it, taking the *depth* of production system into consideration. The situation in which final product is manufactured directly from raw materials is considered, as well as the situation in which production process includes some intermediary stages leading to modules or components development. The relations described with Leontief's formulas are referred to quantitative relations in production systems and to costs of production system as well.

The models introduced above are focused, generally speaking, on mathematical description of relations between various parameters (characteristics) of systems analysed. They do not identify the structure of the system – relations between its elements. Though they were developed to describe phenomena typical for production systems, they can be used (by analogy) to describe logistics systems as well.

The models analysing system's structure in a more detailed way are to be considered as well. The first of them is to be the model of *industrial dynamics* introduced by J. W. Forrester (Forrester J. W., 1965, pp. 67-80). His idea was to identify some categories of abstractive elements of the system, including:

- levels
- material flows
- decisions regulating intensity of material flows
- information channels linking levels and decisions.

These elements are used to build manufacturing system model. The model to be built is dynamic – it changes its status quo and behaviour because of changes in intensity of material flows controlled by decisions taken. Forrester model can be applied to manufacturing and logistics systems description.

The model of *system equations* introduced by H. Schmigalla (Schmigalla H., 1988) is based on different assumptions. It includes numerous equations, which describe relations between elements of the system and between its parameters. The number of equations and variables is equal, which enables identification of each variable. Assortment and production programmes are given at the beginning and constants, relations between system element do not have to be linear, but they can be described with equations on any level or with decision charts. The example of the model built with the assumptions presented above is the one introduced by M. Lesz (Lesz M., 1975).

Both, Forrester and Schmigalla-Lesz models are not optimization models. modification introduced by M. Fertsch (Fertsch M., 1993) enables conversion of the model based on *System equations* to the optimization model. It basically requires dividing the model into two parts:

- constant part, which describes relations in the system's structure,

- dynamic part, which describes relations between system's parameters. The relations are described with mathematical programming tools (linear, square) or with a game represented with matrixes (Fertsch M., 1995).

The next modification introduced to models based on system equations is the one introduced by P. Pawlewski (Pawlewski P., Trujillo J. A., Golińska P., Pasek Z. J. and Fertsch M., 2008). It is based on introducing a unit RO (*Resource-Operation unit*) to the system description to link the resources and operations they are used in. Such approach allows to use IDEF group methods for system modelling and optimization (*Integration Definition for Function Modelling*) (Announcing the Standard…, 1993).

The two groups of models presented above identify and describe relations between various characteristics (parameters) of systems analysed and describe relations within the system and they represent class of models based on formal relations (mathematical relations). However, in production management, the class of descriptive models is also widely discussed. As most of the models in that class is predicted only – they refer to the systems which are developing, or are to be built, they need some detailed explanations.

Classic descriptive model of manufacturing system is the one based on dichotomy between push and pull systems. Push systems are sometimes referred to as MRP or American-European systems, while pull systems are referred to as Japanese or JIT systems. The literature on the subject is extensive and includes numerous valuable positions. Generally however, it claims that there are two different structures of production systems. For the first one, push model, the criteria for its development is maximization of resources use. Additionally, there some other criteria used, including:

- maximization of similarities between products use (concerning both technology, and process organization)
- minimization of assortment manufactured in analysed production unit
- minimization of variety of machines and devices in one production unit
- closing the process, which is simply limitation of cooperation between units, making all the operations in one production unit, until the product is finished.

The structure of manufacturing system is designed with the following steps:

1. identification of assortment manufactured in predefined production system
2. identification of assortment which can be processed in smaller units (cells)
3. designing the cells identified
4. combining the cells into departments etc.

The second model is the pull model, and is also called TPS – *Toyota Production System*. It is based on maximization of production flows and fast reaction to changing demand. Production flow is linear. Design process deals with all the assortment and all the production processes, the products are not grouped to identify smaller production units. Workstations which cannot be, because of technology etc., a part of production line are allocated in its closest neighbourhood, in the form of workshops.

In the literature of the subject the kind of Japanese model, called Just-In-Time production system is described (Armstrong M., 1993, pp. 150-158). The idea is to provide continuous and frequent deliveries of products or services to obtain the following results: minimization of stock and costs they are generating, as well as faster reaction to demand and providing necessary products and elements in shortest time possible.

Dichotomy of *American-European* and *Japanese* models is referred to production systems functioning before 1990. Nowadays, models of production system are also divided into two groups, namely lean manufacturing systems and agile manufacturing systems. The idea is also used for logistics systems and they are also referred to as lean and agile. Lean manufacturing systems are designed to manufacture standard products to satisfy the market. The products are manufactured in optimized production processes, with special equipment.

In Lean manufacturing, manufacturing system is organized according to JIT idea. On the other hand, agile manufacturing systems are designed to manufacture unique products, according to individual customers' requirements. Manufacturing system in that case is based on traditional production units equipped with universal machines, partially automated. High skills of operators and other employees are required, as well as advanced technical knowledge.

The author of the next descriptive model of production system is C. H. Dagli (Dagli C. H., 1994, pp. 13-15). He introduces the terms *intelligent manufacturing* and *intelligent manufacturing system* and defines them as follows. Intelligent manufacturing system is an entity including:

- world model, which includes information on system environment condition
- value judgment system, which analysis information on system environment condition included in the world model and generates alternative actions based on that analysis
- behaviour generation subsystem which assesses alternatives developed by the value judgment system and defines goals and plans using them
- sensory processing subsystem which provides communication and exchange of information between the world model, subsystems listed above and executive elements of the system, as well as between intelligent manufacturing system and its environment.

Intelligent manufacturing system model seems applicable also in the area of logistics, which is proven by initiating a research problem on *intelligent logistics* in Poland.

C. H. Dagli's contribution to development of descriptive models of manufacturing system is not only intelligent manufacturing system. In 2005, he introduced the idea of manufacturing system which is to be resistant to disturbances, flexible, and adaptive (Dagli C. H. and Meyyappan L., 2005). Such system works similarly to a bee hive. In his further publications C. H. Dagli introduced assumptions for the system modes work and behaviour (Dagli C. H., 2007).

The next idea, quite similar to intelligent manufacturing system, though based also on the computer-integrated manufacturing – CIM – idea, is the model of digital production developed by *Fraunhofer Institut fuer Fabrikanlagen* (Spath D., 2007). The structure of the model is similar to CIM idea. In the digital production model the flow of information is stressed, and not only within the system, but also exchange of information between the system and its environment is considered.

## 3. CONCLUSION

In the analysed group of models, there were both formal and informal ones fund. The formal models group includes the two following sub-classes:

- models based on mathematical interpretation of relations between various parameters (characteristics) of systems analysed
- models describing the structure of productions system and relations between various parameters (characteristics).

In the descriptive models class there were no sub-classes identified because of the character of this group.

Some of the models presented can be potentially used for logistics systems description, however such were not found in the literature on the subject.

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