**Antoni Świć[1], Arkadiusz Gola[2]**

# ECONOMIC ANALYSIS OF CASING PARTS PRODUCTION IN A FLEXIBLE MANUFACTURING SYSTEM

***The paper presents a method for the determination of economic feasibility of the production of casing-class parts in a flexible manufacturing system (FMS) without the necessity of developing technological processes of their machining. The justifiability of the production of parts is determined on the basis of their technological complexity. Machining of parts in FMS is justified when their technological complexity is lower than the threshold technological complexity determined for the manufacturing system.***

***Keywords:*** *economic feasibility of manufacturing of parts, flexible manufacturing system, technological complexity of parts.*

**Антоні Швіць, Аркадіуш Гола**

# ЕКОНОМІЧНИЙ АНАЛІЗ ВИГОТОВЛЕННЯ ДЕТАЛЕЙ КОРПУСІВ У ГНУЧКІЙ ВИРОБНИЧІЙ СИСТЕМІ

***У статті подано методику визначення економічної рентабельності виготовлення корпусів у гнучкій виробничій системі (ГВС) без необхідності розробки технологічних процесів їх обробки, обґрунтовано, що доцільність обробки деталі встановлюється на основі її технологічної складності, обробка деталі у ГВС буде обґрунтованою у випадку, коли її технологічна складність є не меншою від граничної технологічної складності, визначеної для виробничої системи.***

***Ключові слова:*** *рентабельність виготовлення деталей, гнучка виробнича система, технологічна складність деталі.*

**Антони Швиць, Аркадиуш Гола**

# ЭКОНОМИЧЕСКИЙ АНАЛИЗ ПРОИЗВОДСТВА КОРПУСНЫХ ДЕТАЛЕЙ В ГИБКОМ АВТОМАТИЗИРОВАННОМ ПРОИЗВОДСТВЕ

***В статье представлена методика определения экономической целесообразности производства корпусных деталей в гибком автоматизированном производстве (ГАП) без необходимости разработки технологических процессов их обработки. Обосновано, что целесообразность обработки деталей определяется на основе ее технологической сложности. Обработка детали в ГАП является обоснованной в случае, когда ее технологическая сложность не меньше предельной технологической сложности, определенной для производственной системы.***

***Ключевые слова:*** *рентабельность производства деталей, гибкое автоматизированное производство, технологическая сложность детали.*

**1. Introduction.** The present market requirements, manifested e.g. in individualisation of customer requirements and growing pressure of cost and quality competition on the global scale, create a situation where for a company to develop or sometimes even to survive at a market it must possess the capability of effective manufacturing of its products in small production batches at minimal production costs. Thus,

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

the manufacturing equipment used in the production process must be characterised by high efficiency on the one hand, and by a high level of adaptability to variable production tasks. The means of production should, therefore, be characterised by high levels of automation, flexibility and — at the same time — of economic effectiveness. Those conditions are met by flexible manufacturing systems (FMS) (ESP) [4, 5, 11, 14, 16].

The production of parts in FMS should be economically profitable. Therefore, an important problem is the development of a methodology of qualification of the parts for production in FMS so as to ensure economic profitability of the system operation [12, 15].

The economic feasibility of machining of parts in a flexible manufacturing system (FMS) can be determined:

- in the case of a range of the parts for the machining of which the FMS will be designed and constructed,
- for an actual (existing) system.

We must also consider that either:

- the parts have been manufactured earlier — then the technology developed for the FMS can be compared with the previous processes as a reference [1, 3, 9, 10, 13, 15],
- the parts will be introduced into production for the first time.

To determine the economic feasibility of machining of a part in a system, it is necessary to develop the technological process of its production. The development of such a process is labour-consuming and costly, and at this stage it is still not known whether the part will be produced in the system (whether the technological process will be utilised). The study demonstrated that the feasibility of machining of a part in a flexible manufacturing system can be determined on the basis of its technological complexity, without the need of technological process.

**2. Determination of feasibility of machining of parts in a FMS based on their technological complexity (without designing a technological process).** The feasibility of machining of parts can be determined on the basis of their technological complexity (Z), taking into account the functional relationship between the cost and time of machining and the technological complexity, production program and the size of the batch [2, 6, 7]. The technological complexity of a part is the degree of complexity involved in achieving the desired shape, dimensions, surface roughness and mutual positioning of surfaces of the part in accordance with the adopted technical requirements of machining the part on the available technological means.

The technological complexity of a part comprises: shape and geometrical dimensions, the accuracy of machining and mutual positioning of features, roughness and the distribution of machined surfaces on the shape of a part.

Analysis of methods for the determination of the complexity of parts, applied in their selection for machining on CNC machine tools that can be adapted for FMS conditions, revealed that each of the methods emphasises different elements of complexity [6]. Increments of complexity are not uniform for various methods, so basing on them it is not possible to determine the applicability of a part for production in a FMS. Therefore, it was necessary to develop a new method. The essence of the method consists in the technological complexity of the technological elements and of the part as a whole being determined on the basis of the time of performance [6]. In the case of the parts with a known production program and batch size there is a known threshold technological complexity ($Z_{gr}$) — after achieving of which the machining of the parts in a FMS will be economically feasible. The threshold technological complexity is the complexity of the parts machined in a system, for which at a given volume of production program and production batch size their production in the system becomes economically feasible. This means that at a technological complexity of a part being equal to the threshold technological complexity the cost of producing the part in a FMS ($K_{ESP}$) is equal to the cost of its production on conventional machine tools ($K_{OK}$): $K_{ESP}=K_{OK}$.

Therefore, the threshold technological complexity of a part determines the threshold or economic feasibility of its production in a flexible manufacturing system.

To determine the threshold technological complexity of the parts machined in a given FMS it is necessary to determine the unit cost of machining, for various production batch sizes, in the system and in the case of the base variant. The results obtained permit the identification of the functional relationship between the cost and time of production and the technological complexity, batch size and production program. A part for which the technological complexity Z is greater than $Z_{gr}$ meets the conditions for machining in FMS (the machining of the part will be efficient) — Fig. 1. The threshold technological complexity should be determined for a specific FMS and a representative group of parts so that the obtained result could be applicable to a whole set of parts of a given class, machined in the system.

**3. Determination of rational scope of application of FMS.** The best will be such a process of machining through which the maximum effect will be achieved ($K_{min}$ — minimum cost of machining, $T_{min}$ — minimum time of machining).

The cost and time of machining are functions of input variables: *RO* — group of machine tools applied in the process, *Z* — technological complexity of the parts machined, *P* — production program, *N* — batch size, *O* — environment (current organisation, economic and technical conditions) — Fig. 2:

$$K = f(RO, Z, P, N, O), \qquad (1)$$

$$T = f(RO, Z, P, N, O). \qquad (2)$$

Practice shows that only in rare cases the output parameters *K* and *T* can simultaneously assume levels of importance corresponding to the maximum effect. The usual situation is such that the levels of importance of variables (*RO, Z, P, N, O*) at which the most satisfactory values of one output variable are achieved do not permit the same for the other. In such cases the maximum effect is achieved at compromise levels of importance of the input variables.

Parameters *RO* and *O* are quality parameters: they are discrete values and therefore the functions shown above, in the case of the analysed set of parts ($ZO_n$) and set of machine tools ($RO_m$), are defined by the set of their possible realisations.

In the case of a batch of the parts, the most advantageous will be the process realised on machine tool group $RO_i = b$, permitting the achievement of the best results:

$$K_{i\neq b} - K_{i=b} = \Delta K > 0, \quad (3)$$

$$T_{i\neq b} - T_{i=b} = \Delta T > 0. \quad (4)$$

At the same time the process should proceed at such levels of importance of *Z, P, N* that:

$$K_{i=b} \rightarrow (K_{i=b})_{\min}, T_{i=b} \rightarrow (T_{i=b})_{\min}$$

Parameters (*Z, P, N*), meeting the conditions (3), (4), determine the rational scope of application of the selected group of machine tools.

Functions (3), (4) should be constructed on the basis of industrial data of a specific company, as in the case of different manufacturers even similar organisation, economic and technical data *(O)* do not provide the grounds for the claim that the production results achieved will be similar.

The determination of the rational scope of application of machine tools that are mutually exchangeable technologically in the analysed manufacturing system and in the base production consists in the analysis of a set of the parts that fulfil the relations (5), (6).

$$\Delta K = K_{baz} - K_{ESP} > 0, \quad (5)$$

$$\Delta T = T_{baz} - T_{ESP} > 0. \quad (6)$$

Parameters (*Z, P, N*), for which the condition $\Delta K > 0$ and $\Delta T > 0$ is fulfilled, define the rational scope of application of FMS. As an example, for a machining system composed of two machining centres type C2H, the rational scope of application of the system in the production of casing-type parts of various complexity, batch size and production program was determined graphically: Fig. 3 — with relation to the cost of machining of parts, Fig. 4 — with relation to the labour requirements of machining, and Fig. 5 — the full rational scope of application of the FMS (common area relates to cost and labour requirements of machining).

The flexible manufacturing system should be applied to produce the parts with complexity, production program and batch size below the threshold surface shown in the diagrams, separating the areas of economic feasibility of machining in FMS and on conventional machine tools.

In Fig. 5 one can see that:

- machining of small batches of the parts with low technological complexity in FMS is cost effective only in the case of a large production program,

- the parts with high technological complexity can be cost effectively machined in FMS even at a small production program.

**4. Conclusions.**

1. Determination of technological complexity of the parts in accordance with the developed methodology permits the definition of rational, with relation to the cost of production, scope of application of an existing FMS.

2. On the basis of the determined threshold technological complexity Z, based on the rational scope of application of a designed FMS, we can determine at what batch sizes and production program the machining will be cost effective.

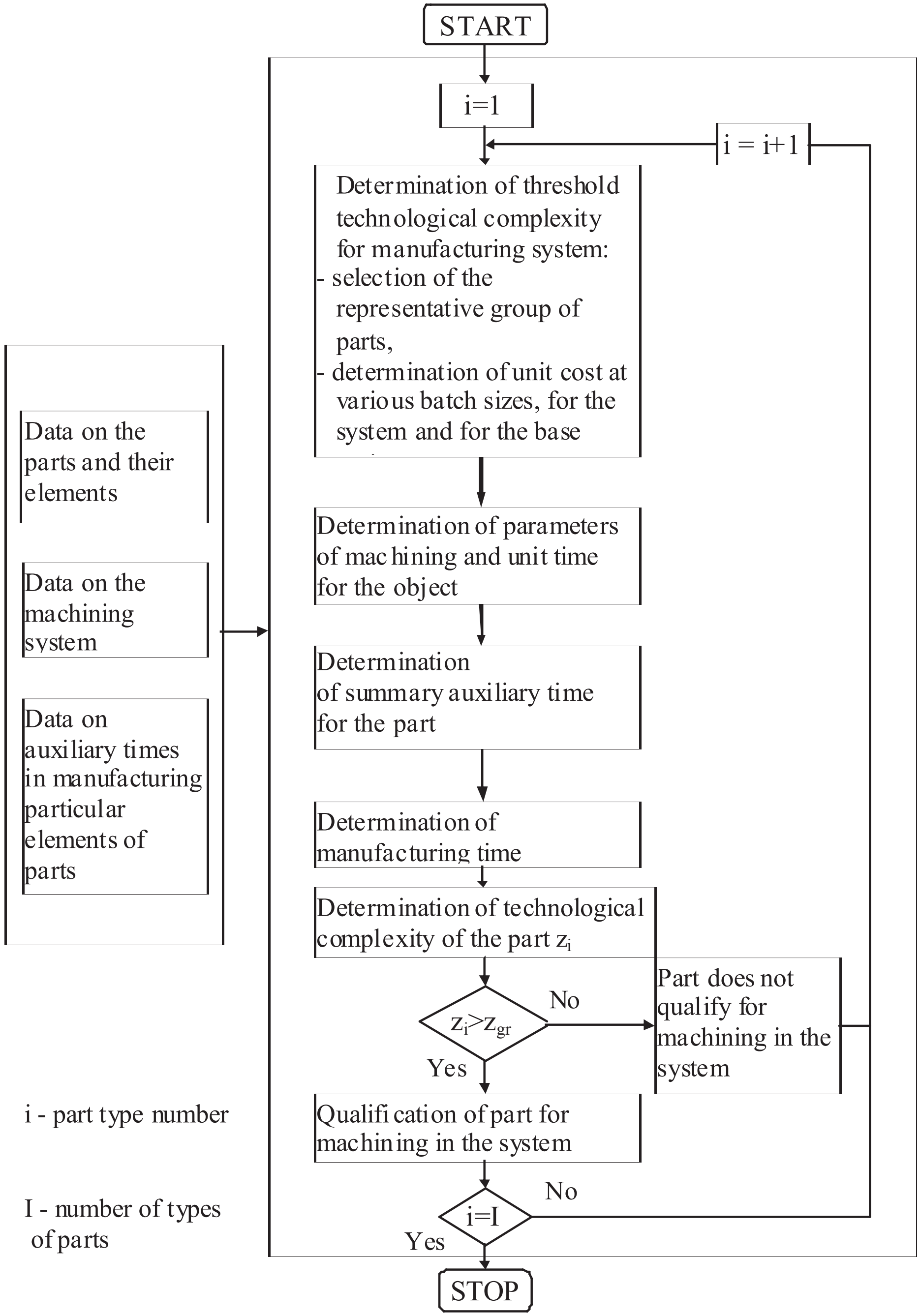


*Figure1.* **Algorithm of determination of feasibility of part machining in a system**

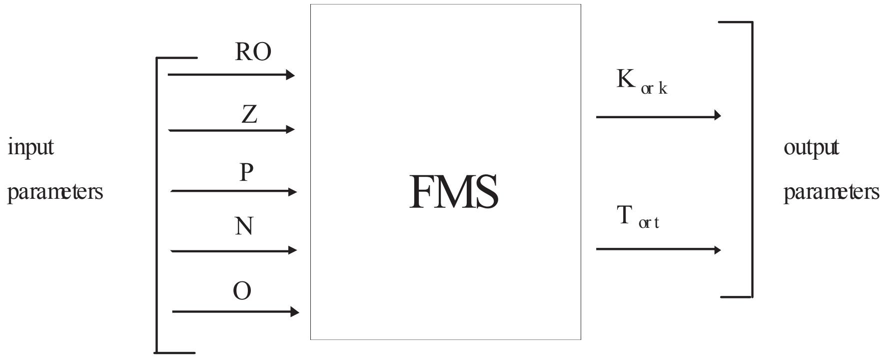


*Figure 2.* **Model of the process of machining of the parts in FMS: *k* — unit cost of part machining spent on processing of a unit of information, *t* — unit time of machining necessary for processing of a unit of information**

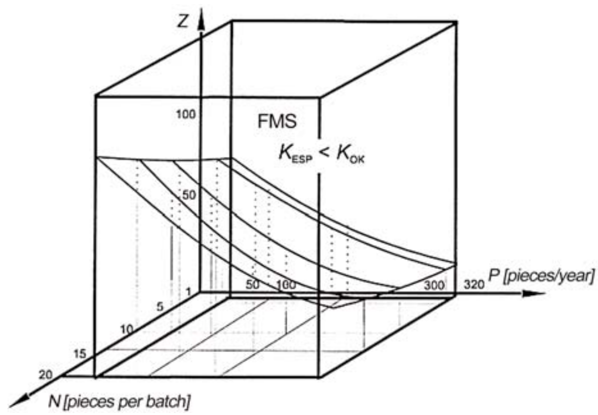


*Figure 3.* **Graphical interpretation of the area of application of FMS and conventional machine tools (OK) with relation to cost of machining of the parts**

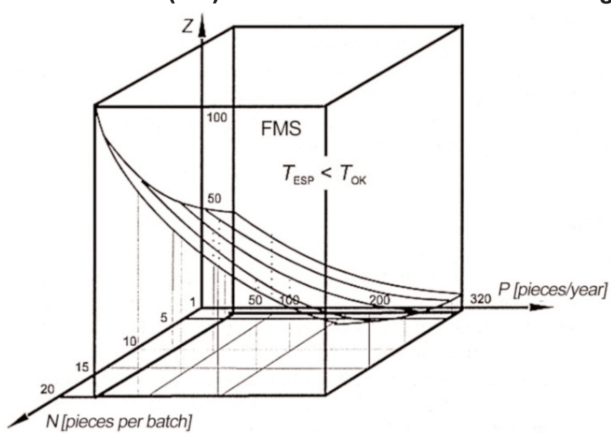


*Figure 4.* **Graphical interpretation of the area of application of FMS and conventional machine tools (OK) with relation to labour requirements of machining of the parts**

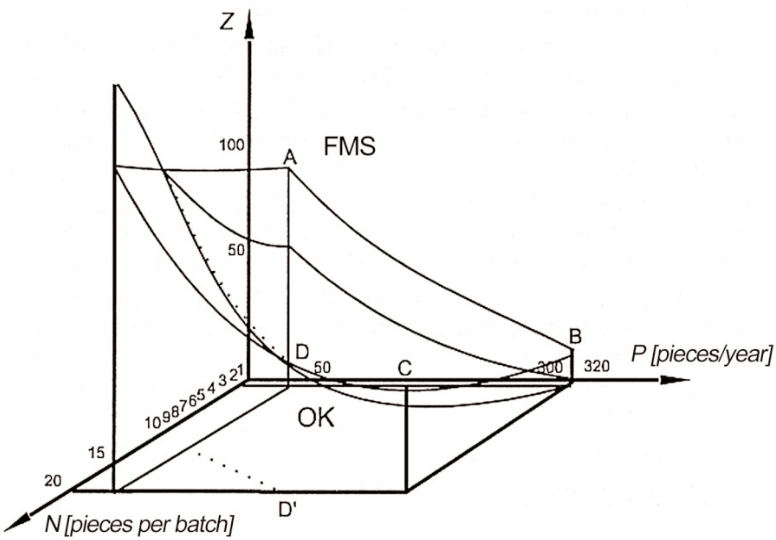


*Figure 5.* **Graphical interpretation of the rational area of application of FMS and conventional machine tools (OK)**

3. The developed method of determination of the technological complexity of the parts permits the identification of the applicability of the parts for machining in an existing FMS without the need to develop the technological process (the technological complexity is determined and compared with the threshold technological complexity determined for the manufacturing system. The method, though simple, permits the obtainment of sufficiently accurate results as it takes into account a greater number of factors determining the technological complexity of the parts.

4. The efficiency of operation of a flexible manufacturing system largely depends on suitable choice of the parts to be machined. The qualification of the parts to be machined should be conducted on the basis of the threshold technological complexity on their machining in the system.

5. The results of the study will be useful in:

- determination of feasibility of designing and constructing a flexible manufacturing system planned for the production of a specific assortment of the parts,
- determination of feasibility of machining parts in a system already in operation,
- determination of cost effectiveness of transferring production of the parts from conventional machine tools to a FMS.

6. The developed method for determination of technological complexity of parts and of cost effectiveness of production of the parts can be applied not only in relation to flexible manufacturing systems but also to various kinds of convertible production systems extensively used in industry.

**References:**


*Bednarek, M., Borowski, J., Dworczak, M., Was, A.* (1985). CNC machine tools. Fundamentals of operation (in Polish). Podstawy eksploatacji. Warszawa, WNT.

*Gola, A., Swic, A.* (2011). Computer-aided machine tool selection for focused flexibility manufacturing systems using economical criteria. Actual Problems of Economics, 10 (124), pp. 383-369.

*Харченко, А. О.* (2004). Станки с ЧПУ и оборудование гибких производственных систем, Видавничий дім ПРОФЕСІОНАЛ, Киев.

*Kanada, J. R., Sullivan, W.G.* (1989). Economic and Multiattribute Evolution of Advanced Manufacturing Systems Englewood Cliffs. New Jersey, Prentice Hall.

*Mishra, S., Prakash, Tiwari M.K., Lashkari R.S.* (2006). A Fuzzy Goal-Programming Model of Machine-Tool Selection and Operation Allocation Problem in FMS: A Quick Converging Simulated Annealing-Based Approach, International Journal of Production Research, Vol. 44, No. 1, pp. 43-76.

*Swic, A., Lenik, K., Zajac, S.* (1996). Economic analysis of the process of machining of casings in a flexible manufacturing system (FMS) (in Polish), Mechanika. Kwartalnik Akademii Gorniczo-Hutniczej im. Stanislawa Staszica w Krakowie, T. 15, z. 1, s. 43-48.

*Swic, A., Mazurek, L.* (2011). Modeling the reliability and efficiency of flexible synchronous production line. Eksploatacja i Niezawodnosc - Maintenance and Reliability, 4 (52), pp. 41-48.

*Swic, A., Taranenko, W.* (2012). Adaptive control of machining accuracy of axial-symmetrical low-rigidity parts in elastic-deformable state. Eksploatacja I Niezawodnosc - Maintenance and Reliability; 14 (3): 216-222.

*Swic, A., Taranenko, W., Szabelski, J.* (2011). Modelling dynamic systems of low-rigid shaft grinding. Eksploatacja i Niezawodnosc - Maintenance and Reliability, 2 (50), pp. 13-24.

*Taranenko, G., Taranenko, W., Swic, A., Szabelski, J.* (2010). Modelling of dynamic systems of low-rigidity shaft machining, Eksploatacja i Niezawodnosc - Maintenance and Reliability, 2010, nr 4, pp. 4-15.

*Terkaj, W., Tolio, T., Valente, A.* (2008). Focused flexibility in production systems [in:] ElMaraghy H. (ed.), Changeable and reconfigurable manufacturing systems, Springer, New York.

*Tolio, T.* (ed.) (2009). Design of Flexible Production Systems. Methodologies and Tools, Springer-Verlag, Berlin Heidelberg 2009.

*Tolio, T., Valente, A.* (2006). An approach to design the flexibility degree in flexible manufacturing system. Proceedings of flexible automation & intelligent manufacturing conference, Limerick, Ireland, June 25-27, pp. 1229-1236.

*Wang, T. Y., Shaw, C. F., Chen, Y. L.* (2000). Machine Selection in Flexible Manufacturing Cell: a Fuzzy Multiple Attribute Decision Making Approach. International Journal of Production Research, Vol. 38, No. 9, pp. 2079-2097.

*Wiendahl, H.P., ElMaraghy, H.A., Nyhuis, P., Zah, M.F., Wiendahl, H.H., Duffie, N., Brieke, M.* (2007). Changeable manufacturing - classification, design and operation, Ann CIRP 56, No. 2, pp. 783-809.

*Zawadzka, L.* (2007). Contemporary problems and directions of development of flexible manufacturing systems (in Polish). Gdansk,Wyd. Politechniki Gdanskiej.

Стаття надійшла до редакції 02.08.2012.