Evaluation of the technological effects of application of the FMS elements

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Abstract. Flexible manufacturing systems (FMS) represent complex systems with great technological capabilities that are able to simultaneously achieve high level of flexibility, cost effectiveness and productivity. However, due to high investment cost and cost of exploitation of the FMS elements, the conditions for their rational use are required. Taking into account the increasingly complex conditions of production and launch of products, a systematic approach in the planning and implementation of FMSs is needed, thereby including the most significant technological and economical characteristics. This paper introduces two methodologies for evaluating the technological effects of application of the FMS elements at the conceptual level along with their verification for a single family of rotational parts.

1. Introduction

Flexible manufacturing systems (FMS) represent the basis for production systems enabling them to simultaneously achieve a high level of flexibility, cost effectiveness and productivity [1], [2]. The basic units of FMSs are CNC machine tools, especially at today's level when they are multifunctional and can integrate various machining processes (turning, milling, grinding) and various manufacturing technologies (cutting, heat treatment). By interconnecting machine tools with manipulation, measurement and transportation systems as well as their computer numerical control, FMSs of a different level of complexity, productivity and flexibility are created, figure 1 [3].

In modern industrial production there are several levels of complexity of flexible manufacturing systems: Flexible Manufacturing Modules (FMM), Flexible Manufacturing Cells (FMC), Flexible Manufacturing Groups (FMG), Flexible Manufacturing/Transfer Lines (FML) and as the most complex which include all the previous-Flexible Manufacturing Systems (FMSs) [4], [5].

FMSs are designed to manufacture one or more product families whose development and implementation are based on the principles of group technology [1], [4]. By applying the concept of group technology it is possible to set the necessary bases for defining and evaluating the effects of the application of the FMS elements that will be applied in manufacturing processes of an appropriate product range or product families. These bases can be set as a result of a required analysis of all parts from the observed production program, or perhaps as a result of an appropriate analysis of representatives from a product group [6].
This paper introduces two methodologies for evaluating the technological effects of application of the FMS elements for the example of a formed technological group of rotational-symmetric parts.

Figure 1. Productivity and flexibility of FMSs of different levels of complexity [3]

2. Theoretical bases of methodologies
The proposed methodologies for evaluating the effects of application of the FMSs elements consist of the following phases:

- Analysis of a production program, classification of parts and formation of part groups (families);
- Design or selection of complex parts (representatives of part families);
- Process planning for group of parts (GT process plans are designed);
- Precision of process plans for selected products and determination of manufacturing times;
- Evaluation of technological effects of the application of FMS elements.

Starting from the principle of product classification and grouping, a product range of a production system can be systematized according to the design and technological similarity among certain part families for which the concept of group technology is rationally applied. On the basis of group technology established by Mitrofanov and implemented by Burbidge, a group approach to planning of effective production and its structures has been developed.

GT Process planning enables easy and rapid precision of process plans for individual parts of a single group. This is achieved in the following way [6]:

1. Specification of process plans for all parts is done in the case of the detailed/final planning of FMSs, thus providing detailed techno economic data (time, costs, degree of utilization, etc.).
2. Specification of process plans for representatives of an appropriate product group is done in the case of the conceptual/preliminary planning of FMSs, thus providing approximate techno economic data, whose accuracy depends on the methodology that is being applied.

In order to achieve more rational and faster determination of manufacturing time of a single part group within the conceptual planning, it is necessary to specify manufacturing operations for an appropriate representative on the basis of the adopted method. These methods are used for determining processing time (tₚ) and setup time (Tₛₚ) of operations of the considered technological groups. They are used in practice as analytical or graphical methods. As far as this study is concerned, these two methods will be considered:

- Similarity method (graphical and/or analytical);
- Method based on part representatives of technological groups (analytical).

Both methods enable approximate time determination with good reliability which in production practice provides a good basis for determining the level of complexity, the number of elements of machining systems and the degree of their utilization. The following chapter shows the application of
the observed methods used for evaluating the effects of application of the FMS elements for the case of turning process of the specified part group.

3. Evaluation of the effects of application of the FMS elements

3.1. Process planning for group of parts
By analyzing the production program of a single production system, the technological group of rotational parts was formed using the design-technological classification system. One of the observed groups is a group of axles whose main information is given in table 1.

| Part designation | Quantity [pcs/batch] | Mass [kg] | Price [€/pcs] |
|------------------|----------------------|-----------|--------------|
| P1               | 708 033              | 320       | 0,126        | 15.000       |
| P2               | 708 038              | 300       | 0,134        | 15.400       |
| P3               | 708 041              | 280       | 0,109        | 14.200       |
| P4               | 708 046              | 400       | 0,109        | 14.200       |
| P5               | 708 047              | 350       | 0,109        | 14.200       |
| P6               | 708 169              | 260       | 0,133        | 15.400       |
| P7               | 708 170              | 340       | 0,133        | 15.400       |
| P8               | 708 181              | 360       | 0,149        | 15.700       |

Figure 2. 3D model of the complex part

Table 2. Content of the GT Process plan

| Process No. | Process designation           | Machine type /workplace            |
|-------------|--------------------------------|------------------------------------|
| 10          | Cut-off                        | Metalsaw                           |
| 20/1        | Turning left side              | CNC Turning machine                |
| 20/2        | Turning right side             |                                    |
| 30          | Control                        | Control place                      |
| 40          | Milling                        | CNC milling machine                |
| 50          | Dressing                       | Work place                         |
| 60          | Annealing                      | Heat Treatment Furnace             |
| 70          | Heat treatment control         | Hardness testing device            |
| 80          | Grinding central nests         | CNC Grinding machine               |
| 90          | Grinding holes                 | CNC Grinding machine               |
| 100         | Grinding outside               | CNC Grinding machine               |
| 110         | Final control                  | Control place                      |
Based on the geometric and technological characteristics of these parts, the imaginary complex part with all the corresponding features is designed, figure 2. Based on the designed 3D model/2D drawing of the complex part, production quantity, available resources and other necessary data, a GT process plan is planned. Content of the GT process plan is given in table 2.

3.2. Application methods

3.2.1. Similarity method. In order to determine processing time of the observed part group, it is necessary to point out the technologically simplest and the most complex part of this group as well as to specify the GT processes (or just manufacturing operations) for them. As a criterion for selecting the simplest and most complex part of the group, the degree of technological complexity is usually applied, that is, the number of operations in the observed process. The total processing time \( t_k \) for realization of machining process of the part group is determined on the basis of the following expression:

\[
t_k = \sum_{i=1}^{k} (Q_i t_{ki})
\]

in which:
- \( k \) - number of different parts in the group;
- \( Q_i \) - quantity of individual parts of the group;
- \( t_{ki} \) - processing time for certain parts of the group.

Processing times \( t_k \) for machining processes include machining \( t_g \) and auxiliary times \( t_p \), and they are determined from the similarity diagram. In this example, the diagram showing processing times of the turning process for the group of axles performed on the CNC turning machine is shown in figure 3. The diagram shows dependency between the processing time and the number of operations where the simplest part have 23 operations and processing time of 3.1 minutes per piece, while the most complex part has 30 operations and processing time of 4.5 minutes per piece. Processing times of turning process for the specific parts of the technological group can be determined graphically using the diagram in figure 3 or analytically with the predetermined path coefficient which describes the change in processing time \( t_k \) depending on the number of operations \( z \).

**Figure 3.** Dependency between the processing time and the number of operations for the turning process
According to figure 3, the path coefficient (k) is determined in the following way:

\[
k = \frac{t_{\text{max}} - t_{\text{min}}}{z_{\text{max}} - z_{\text{min}}} = \frac{4.5 - 3.1}{30 - 23} = 0.2
\] (2)

As an example, we show the procedure for determining processing time for the part P4 with designation “708 046” which in this process (no. 20) has 29 operations:

\[
t_{\text{kp}} = t_{k} + k \cdot (z_{4} - z_{3}) = 3.1 + 0.2 \cdot (29 - 23) = 4.3
\] (3)

3.2.2. Method based on representatives of part groups. The application of this method begins with selecting a part representative based on the ABC analysis which determines the dependency between the type of part and the corresponding quantities, masses, values, profit etc. Then, it specifies machining processes based on the appropriate GT process plans, including the determination of processing times of these representatives (t_{kp}). Based on table 3, a quantitative, mass and value ABC analysis is performed on the basis of which the part P8 (708181) is selected as a product representative of the group of axles. As an example, figure 4 illustrates the diagram of value ABC analysis.

**Table 3.** Data for ABC analysis

| Part       | Q_i [pcs/yr] | m_i [kg/yr] | V_i [€*103/yr] | Q [%] | m [%] | V [%] |
|------------|--------------|-------------|----------------|-------|-------|-------|
| 708 033    | 3200         | 403.2       | 48000          | 12.26 | 12.36 | 12.33 |
| 708 038    | 3000         | 402         | 46200          | 11.49 | 12.32 | 11.87 |
| 708 041    | 2800         | 305.2       | 39760          | 10.73 | 9.36  | 10.21 |
| 708 046    | 4000         | 436         | 56800          | 15.33 | 13.36 | 14.59 |
| 708 047    | 3500         | 381.5       | 49700          | 13.41 | 11.69 | 12.76 |
| 708 169    | 2600         | 345.8       | 40040          | 9.96  | 10.60 | 10.28 |
| 708 170    | 3400         | 452.2       | 52360          | 13.03 | 13.86 | 13.45 |
| 708 181    | 3600         | 536.4       | 56520          | 13.79 | 16.44 | 14.52 |
| Σ          | 2610         | 3262.3      | 389380         | 100%  | 100%  | 100%  |

**Figure 4.** Value-based ABC analysis
In order to determine the processing time of the observed technological group for the process no. 20, a reduced quantity of the group \( Q_r \) is determined, according to the expression (4):

\[
Q_i = Q_i \cdot r_i \tag{4}
\]

in which: \( Q_i \) - quantity of individual parts of the group; 
\( r_i \) - degree of reduction of the i-th part.

The degree of reduction of a specific part of the observed group includes reduction for mass \( (r_m) \) and complexity \( (r_s) \), which can be expressed by (5):

\[
r_i = r_m \cdot r_s \tag{5}
\]

The degree of reduction for mass and technological complexity is determined respectively according to this expression (6):

\[
r_m = \frac{m_i}{m_p}, \quad r_s = \frac{s_i}{s_p} \tag{6}
\]

in which: \( m_i \) - mass of individual parts; 
\( s_i \) - degree of technological complexity of parts; 
\( m_p \) - mass of the representative of the part group; 
\( s_p \) - degree of complexity of the representative.

The degree of technological complexity of specific parts of the group is determined by the ratio between the number of operations of individual parts and the number of operations of the corresponding representative. The reduced quantity of all parts of the group is determined by the expression (7) and given in table 4:

\[
Q_r = \sum_{i=1}^{k} Q_i = \sum_{i=1}^{k} Q_i \tag{7}
\]

### Table 4. Reduced quantity of the axle group

| No | \( Q_i \) [pcs/yr] | \( m_i \) [kg/pcs] | \( s_i \) | \( r_m \) | \( r_s \) | \( r_i \) | \( Q_r \) |
|----|------------------|------------------|-----|-------|-------|-------|--------|
| P1 | 3200             | 0.126            | 23  | 0.846 | 0.821 | 0.695 | 2223   |
| P2 | 3000             | 0.134            | 24  | 0.899 | 0.857 | 0.771 | 2313   |
| P3 | 2800             | 0.109            | 30  | 0.732 | 1.071 | 0.784 | 2195   |
| P4 | 4000             | 0.109            | 29  | 0.732 | 1.036 | 0.758 | 3031   |
| P5 | 3500             | 0.109            | 28  | 0.732 | 1.000 | 0.732 | 2560   |
| P6 | 2600             | 0.133            | 26  | 0.893 | 0.929 | 0.829 | 2155   |
| P7 | 3400             | 0.133            | 26  | 0.893 | 0.929 | 0.829 | 2818   |
| P8 | 3600             | 0.149            | 28  | 1.000 | 1.000 | 1.000 | 3600   |
|    | REDUCED QUANTITY |                  |     |       |       |       | \( Q_r = 20894 \) |

The total processing time of the observed group when machining on CNC turning machine is:

\[
T_c = Q_r \cdot t_w = 20894 \cdot 4.1 = 85665.4 \text{ [min/yr]} \tag{8}
\]
If we assume that the planned production quantity of some product is $Q_i$, then the total workload of machine/workplace in a specific machining process of creating this product in the specified time period is determined by the expression (9):

$$T_i = Q_i \cdot t_{\text{u}_i} + Q_i \cdot \frac{T_{pz}}{z_s} = Q_i \cdot t_{\text{u}_i} + n_s \cdot T_{pz} \, \text{[min/yr]}$$

(9)

where:
- $T_i$ - total processing time;
- $T_{pz}$ - setup time for batch of parts;
- $z_s$ - number of parts within the batch;
- $n_s$ - number of batch in time period.

If it is assumed that the observed facility will work for $m_e = 250$ days per year in $s_e = 2$ shifts per day with $n_e = 7.5$ hours per shift and efficiency of $\eta_e = 0.8$, what follows is that the effective work capacity of machine/workplace equals $K_e = 180000$ minutes per year.

Based on the previously calculated processing time, assuming that $n_s = 10$ batch per year, the required number and degree of machine utilization for the observed turning process is:

$$T = 85665.4 + 10 \cdot 30 = 85965.4 \, \text{[min/yr]}$$

(10)

$$N = \frac{T}{K_e} = \frac{85965.4}{180000} = 0.4776$$

(11)

$$\eta = \frac{0.4776}{1} = 47.76\%$$

(12)

If it is assumed that operators work for $m_e = 250$ days per year in $s_e = 1$ shift per day with $n_e = 7.5$ hours per shift and efficiency of $\eta_e = 0.8$, it follows that $K_e$ equals 90000 minutes per year:

$$N = \frac{T}{K_e} = \frac{85965.4}{90000} = 0.9552$$

(13)

$$\eta = \frac{0.9552}{1} = 95.52\%$$

(14)

4. Conclusions

The main objective of this paper was to present two rational methodologies for evaluating the technological effects of application of the FMS elements at the conceptual level.

The paper shows that by classifying and grouping of parts, and then by designing the content of GT process plans and corresponding group operations on the basis of complex parts, good bases for selecting types and levels of complexity of the FMS elements for individual group operations may be created. It was shown that by specifying GT process plans for the selected products–part representatives, quality technological bases for evaluating the effects of application of the FMS at the conceptual level can be generated. It can be achieved through the calculation of the number and degree of utilization of the elements of the FMS.

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References

[1] Radharamanan R 1994 *Group technology concepts as applied to flexible manufacturing systems*

International Journal of Production Economics Vol. 33 ISSN 0925-5273 pp.133-142
[2] Zäh M F, Beetz M et al. 2009 *The cognitive factory* H.A. ElMaraghy (ed.) Changeable and Reconfigurable Manufacturing Systems ISBN 978-1-84882-067-8 pp.355-371

[3] Gania I P, Stachowiak A, Oleśków-Szlapka J 2017 Flexible Manufacturing Systems: Industry 4.0 Solution Proceedings of 24th International Conference on Production Research (ICPR 2017) Poznan (30.7.-3.8.2017) pp.57-62

[4] Shivanand H K, Benal M M, Koti V 2006 *Flexible Manufacturing System* ISBN 978-8122418705 pp.22-4

[5] Satya S C, Douglas NH 2008 *The evolution of manufacturing cells. An action research study* European Journal of Operational Research Vol. 188 ISSN 0377-2217 pp.153-168

[6] Todić V, Zeljković M, Tepić J, Milošević M, Lukić D 2012 Techno-Economic Method for Evaluation and Selection of Flexible Manufacturing Systems Metalurgija Vol. 51 No. 3 ISSN 0543-5846 pp.349-353