Development of a formalized system for analyzing the technological design of products in mechanical engineering

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Abstract. This article discusses a typical production structure, describes the theory and terminology. The article also presents theoretical information on presentation of data, knowledge and types of knowledge, data formalization and describes the concept of formalization. The problem of automating the assessment of manufacturability of the product design using modern information technologies and data analysis was discussed. An algorithm for typical formalization of information used in the analysis of manufacturability was developed, and an example of its used for an electronic part model was provided.

1. Introduction
Nowadays, technology goes ahead by leaps and bounds. Computers and production equipment have become commonplace in the production cycles. With the use of automated equipment, electronic models of the product, production quality and output of the product can increase, and production costs can decrease. However, in reality, the situation is much more complicated.

In the manufacture of any product, the abbreviation TP is used.

According to GOST 3.1109-82: “The technological process is part of the production process that contains actions aimed to change and (or) determine the state of the labor subject” [9].

The technological process can be described as follows: you need to convert input data into output data. “Input data” can be very diverse (Figure 1).

| INPUT DATA          | OUTPUT DATA                |
|---------------------|----------------------------|
| Geometry            | New geometry               |
| Technological       | Thermally treated material |
| requirements        | Sub-assembling             |
| Type of a product   | Improved production cost   |
| Type of a material  | Product                    |
| Assembling unit     |                            |
| Node                |                            |
| Aggregate           |                            |
| Price               |                            |
| Production cost     |                            |

Figure 1. The process structure.
An ordered sequence of interrelated actions” is a method for converting input data into output data. Such actions are called “technological operations”.

GOST 3.1109-82 states: “a technological operation is a completed technological process carried out at one workplace” [9].

When designing the TP, an important parameter of the product is manufacturability, because the higher the manufacturability of the product, the less maintenance operations should be performed in the TP. Therefore, there will be less resources to perform the TP and wages for employees. The cycle schedule can be reduced and the output can be increased which will decrease the cost of the product.

Therefore, in the technological preparation of production (TPP) for the manufacture of a new product, manufacturability of the product design is used.

2. Materials and Methods
According to GOST 14.205-83: “Manufacturability of product design (MPD) is considered as a set of product design properties that determine its adaptability to achieve optimal costs in the production, operation and repair for specified quality indicators, output volume and work execution conditions” [8, 14].

Traditionally, the product is assessed by analyzing and comparing certain indicators according to GOST 14.201 (the complexity of manufacturing the product; specific material consumption of the product; technological cost, etc.).

This method has several disadvantages:
- the human factor;
- time for the analysis of MPD increases, which affects the period of technological preparation;
- need for specialists with extensive experience, which increases the analysis cost.

Therefore, this traditional method is outdated for automated production, in which the main role belongs to computers.

It should be noted that when using computers and CNC machines, certain CAD programs are used. They are designed for the final design stages (design of technological documentation, analysis of rationality of decisions made, selection of equipment). The technologists make decisions.

In order for the MPD assessment to be carried out, an electronic model of the product and a list of significant parameters are required. These parameters must be formalized [14].

Since there is a huge amount of knowledge, it is also necessary to formalize it.

A large number of models (languages) of knowledge representation have been developed, their visual classification is presented in Figure 2.
For a certain type of production, it is necessary to analyze all the data and knowledge that is necessary to analyze the MPD and determine which model of knowledge representation to use in the knowledge base.

For the automated analysis, a simplified information formalization scheme for analyzing the manufacturability of a product’s design in machine-building production is shown in Figure 3. The database stores data that is necessary to perform a MPD analysis for a specific type of products; in the knowledge base, depending on the chosen model of knowledge representation, certain types of knowledge are stored.

**Figure 3.** Typical information formalization scheme for the analysis of TCI.

3. Results and Discussion
Consider two examples of “significant parameters” for the TCI analysis using the beam (Figure 4).

**Figure 4.** Aviation part "Beam".

A hole of the beam hinge can be used as a parameter. It is responsible and has an accuracy class (Figure 5). We also take a radius transition, since smooth transition occurs from the contour of the part to the theoretical contour of the aircraft (Figure 6).
Based on the data of the electronic model, we analyze what is the output data. The results are presented in Table 1.

**Table 1.** Significant parameters of the structural elements.

| No. | Structural element | Significant parameter of the structural element | Tool / equipment for implementation |
|-----|--------------------|-----------------------------------------------|------------------------------------|
| 1   | Hole 17H8          | Constructive electronic layout.               | A tool with numerical control.     |
|     |                    | Coordinates of the hole center               | Roughing cutter for making holes   |
|     |                    | Hole geometry                                 | with a diameter of 10H9 for cutting|
|     |                    | Work piece material                            | Semi-finishing and finishing      |
|     |                    | Theoretical electronic layout                 | cutter for making final holes     |
|     |                    | Constructive electronic layout.               |                                    |
|     |                    | Rounding geometry                              |                                    |
|     | Radius transition  | Coordinates of the rounding center            | Machine with numerical control.   |
|     |                    | Surface roughness                             | Rough cutter.                      |
|     |                    |                                                | Semi-rough cutter for performing   |
|     |                    |                                                | roughness Ra 3.2.                  |
“Significant parameters”, i.e., structural elements of the part presented in the table determine the geometric and technological properties of the product.

The authors defined CE as a parameterizing element of the product design form with a generic name as part of the adopted classifier, formed taking into account the composition of features that are essential for the designer” [6].

The frame system can be used for evaluating the MPD. It is based on the minimum structural elements of the product. “The advantage of the frame system is that slot values are represented in a single copy, because they are included in one frame that describes the most complete concept that contain a slot with this name. This property of frame systems provides economical location of the knowledge base in computer memory. Another advantage of frames is that the value of any slot can be calculated using appropriate procedures or found by heuristic methods. Frames allow you to manipulate both declarative and procedural knowledge” [6].

After identifying the significant parameters of all structural elements, we will represent them in the form of a frame.

The frame structure for performing the technological operation “hole” is presented in Table 2.

Table 2. The frame structure for the operation "hole"

| Slot name          | Slot value                      | Method to determine the value | Attached Procedure | Slot name          |
|--------------------|---------------------------------|------------------------------|--------------------|--------------------|
| Hole geometry      | Hole geometry coordinates       | Structural Electronic Model   | Electronic Model Parts | Hole geometry      |
| Hole Center        | Coordinates in two axis of the hole | Structural Electronic Model   | Hole geometry      | Hole Center        |
| Coordinates        |                                 |                              | Coordinates        | Coordinates        |

The frame structure for performing the technological operation "thickness transition" is presented in Table 3.

Table 3. Frame structure for the operation "thickness transition".

| Slot name                               | Slot value                        | Method to determine the value | Attached Procedure | Slot name                               |
|-----------------------------------------|-----------------------------------|------------------------------|--------------------|-----------------------------------------|
| Rounding geometry                       | Fillet Geometry Coordinates       | Structural Electronic Model   | Electronic Model Parts | Rounding geometry                       |
| Coordinate of the center of the fillet | Coordinate in 2 axes of the center of fillet | Structural Electronic Model   | Fillet geometry     | Coordinate of the center of the fillet radius | radius |

Some attributes are obtained from the parameters of another slot.

The final scheme for formalizing information of a MPD analysis is presented in Figure 7.

4. Conclusion

Using the 3D model of the part, a scheme for formalizing information was designed; data and knowledge were structured. In future, one can select all the FE details, due to which one can evaluate the MPD. For example, “the product will be analyzed as a part consisting of many structural elements: cylindrical, conical, curved surfaces of revolution, edges. Surfaces can be internal and external. The overlay elements are chamfers, flats, threads, additional holes, pockets, protrusions, coatings and heat treatment” [6].

The authors plan to develop an algorithm for recognizing typical structural elements using an electronic product model for the automated assessment of manufacturability of a product’s design, as well as to form a CE database.
The technologist, using the integrated software application, will be able to analyze the electronic model of the part, get information in the form of technological recommendations, and make a decision: which option is most preferable for this type of manufacturing of the part. This program can be useful for designers. They will know whether this design is technologically advanced for production [15].

Figure 7. The scheme of formalization of information for the MPD analysis.

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