Introducing a quality factor into the MES system when calculating machinery production schedule together with measuring equipment

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Abstract. The article is devoted to the inclusion of measuring equipment used to control the geometric parameters of a product after its production in the production schedule recalculation system. The factors that have a negative impact on the production process and subsequent product control are identified. It was revealed that drawing up a production schedule without using the MES system, if it is necessary to manufacture a certain number of products instead of rejected ones, is associated with a high risk. It is indicated that inclusion of measuring equipment and measuring operations in the MES system of the machinery leads to the production process optimization and reduction of the human factor influence. The coefficient characterizing the efficiency of recalculating the production schedule in the case of the inclusion of measuring equipment in the MES-system of the machine park is determined.

In the conditions of the modern world, modern industrial systems and engineering production are dynamically developing. Effective management of a machine-building enterprise now requires the adoption of drastic measures to increase its competitiveness [1]. This characterizes the key role of information in the functioning processes of an organization. In this regard, the use of various digitalization systems and automation of enterprise management is relevant. These include various products, such as digital twins of products and production, CAD/CAM/CAE systems, organization management automation systems, such as, for example, ERP (Enterprise Resource Planning) or MES (Manufacturing Execution System).

MES systems plan technological operations performed at specific workplaces. They also provide the ability to control the production volume by analyzing and optimizing loading of various types of equipment [2]. Since modern production is characterized by a large range of equipment and production volumes, it is not possible to efficiently calculate the optimum production schedule only by the capabilities of specialists. Using the data of the planning and control levels, MES manages current production activities in accordance with incoming orders, the requirements of design and technological documentation, the current state of equipment, while pursuing the goals of achieving maximum efficiency and minimum cost of production processes.

The main function of MES-systems is to compile an optimum production schedule or recalculate it in connection with the emerging need [3]. For this, a dynamic computer production model is built in MES systems. It implements continuous simulation of the movement of material flows within the organization in accordance with technological routes. Due to this, MES provides the opportunity not only to monitor the current production schedule at the production site, but also to simulate various
situations related to the failure of any equipment, delay of raw materials at the input of the technological process, or with other limiting criteria.

The production schedule is visualized in the MES system using the Gantt chart. A Gantt chart is a type of a bar chart that serves to visualize a work plan based on its duration. It is one of the project planning methods. In general, on one of the diagram axes, the performed work, processes, actions are measured, and the other axis is a timeline. Accordingly, each work, process is visualized by a strip (segment), whose length corresponds to the duration of the work or process. Usually, work of the first order of priority is plotted above, of the second order of priority - below, and so on, until final work or process. Thus, the Gantt chart visualizes any sequence of processes, including production schedule of an organization, in a convenient way for perception.

Basically, MES systems include machine tools [4]. However, an integral stage of the product life cycle at the enterprise is its control after manufacture. Often this control is to measure the geometric parameters of the product. At large enterprises, characterized by mass or large-scale production, one of the most common types of measuring equipment is a coordinate measuring machine. This equipment allows automated measurements of geometric parameters of complex products with a high degree of accuracy. With its help, you can track defective products, and get information about how many products need to be finalized or remade instead of the rejected ones. Thus, in the case of inclusion of measuring equipment in the MES system, it becomes possible to automatically recalculate production schedule based on information about defects received in an automated mode from a coordinate measuring machine. Also, it becomes possible to include the process of measuring geometric parameters into the calculation of production schedule, which enables you to optimize the time of the entire process. In addition, in case of failure of the coordinate measuring machine, the MES system will allow recalculating the production schedule considering the available operational measuring equipment [5].

The ‘cause-effect’ diagram (Figure 1) shows the factors that negatively affect the manufacturing process when manufacturing a product with the help of the MES system. In the considered example, measuring equipment is not included in the MES system.

The analysis of factors showed that, mainly, the human factor has a negative impact on the process, as well as the fact that measuring equipment is not included in the MES system. In order to assess how
these factors influence the production process operations, an FMEA analysis was carried out, a fragment of which is presented in Table 1.

In the above fragment, column A characterizes the probability of non-compliance, the severity of the consequences for the consumer is characterized by column B, and the probability of non-detection of non-compliance before the moment of its manifestation is characterized by column E on a scale from 1 to 10, where 1 corresponds to the lowest value of the characteristic, and 10 to the highest. RPZ = A*B*E - characterizes the risk factor of the operation. Thus, it can be concluded from the above fragment that the operation of increased risk is the operation of manually recalculating production schedule if it is necessary to correct the defect or to produce the necessary number of parts to replace the rejected ones.

Table 1. A fragment of the FMEA analysis of the technological process of product manufacturing and measuring its geometric parameters without including measuring equipment in the MES system.

| №  | Operation                          | Potential defect                  | Potential cause            | Potential consequences  | A  | B  | E  | RPZ |
|----|------------------------------------|-----------------------------------|----------------------------|-------------------------|----|----|----|-----|
| 58.1.1. | Isolation of rejected products in the hold area | Wrong items are placed in the hold area. | Operator inattention | Time losses         | 2  | 4  | 3  | 24  |
| 58.1.2. | Recalculation of production schedule | Incorrect recalculation           | Human factor              | Time and financial losses | 6  | 5  | 3  | 90  |
| 58.1.3. | Making the right amount of parts to replace the rejected ones | Wrong number of parts manufactured | Operator inattention | Time and financial losses | 3  | 8  | 2  | 48  |
| 58.2.1. | Recalculation of production schedule | Incorrect recalculation           | Human factor              | Time and financial losses | 6  | 5  | 3  | 90  |
| 58.2.2. | Reconstruction                      | Incorrect reconstruction           | Low qualifications of operator | Time and financial losses | 2  | 8  | 3  | 48  |

To evaluate the correctness of certain RPZ indicators, a factor analysis is necessary. The factor analysis is carried out to determine the final value of the parameter A, B and E obtained by the expert assessment method during FMEA analysis. The factor analysis is a method that enables you to determine and evaluate the degree of mutual influence of variables. After conducting the factor analysis for the manual recalculation of production schedule, the adjusted RPZ coefficient turned out to be 93, which confirms correctness of the calculation in the FMEA analysis.

To evaluate the positive effect when measuring equipment is included in the MES system of the technological process, an FMEA analysis of this process was carried out, a fragment of which is presented in Table 2.

As follows from the analysis, when measuring equipment is included in the MES system, the risk factor associated with the recalculating operation of production schedule decreased by more than 6 times. Thus, introduction of measuring equipment into the system for calculating the optimum production schedule is the measure that will improve the efficiency and predictability of the entire technological process of manufacturing a particular product.
Table 2. A FMEA analysis fragment of the product manufacturing process and measuring its geometric parameters when measuring equipment is included in the MES system in conjunction with the machinery.

| № | Operation                              | Potential defect / Potential cause | Potential consequences | A | B | E | RPZ |
|---|---------------------------------------|-----------------------------------|------------------------|---|---|---|-----|
| 58.1.1. | Isolation of rejected products in the hold area | Wrong items are placed in the hold area. / Operator inattention | Time losses | 2 | 4 | 3 | 24 |
| 58.1.2. | Recalculation of production schedule in MES-system | Program not responding / Software error | Time and financial losses | 1 | 7 | 2 | 14 |
| 58.1.3. | Manufacturing the right amount of parts to replace the rejected ones | Wrong number of parts manufactured / Operator inattention | Time and financial losses | 3 | 8 | 2 | 48 |
| 58.2.1. | Recalculation of production schedule in MES-system | Program not responding / Software error | Time and financial losses | 1 | 7 | 2 | 14 |
| 58.2.2. | Reconstruction Incorrect reconstruction / Low qualifications of operator | Time and financial losses | 2 | 8 | 3 | 48 |

If we consider the technological process of product manufacturing as a set of production and measuring operations for which both machine and measuring equipment is used, then we can note that the following factors influence such a system.

System availability (determined by coefficient \(E_1\) - equipment availability coefficient) is characterized by the ratio of the difference between the total equipment loading time and its downtime to the total equipment loading time. The values of this coefficient are influenced by various inconsistencies or losses, which can include equipment breakdowns, time spent on changing tools, delivery of equipment for accuracy and time spent on checking equipment.

Work efficiency (determined by coefficient \(E_2\) - work efficiency coefficient) is characterized by the ratio between the product of the theoretical time of the production cycle and the volume of production to the working time of production. The main types of losses in this case include idle operation of the equipment and its operation not at full capacity [6].

The quality level (determined by coefficient \(E_3\) - quality level coefficient) is characterized by the ratio of the difference between the volume of manufactured products and the number of defective products to the volume of manufactured products. Losses may occur in case of a violation in the manufacturing process [7].

Further study of these coefficients affects the regulated appointment of preventive maintenance of equipment in the schedule of such repairs of the service of the chief mechanic of the enterprise [8].

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