Implementing the Industry 4.0 Concept in the Information System at the Preproduction Stage

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Abstract. The Industry 4.0 concept implementation relevance lies in the transition of industrial enterprises to digitalizing information processes that ensure real-time data exchange between participants. Preproduction is one of the main data processing integration stages. The research objective is to reduce the production cycle due to the timely provision of the item manufacturing data by the automated production control system TechnologiCS. The research technique comprises the system simulation theory and mathematical tools of graph theory. A mathematical model has been developed for launching items into production based on the equipment load and the labor intensity of the item manufacture. The processes have been implemented in the TechnologiCS information system in the form of additional subroutines. The preproduction techniques introduced allow reducing the PC operator workload and minimizing errors when performing the processes. The methodological recommendations proposed herein can be used in arranging the manufacture of various products.

Keywords: Preproduction · The Industry 4.0 concept · Information system · PLM · Labor intensity · Machine pool

1 Introduction

In the current conditions of a dynamically changing market, the main factor of a successive enterprise is its competitiveness and efficiency [1]. A way to reduce labor and material costs is the use of information systems at the preproduction stage as part of developing the Industry 4.0 concept. Digitalization allows implementing mathematical models and optimizing production processes, thereby reducing the item manufacturing time [2].

In the production accounting, the Industry 4.0 concept was implemented in the PLM-class TechnologiCS 7.9 information system. This software ensures real-time data exchange in the item design and production cycle. The information system is based on a unified MS SQL database and a file server to store e-documents. The TechnologiCS system covers all processes at the enterprise from the design to the production of a complex technical item, shipping it to the supplier, and tracking warranty obligations [3].

TechnologiCS consists of the following basic components (Fig. 1):

A. A. Radionov and V. R. Gasiyarov (eds.), *Proceedings of the 7th International Conference on Industrial Engineering (ICIE 2021)*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-3-030-85230-6_5

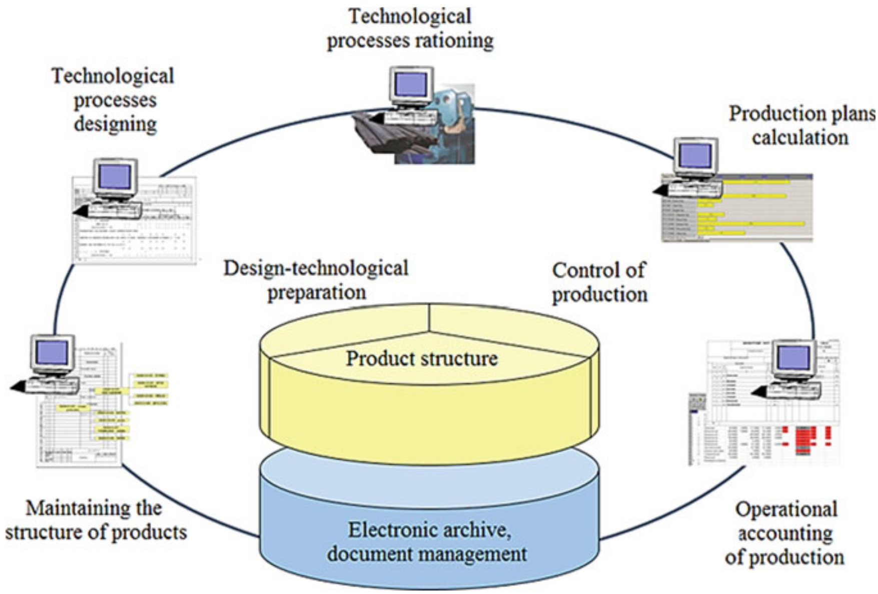


Fig. 1 TechnologiCS system structure

- Maintaining RD. RD means reference data. In the TechnologiCS system, all data is stored in its main (item) reference tables [4]. The items are divided into main classes such as parts, assembly units, materials, etc.,
- Managing the product composition. For each product, the design specifications are developed. Specifications may be included in each other at any nesting level, and on their basis, the tree structure is built for the product in the database,
- Designing and regulating processes. The process design starts with the development of routing technology determining the sequence of basic operations. Simultaneously, tools and process equipment are chosen, time rates are calculated, and the work category is determined. For the items, the system allows designing both customized and standard (group) processes, based on which manpower and materials are rated,
- Preproduction. The system uses data to generate the enterprise's planned orders for any period, including deficiency and purchased component lists. Based on these documents, an item manufacturing cyclogram is built [5], and the process equipment load is planned,
- Operational planning. At the operational planning stage, route sheets for the item manufacture are drawn up, based on which the actual handover is performed, specifying the performance time, the performer, and the labor intensity for the particular operation. The results obtained allow drawing up the item manufacturing schedule considering the actual parameters and analyzing the types and causes of defects [6],
- Inventory control. Based on the item reference table, quantitative inventory control is performed by storage locations at the enterprise. In this mode, the material and technical flow between structural subdivisions and personnel is ensured. Inventory

control can be arranged at any enterprise's organizational structure level (from a workshop warehouse to a particular workplace or employee).

When introducing the TechnologiCS information system in the production, the main tasks comprise:

- reducing the "order generation—production support—meeting the production target" cycle time [7],
- providing real-time process information.

When generating a production order for the manufacture of items, a manufacturing bill of material is drawn up based on the specifications and processes approved. The item composition and the process time rate data allow building an item manufacturing cyclogram (Fig. 2). This cyclogram has some significant drawbacks, i.e., the equipment load is not considered, and the minimum changeover is not set. To obtain more accurate data, a mathematical model is used to calculate the scheduled launch dates.

Fig. 2 Item manufacturing cyclogram

1.1 Mathematical Model to Calculate the Scheduled Launch Dates

When launching a manufacturing specification into production, the time of manufacture should be calculated considering the equipment already involved in other orders [8]. With the standard calculation of the item launch time, the fundamental factor is the manufactured item composition. Based on the process time rates and the item composition, the item manufacturing schedule is built, the primary task of which is to provide the components for the top-level assembly unit. Such a scheme involves equipment downtime since it does not consider the equipment load. The optimal machine loading option should be determined with the shortest item production cycle. To calculate this option, mathematical simulation is used. The main source data are the machine setup and machining times, equipment loading schedule (Fig. 3), the scheduled item manufacturing date, and the item manufacturing procedure.

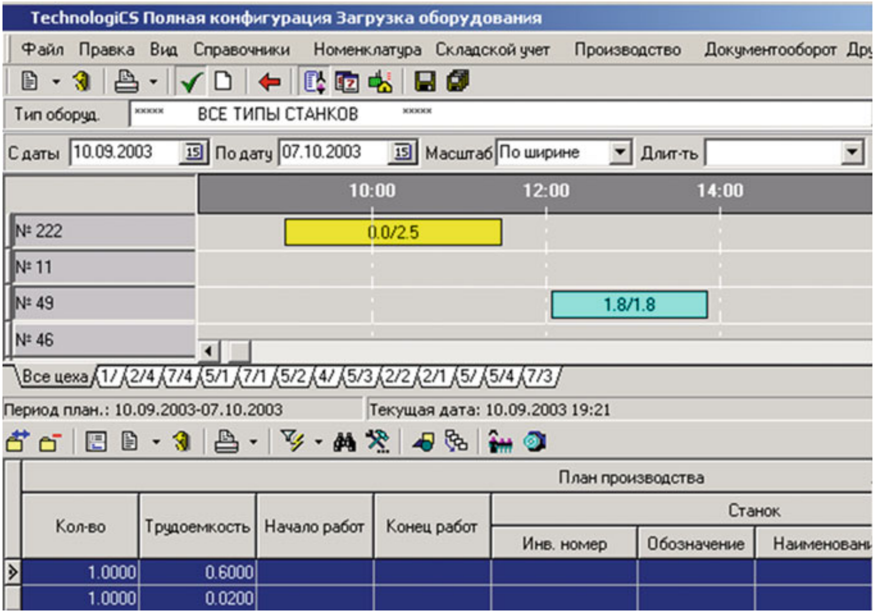


Fig. 3 Equipment loading schedule

Each state of the production process is described by a list, the length of which is equal to the number of the part batches [9]. Each element in the list is an operation number for a certain part batch corresponding to the order in the list. The system states are represented in "Eq. 1"

$$\mathrm{EL}_0 = [e_{11}, \ldots, e_{i1}, \ldots, e_{N1}] \tag{1}$$

where EL_0 is the initial system state, e_{i1} is the number of the first operation for the i-th batch of parts, and N is the number of the part batches.

Accordingly, at any time instant, the system state will take the form of "Eq. 2"

$$\mathrm{EL}_j = \left[e_{1k_1}, \ldots, e_{ik_i}, \ldots, e_{Nk_N}\right] \tag{2}$$

where e_{ik_i} is the k_i -th operation for the i-th batch of parts.

The subsequent operation is chosen according to a criterion or a combination of several criteria previously selected for a given production [10]. E.g., according to the maximum batch processing time, the batch or particular operation priorities, or the need for changeover [11]. The subsequent state is chosen based on the distance ρ, which will be used in building an algorithm for changing the system states [12]. Let us denote the start and end batch processing and the scheduled batch handover instants as S, D, and R, respectively. The S and D values will be considered the solution to the problem.

The target function of solving the planning optimization problem is determined by "Eq. 3"

$$L = f(S, D, R, w) \tag{3}$$

where w is various user-specified priorities for parameter combinations.

The L function can be determined by "Eq. 4"

$$L = \sum_{1}^{N} (w_1 * T_j + w_2 * E_j) \rightarrow \min \tag{4}$$

where $w_1 + w_2 = 1$; $T_j = \max(d_j - r_j)$ is the delay time; $E_j = \max(r_j - d_j)$ is the lead time; r_j is the scheduled j-th batch handover instant; d_j is the calculated j-th batch handover instant.

Let us pass directly to the optimization algorithm. Let us consider a graph $G = (U, V)$, where the vertices V are the already mentioned EL system states, and the edges U correspond to the transition from one state to another; thereat, the edge weights depend on the system state distance ρ function. The solution to the planning problem is to find a path on graph G that allows minimizing the target function L. Since this problem is NP-complete, it makes sense to search for its solution among stochastic algorithms [13].

In the planning problem, an initial weight τ_0 is assigned to each edge of the graph G, and then a cycle is started. Each subsequent state of the system is chosen as follows:

The equi-function of the distance between i-th and j-th states is determined by "Eq. 5"

$$\mu_{ij} = \frac{1}{\rho_{ij}} \tag{5}$$

The probability of transition from state i to state j is determined by "Eq. 6"

$$\rho_{ij} = \begin{cases} \frac{\tau_{ij}^{\alpha} * \mu_{ij}^{\beta}}{\sum h \in \mathrm{EL} \tau_{ih}^{\alpha} * \mu_{ih}^{\beta}} \\ 0, j \notin \mathrm{EL} \end{cases} \tag{6}$$

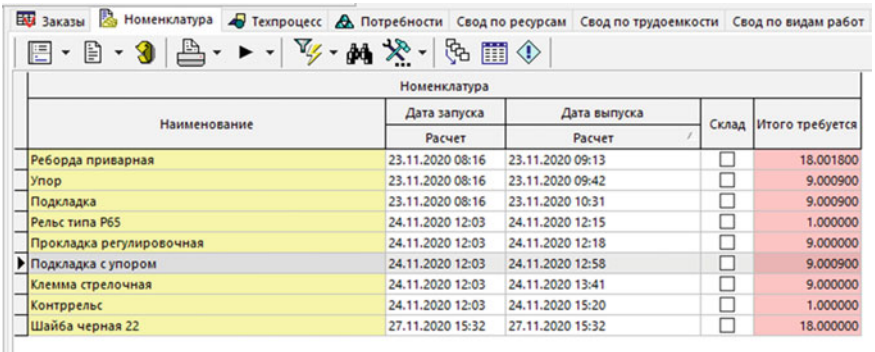
where h is the index on all elements from the list of states allowed EL; α, β are the configurable numerical coefficients.

After passing the first cycle, the edge weights are updated, and the edges are marked according to the path. After the first cycle is completed, the second one is performed, etc., until the convergence condition [14] is fulfilled, e.g., a small change in the target function. Based on this calculation, a monthly manufacturing plan is built (Fig. 4).

The algorithm output comprises the launch and manufacture dates, as well as equipment and manpower loading schedules. The demands for materials and tools are projected onto the resulting calculated production schedule, focusing on the manufacturing operation dates. The information system generates the following data: a launch schedule by particular items; a schedule for the procurement of materials, components, and tools; an equipment loading schedule; a manpower loading schedule.

2 Conclusion

Adaptation of the PLM-class information system to the Industry 4.0 concept at the pre-production stage allows reducing the item production cycle and calculating the scheduled launch dates for each item. The mathematical model proposed allows quickly recalculating the scheduled manufacturing dates, considering changes in the machine pool load or the item composition.



Номенклатура				
Наименование	Дата запуска	Дата выпуска	Склад	Итого требуется
	Расчет	Расчет		
Реборда приварная	23.11.2020 08:16	23.11.2020 09:13	☐	18.001800
Упор	23.11.2020 08:16	23.11.2020 09:42	☐	9.000900
Подкладка	23.11.2020 08:16	23.11.2020 10:31	☐	9.000900
Рельс типа Р65	24.11.2020 12:03	24.11.2020 12:15	☐	1.000000
Прокладка регулировочная	24.11.2020 12:03	24.11.2020 12:18	☐	9.000000
Подкладка с упором	24.11.2020 12:03	24.11.2020 12:58	☐	9.000900
Клемма стрелочная	24.11.2020 12:03	24.11.2020 13:41	☐	9.000000
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Шайба черная 22	27.11.2020 15:32	27.11.2020 15:32	☐	18.000000

Fig. 4 Monthly manufacturing plan

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