Software module for project analysis in mechanical processing and welding of frame structures

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Abstract

A preliminary analysis of the technical project is crucial for aligning the expectations of all participants. Developing and using software modules for operational planning shows promise. These modules allow the project executor to assess the technological support required for the project and determine whether other participants need to be involved in specific technological operations. It is important to evaluate the effectiveness of using both primary and ancillary technological equipment, as well as the availability of employees with the required qualifications. Evaluating the project involves analyzing the geometric parameters of the product's components, which are obtained from the results of 3D modeling. The proposed mathematical models for project analysis enable financial assessment and help determine the overall time spent on the project. The software module analyzes user input and can be adapted to changing production conditions.

Keywords

database, mathematical modeling, information systems, tooling, welding operation

1. Introduction

The modern production of industrial products relies on a functional and cost analysis for project implementation. Typically, planning departments conduct a consolidated analysis of the cost of order fulfillment, especially in mechanical engineering. However, this approach often overlooks the specific needs of production. For industrial enterprises with a well-established base of metal-cutting machines and other metal-processing equipment, this approach is more justified. It allows for a more efficient use of equipment and concentration of operations. The selection of qualified employees for performing technological operations also plays a crucial role. However, industrial bases with low equipment usage tend to prefer technical projects with significant differences in financial indicators for process organization and implementation coverage.

For small and medium-sized businesses, using aggregated analysis, such as analyzing the mass of finished products, may not always be justifiable. When production capacities are at their

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maximum, it's important to consider factors like the time taken for each operation, the sequence of technological operations, labor costs, potential risks, minimal material procurement costs, and expenses for consumables and auxiliary materials. These factors carry more weight for small businesses compared to larger ones, as they can have a bigger impact on the overall financial performance of the business.

We have determined that it is crucial to develop autonomous functional modules for technical and financial analysis. The importance of this issue is evident due to the specialization of its operation, particularly its focus on executing a specific project. A formal description of the project's elements enables a functional and cost analysis of each technological operation. Consequently, this allows for accurate prediction of the project's cost and execution time.

2. Related works

Many countries have experienced significant economic changes due to the COVID-19 pandemic and russia's military invasion of Ukraine. As a result, manufacturing companies are seeking to reduce costs to stay competitive during these crises. This includes optimizing production facility maintenance costs. One way to achieve this is through effective maintenance planning, integrated production and maintenance planning, and by improving machine durability. This can be accomplished by redistributing the workload of production equipment and ensuring equal load factors for technological equipment [1].

Effective production planning involves using a variety of input data indicators. These indicators can be either typical or original, depending on the specific production conditions. Advanced design systems incorporate planning modules based on Industry 4.0 principles. The traditional hierarchical approach to production planning and control (PPC), as described by Rahmani M. et al. [2], limits the use of production feedback data in tactical production planning. Another important factor to consider is the cost of analyzing production processes. In some cases, developers create functional modules to improve the productivity of PPC processes and organize production more effectively. They utilize cutting-edge technologies, including the Internet of Things, big data analytics tools, and machine learning running in the cloud or on edge devices, as mentioned by Olumide E. et al. [3].

It is widely recognized that the planning of production processes is a crucial aspect of organizational work within an enterprise. This stage is an essential step in decision-making before the commencement of production activities. The primary objective of such planning is to achieve maximum profit while minimizing production costs [4]. The planning of production processes is defined as the process of producing goods and services over a specific period, taking into account various resources such as labor, materials, and equipment. In many mathematical models, the production planning model itself is developed based on multiple variables and parameters, which can aid in making production decisions as efficiently as possible [2-4].

The production process planning system involves separate studies for each stage. These studies are based on mathematical models for typical and non-typical algorithms [5], which has attracted interest among specialists in developing, researching, and improving these models. For instance, the task of forming the Master Calendar Plan, central to the MRP standard, is presented as a linear programming task. This algorithm is chosen due to the linear nature of specified limitations on production capacities and materials [6]. When there are strict restrictions on production equipment capacity, the plan for replenishing raw materials is shifted to earlier intervals in the planning, and only after that is based on restrictions on consumed power and productivity of the technological equipment. Several strategies for scheduling production replenishments are proposed [7]. The developed algorithms are available in the form of Microsoft Excel templates for use to enhance understanding of the MRP II standard [6].

Considerable attention is devoted to the analysis methods used in algorithms for planning production processes and implemented in mathematical models [7, 8]. Scientists have investigated various algorithms for dealing with Advanced Planning and Scheduling (APS) in the presence of uncertainty. These algorithms are classified into five main categories: stochastic mathematical programming, fuzzy mathematical programming, modeling, metaheuristics, and evidential reasoning. Based on advanced research trends and identified shortcomings, potential research directions are discussed [8].

The software module proposed by us has been closely studied in the context of traditional production planning issues [9]. The study used an Integer Linear Programming (ILP) model to predict the monthly output of a batch of each product to minimize production costs in a plant. The authors developed the model as a Python program and solved it using the simplex algorithm. The model calculates the lowest monthly cost and number of batches by efficiently utilizing both human and material resources. It also considers factors such as overtime costs, periods of labor and machine downtime, and additional labor hours, all of which are added to the monthly production costs [9]. The article describes effective solutions for improving traditional production planning problems and minimizing production costs by considering multiple constraints using operations research. The study accurately determines the difference between monthly production costs and costs calculated using techniques of other common production planning systems [9, 10].

After conducting preliminary analysis, it has been shown that proposed algorithms and schemes for operational planning of production processes heavily rely on mathematical models [4, 6, 7, 9]. Predictive mathematical modeling is a crucial and potent tool for enhancing production processes [11], offering the best comprehension of principles when predicting the possible execution options of the technological process. The authors delve into an examination of the fundamental principles of mathematical modeling within the production process, the mechanism for developing predictive models, and the exploration of challenges that arise during the application of mathematical modeling [11].

The production process can be defined as the application of physical and/or chemical processes to modify the structure, properties, and appearance of source materials in order to produce parts or products [12]. Manufacturing often involves combining several elements to create assembled products. When preparing for the release of new products, it is important to establish a common understanding of production development, planning, and control, including typical products like just-in-time and cost-effective production [12]. These indicators are crucial for analyzing efficiency in production processes. Production efficiency is greatly affected by maintenance, which is often overlooked when the focus is on production planning. The symbiotic relationship between technical activities and production activities is a critically important factor that is not taken into account when planning activities [13].

To effectively manage production processes with a rapidly changing product range, digital production systems must be actively used. These systems allow for flexible adjustments to production and service planning in response to both internal and external changes [14]. However, managing data generated by production systems and processes in dynamic production environments requires the development of new methods and systems. It is important to categorize information flows into technological (technical) and decision-making flows [15].

After analyzing the existing literature, we found support for our proposal to develop a specialized software module designed for the real-time analysis and cost calculation of specific technical projects. This software module should be adaptable to various production conditions.

3. Proposed methodology

During the research, linear regression of the general type, non-linear regression of the general type, 3D modeling, methods for forming a relativistic database and discrete set analysis algorithms were used.

4. Results

We have conducted market research on software products for analyzing and planning production processes. Individual automated design systems can incorporate autonomous or integrated modules for planning production processes. To ensure their successful operation, it is essential to acquire the CAD-CAM-CAE system itself and complement it with planning and analysis modules. These systems have a complex structure and require a special level of training for the system operator. In some cases, engineers and scientists have developed specialized software modules for specific productions [6]. We identified the necessity to develop and explore the functionality of a software module that could be adjusted to production conditions across a wide range of products. Initially, a software module for analyzing machining processes and welding technological operations was created [5]. Subsequently, mathematical models and a structure for financial analysis and production process planning were developed.

Among other requirements for the software module were its versatility and ease of use. Additionally, the software module for operational analysis should be accessible on a PC or laptop for an average statistical user.

Over several months, we conducted consultations with representatives from manufacturing companies. During these meetings, we identified a list of common issues that affect most production systems during production planning and preparation. Representatives from the companies provided suggestions for how to improve the organization of functional and financial analysis of production preparation processes, as well as preliminary analysis of the business plan.

Through discussions of various input data parameters and expected results, we determined the most efficient structure for the functional components of the software module. Below is a list of the minimum required functional blocks for these components:

1. Formation of a library of 3D models for each component included in the product's project structure.
2. Save the geometric characteristics of the parameters of each component in the project database.
3. Perform an initial assignment of technology operations for the mechanical processing of each component in the product's project structure.

4. Calculate the manufacturing time for each component included in the product structure from the project.
5. Calculate the minimum time required for producing the necessary number of parts before commencing assembly operations.
6. To provide an estimate of the time spent on assembly operations.
7. Calculate the number of production sites for assembly, welding, mechanical cleaning, surface protection, and painting operations.
8. Investigate the execution time of each technological operation and the approximate duration of the entire project.
9. Determine the required quantity of raw materials for implementing construction solutions.
10. Perform an analysis of the load level of the primary technological equipment based on power parameters and usage time. Also, estimate the financial costs for operating and maintaining such equipment.
11. Perform an analysis of the utilization level of the workshop's auxiliary and transportation equipment based on power parameters and usage duration. Also, calculate the projected financial costs for operating and maintaining such equipment.
12. Determine the required amount of supplies needed to carry out the technological operations.
13. To estimate the expenses involved in paying the salaries of the key employees and support staff.
14. To determine the expenses associated with covering administrative costs.

Based on the research findings and recommendations from individual researchers [7, 9, 14], it is suggested to develop a software module using the open architecture principle. This approach allows users to customize databases to suit their specific needs, modify standard data tables, and edit mathematical expressions within the software module's mathematical model. The module's unique feature is its ability to perform specific mathematical operations based on the structure of the search or analysis request.

4.1. Analysis of the structure of the software module

All data used for analysis is stored in tables, which are a structural component of the database. Some tables store records that are specific to a particular production (**Figure 1**). The data from these tables can be used as input for other tables. Data is exchanged through a special component called a "Form." Information from one table can be used to describe a production object in another table.

Every entry in the software module's table is encrypted. This encryption method allows you to use individual records from the same table to create different queries and reports. Generally, the software module is presented to the user through a main control form, which includes buttons for calling up commands, creating new orders, reviewing previous orders, and monitoring the technical project implementation process.

The design option for the order formation control panel (**Figure 2**) shows a linear structure with several buttons for managing the accounting process. One way to improve this structure is to use a mechanism to substitute numerical or symbolic data when the customer has already contacted the manufacturer for a service earlier.

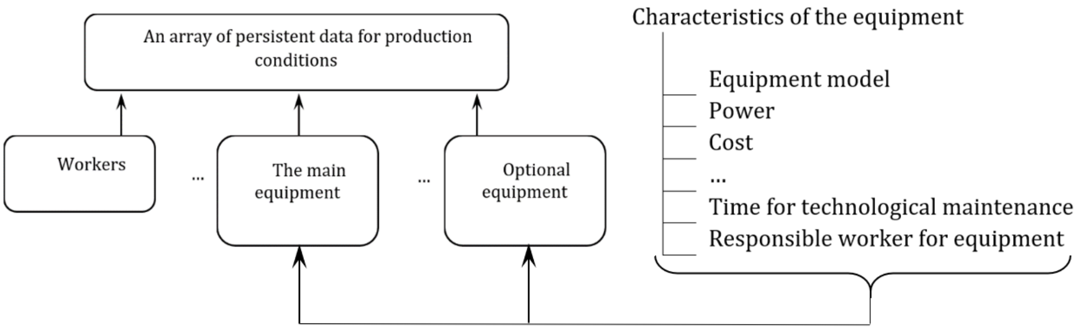

Figure 1: the table "Characteristics of the equipment" to describe the production equipment set.

The software module allows users to access various forms from the main panel. When data is recorded in this panel, the system automatically stores it in corresponding tables, and users can also print the data from the form. If users need to fill out other forms, they can use the command to return to the Main Panel.

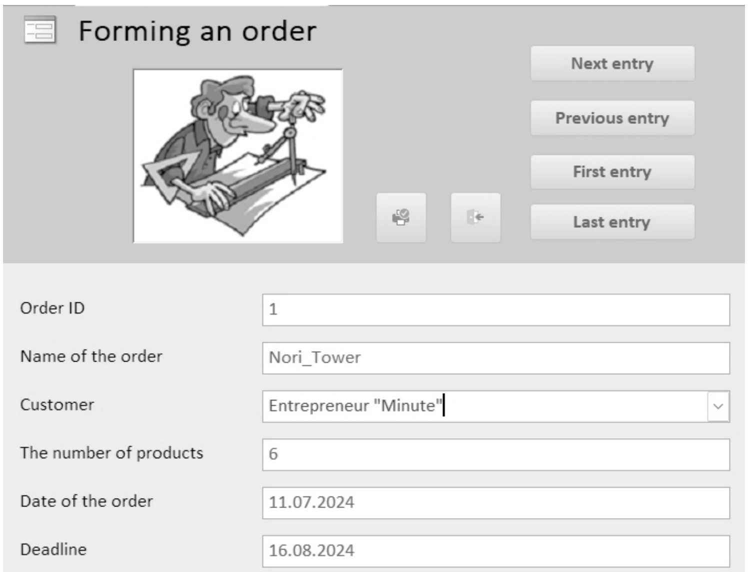

Figure 2: one of the forms for placing an order.

Each working panel may contain control buttons for switching to other panels, returning to the previous data entry level, and accessing other forms for placing an order. After placing the order, users can print the results of the financial and technical analysis. At this stage, the Agreement participants have the opportunity to review the results, make corrections, and promptly receive updated results.

4.2. The characteristics of mathematical support of the software module

The software module includes mathematical descriptions for calculating perimeters and cross-sectional areas of profiles used in frame structures [5]. Various technological parameters, such as the main time for mechanical processing or welding, as well as auxiliary time and time for transporting products around the shop, were calculated using established algorithms. During this stage, adjustments were made to the mathematical expressions, taking into account the specific production conditions of a particular shop or section of the shop. These adjustments included incorporating coefficients to increase or decrease the calculated values. In some cases, it is most effective to create an array of values for a variable parameter. These values can be used for forming requests, and calculating time and financial costs.

5. Conclusions

Assessing a project's financial and technical aspects, it is essential to establish a strong foundation for collaboration between the client and the contractor. Researchers have focused on analyzing methods in production planning algorithms and have incorporated them into mathematical models across various software platforms.

One of the most influential factors in financial and production analysis is examining the 3D model of each component within the project's structure. Leveraging 3D modeling tools provides comprehensive information about the part's geometric parameters and other characteristics.

Calculating cost indicators for order fulfillment and financial expenses to support the operation of main and auxiliary equipment involves using adaptable mathematical expressions tailored to specific production conditions. Special requests are employed for these calculations, comprising a set of mathematical models. The system automatically selects the appropriate mathematical model based on predefined criteria and constraints.

The software module for analyzing machining processes, assembly operations, and welding is designed around an open structure database. This approach enables users to modify its mathematical support to suit their individual needs and production conditions.

The database structure implemented in the software module for analyzing machining processes, assembly operations, and welding has proven its effectiveness when compared to other analysis systems. This efficiency is achieved by adapting the mathematical support to the specific production conditions, taking into account the enterprise's specific work characteristics. The module's capacity for modifying the mathematical apparatus and its versatility have made it an effective tool for preliminary project cost estimation and implementation timelines.

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