Research article
DOI: https://doi.org/10.48554/SDEE.2022.3.2

FUZZY-MULTIPLE APPROACH IN DESIGN AND TECHNOLOGY MANAGEMENT – MODELLING THE PREPARATION OF PRODUCTION AT MACHINE-BUILDING ENTERPRISES

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Abstract

As economic systems are characterised by influential uncertainties (or uncertainty factors), performance assessment in engineering enterprises requires a solid scientific background for managerial decision-making in business. This article offers a model of a fuzzy system for the development of design documentation at the design pre-production stage and technological documentation at the technological pre-production stage. The model aims to manage and frame the process of design and technological pre-production. Based on fuzzy logic tools, the model allows engineering enterprises to operate temporary parametrons of sequential and parallel-sequential processes involved in the development of design documentation and technological documentation. This study demonstrates that a fuzzy-set approach can serve as an effective means for design and technological pre-production management at engineering enterprises in a highly competitive market. Multiple scientific and technological improvements, together with the overall digital transformation of engineering, have driven core changes in business processes, their timing, and costs. Even with tighter deadlines for design and technological pre-production, managerial decisions are expected to fit them with sufficient flexibility to ensure mobility. This fact does not undermine the importance of general supervision and awareness of management over the existing bottlenecks in the entire production management system and in design and technological pre-production.

Keywords: economic models, fuzzy-set approach, engineering enterprises, design and technological pre-production, digital technologies, market environment, business processes, fuzzy logic

Citation: Skorobogatov, A., Kobzev, V., 2022. Fuzzy-multiple approach in design and technology management modeling preparation of production at machine-building enterprises. Sustainable Development and Engineering Economics 3, 2. https://doi.org/10.48554/SDEE.2022.3.2

Научная статья
УДК 658.512.4
DOI: https://doi.org/10.48554/SDEE.2022.3.2

НЕЧЕТКО-МНОЖЕСТВЕННЫЙ ПОДХОД В МОДЕЛИРОВАНИИ УПРАВЛЕНИЯ КОНСТРУКТОРСКО-ТЕХНОЛОГИЧЕСКОЙ ПОДГОТОВКОЙ ПРОИЗВОДСТВА НА ПРЕДПРИЯТИЯХ МАШИНОСТРОЕНИЯ

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Аннотация

Экономические системы характеризуются наличием влияющих на них факторов неопределенности, и анализ деятельности машиностроительных предприятий требует научной базы принятия управленческих решений в бизнес среде. В статье предлагается модель нечеткой системы разработки конструкторской документации (КД) на этапе конструкторской подготовки производства (КПП) и разработки технологической документации (ТД) на этапе технологической подготовки производства (ТПП) для управления конструкторско-технологической подготовкой производства (КТПП) на предприятиях машиностроения. Предложенная модель, основанная на математическом аппарате нечеткой логики, позволяет оперировать временными параметронами последовательного и параллельно-последовательного процессов разработки КД и ТД. Также в работе показано, что нечетко-множественный подход может являться эффективным средством управления КТПП на предприятиях машиностроения в условиях высококонкурентной среды рынка. Тенденции развития науки и техники, связанные с цифровой трансформацией предприятий машиностроения, в корне меняют бизнес-процессы, время их протекания, стоимость, сроки на проведение КТПП также сокращаются. Управленческие механизмы при этом должны работать на минимально коротких дистанциях в структуре, чтобы обеспечить подвижность. При этом должен сохраняться общий контроль и информированность руководства, особенно о наличии «узких мест», во всей системе управления производством и КТПП.

Ключевые слова: экономические модели, нечетко-множественный подход, предприятия машиностроения, конструкторско-технологическая подготовка производства, цифровые технологии, рыночная среда, бизнес-процессы, нечеткая логика.

Цитирование: Скоробогатов, А., Кобзев, В., 2022. Нечетко-множественный подход в моделировании управления конструкторско-технологической подготовкой производства на предприятиях машиностроения. Sustainable Development and Engineering Economics 3, 2. https://doi.org/10.48554/SDEE.2022.3.2

1. Introduction

In a highly competitive environment, engineering enterprises are pressurised by the constant need to not only reduce the pre-production and production time but also the ancillary work. Justification of the possibility of reducing the time spent on design and technological pre-production (DTPP) can be delivered from the minimax approach of fuzzy logic. This study aims to develop an economic model for the management of design and technological preproduction to reduce time at the stages of product development and production. Finding a solution to the problem of how to cut pre-production time at engineering enterprises is highly promising for business, and requires a scientific approach.

Thus, it is a matter of first priority to assess the time spent on intellectual work, which of course includes DTPP. Statistical methods are hardly applicable in terms of knowledge-intensive investment projects, since the cases are rather unique. A more effective tool is the expert forecasting of specifications, which, in turn, is characterised by the minimum, most probable, and maximum values of $\underline{a}_i = (a_{i\,min}, a_i, a_{i\,max})$, where $i = 1...n$ is the ordinal number of an expert, and n is the number of experts (Lebenkova et al., 2020).

However, we believe that management models based on fuzzy logic are more suitable for this case. Currently, such models are implemented in multiple digital systems, ranging from the simplest ones, such as household appliances, to complex dynamic systems, including aircraft, helicopters, cars, trains, etc. (Balmagambetova, 2019). Representing an important stage of a product life cycle, the DTPP process is very complex and is permanently conducted within a man-machine system. Since the operation of many digital systems often defies logic, the minimax approach to fuzzy logic seems to be the most acceptable.

Before moving deeper into the specific digital tools used in the DTPP, it is worth pointing out that the fundamentals of building the digital environment were described by one of its founders, Nicholas Negroponte, in his work "Being Digital" (1995). Today, with the economic situation far from stable, competitive national engineering enterprises gain paramount importance for a country's status. Thus, the level of natural, social, and economic development of each country is measured by the ability of its engineering enterprises to produce high-tech products. Management in DTPP at engineering enterprises is interconnected with management systems at every stage of a product life cycle, innovations, supply chain, and IT architecture (Belyakova and Fokina, 2019; Skorobogatov, 2018).

The IT architecture of a modern engineering enterprise includes a large number of information systems involved in arranging business processes and shaping a business model (DTPP) (Kobzev et al., 2013; Kobzev et al., 2014; Skorobogatov, 2020). As of 2022, the information systems used in DTPP have developed a broader range of functions with a more complex infrastructure. The programmes have exceeded their learning ability, and maintenance costs have increased, resulting in a decrease in their economic efficiency. Thus, reducing the time necessary for the DTPP at engineering enterprises is an urgent task for both the scientific community, and stakeholders of the industry.

2. Literature Review

At present, the fuzzy sets theory is widely applied by a wide range of economic entities (Zvyagin, 2019). Lotfi Zadeh, an American scientist of Azerbaijani origin, developed the fuzzy logic theory, and published his first paper on the fuzzy sets theory in 1965 (Gurbanov, 2020; Fay, 1998). Having received the "Father of Fuzzy Logic" title in 1992 at the international ISAAM Symposium, Lotfi Zadeh presented six fundamental theories. The most recognised works by Zadeh include: "Outline of a New Approach to the Analysis of Complex Systems and Decision Processes", "The Concept of a Linguistic Variable and its Application to Approximate Reasoning", and "Fuzzy Set Theory and Probability Theory: What is the Relationship?" (Gurbanov, 2020).

Similar to mathematics, where classes have clear limits, fuzzy sets make it possible to model complex humanistic systems with membership functions. Although back in the 1960s and 1970s, mathematicians were very cautious about Lotfi Zadeh's works, since they were beyond traditional math frameworks, his ideas proved to be highly practical for economics and IT. Large corporations, such as Nissan, Kodak, and Sony, widely apply Zadeh's scientific findings in their production. He expanded the concept of a set by defining values in the range from 0 to 1, not just 0 and 1. Zadeh's theory has the following form: let *U* be a universal set. Then, a fuzzy set *X* on the set *U* denotes a collection of pairs *X={*µx(x*)/(x)},* where µx(x) is the membership function (Zvyagin, 2019). The concept of a fuzzy set itself can be generalized as follows: Let *U* be the reference set, universe of discourse, and *M* be the grade of membership, µ *A: U→M.* A fuzzy set A-U is denoted by µ *A*, that is, a membership function *{(u, µ A (u)):u€U}*. Therefore, fuzzy set *A* is assigned by a set of three *(U, M, µ A)* (Novotochinova, 2018).

Following the ideas of Lotfi Zadeh, many scientists have contributed to the development of fuzzy sets theory, including Kofman, K. Atanassov, R. A. Aliyev, A. O. Nedosekin, O. V. Loskutov, A. E. Altunin, A. N. Borisov, M. P. Vlasov, etc. The issue of the practical implementation of fuzzy sets theory started to be widely considered by the scientific community due to its promising potential for industries (Shupletsov, 2019; Savchenko et al., 2021; Rahman et al., 2020; Ejegwa et al., 2020; Imeni, 2020). General methodology of management for enterprise architecture was observed in the works of foreign and Russian researchers such as K. Vigers (2013), J. A. Zahman (1987; 1992), I. Ilyin (2017; 2018), D. Kudryavtsev (2020), M. Lankhorst (2013), R. Sessions (2013), N. Porya (2013), A. Levina (2017; 2018), and G. Krayukhin (2019).

The fuzzy-set approach has three major traits typical for studying and modelling complex economic systems and processes: (1) linguistic variables are applied, (2) simple relations between variables are denoted by fuzzy expressions, and (3) complex relations are denoted by fuzzy algorithms (Knyazeva et al., 2018). A theoretical review of the scientific literature on the topic shows that the most preferable tools to assess pre-production deadlines at engineering enterprises lie in the plane of fuzzy mathematics, including fuzzy arithmetics, fuzzy and linguistic logic, and possibility theory. This is because the uncertainties in pre-production are dictated by market conditions, which are largely vague and unreliable (rather than random) in terms of reference data.

3. Materials and Methods

Quantifying uncertainty is an extremely problematic task due to the fact that multiple important factors should be considered, including fluctuations in demand, irregularities of supply, changes in prices for goods and services, energy costs, labour, inflation, and lack of awareness of the situation because data sources are unreliable (Knyazeva et al., 2018). Currently, many researchers emphasize the promising potential of the fuzzy-set approach, instead of probability theory, because it implies determining the possible range and the most probable value for each design parameter, ignoring its relative frequency. According to the findings of domestic and foreign scientists, quantitative methods for risk and uncertainty assessment can be divided into three fundamental groups: (1) probabilistic-statistical approaches, (2) simulation models, (3) elements of game theory, (4) expert systems, and (5) methods based on efficiency and sensitivity analysis (Bezrukova et al., 2015).

Determined by the level of digitalisation and efficiency of software, the information structure of an enterprise provides information support for business processes (Alferyev et al., 2020). In turn, the technological structure of an enterprise is shaped by technical and technological capabilities, as well as engineering facilities, depending on the type of production. Logically, production types (piece, batch flow, and mass production) determine the specific technological processes to be used at an enterprise. The IT strategy frames the development of information technologies and systems that are already implemented, or can be potentially used in the DTPP. (Baskerville et al., 2004; Sebastian, 2011). DTPP is always expected to be completed on time, performing the entire scope of work. Figure 1 shows the major areas for pre-production.

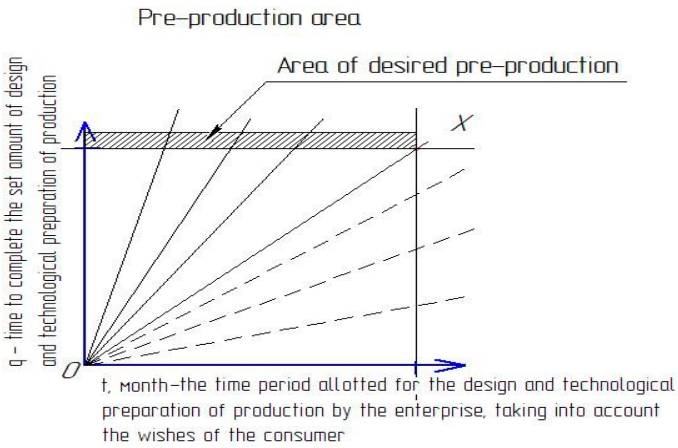

Figure 1. Areas for design and technological pre-production

The process of DTPP at an engineering enterprise implies close and permanent interaction between two separate areas: design pre-production (DPP) and technological pre-production (TPP) are interconnected with each other. To better trace this connection, we assessed the design documentation (DD) and technological documentation (TD) and incorporated the fuzzy-set approach.

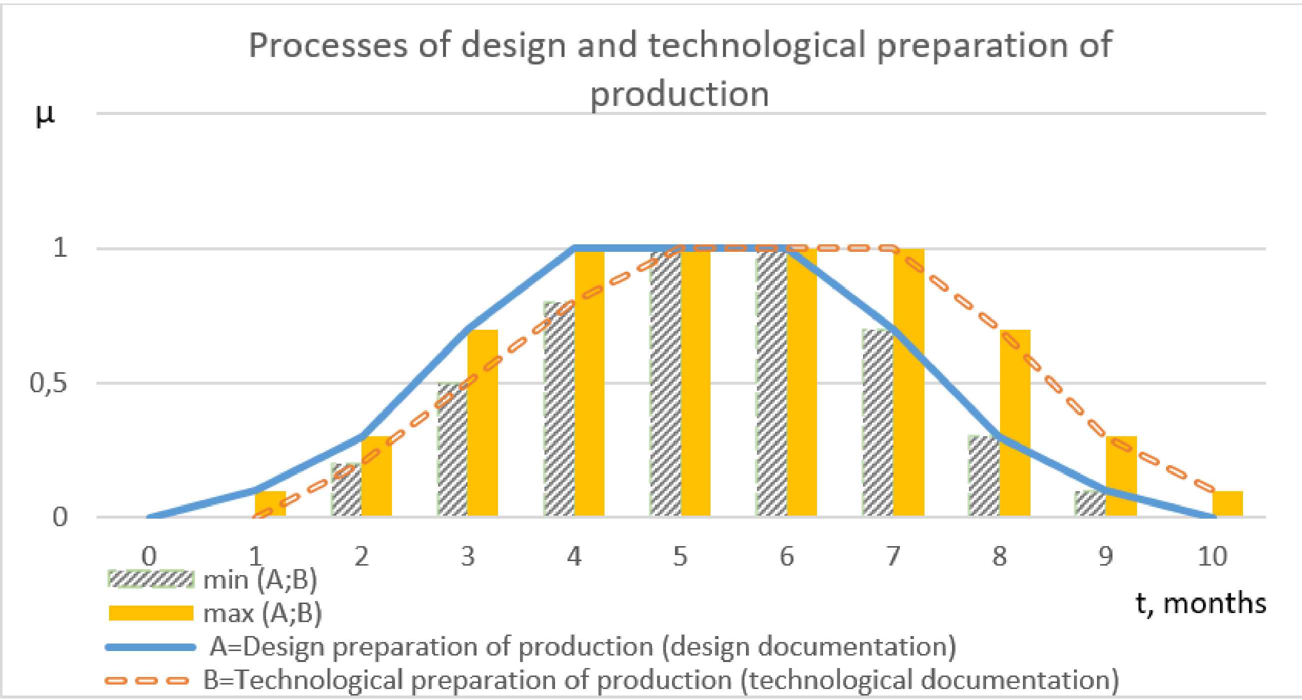

Figure 2. Design and technological pre-production via the minimax approach of fuzzy logic

The minimax approach of fuzzy logic was used to process data on DTPP according to the grade of membership of design documentation (DD) and TD.

Line A for the design pre-production indicates the duration of DD development. Line B for the technological pre-production indicates the duration of TD development.

The conjunction μ Aμ B tends to min (μ A, μ B), then the function for the simultaneous development of DD and TD is:

$$\overline{A} \cap \overline{B} = \int_U (\mu_{\overline{A}}\ (x)\ (x))/(x) \qquad (1)$$

where $(\mu_{\overline{A}}(x)\ \mu_{\overline{B}}(x)) = min\ \{\mu_{\overline{A}}(x), \mu_{\overline{B}}(x)\},\ x \in U$

The disjunction μ Aμ B tends to max (μ A, μ B), then the function with DD development without TD development, or TD development without DD development is:

$$\overline{A} \cap \overline{B} = \int_U (\mu_{\overline{A}}(x)\, \mu_{\overline{B}}(x))/(x) \qquad (2)$$

where $(\mu_{\overline{A}}(x)\, \mu_{\overline{B}}(x)) = max\{\mu_{\overline{A}}(x), \mu_{\overline{B}}(x)\},\ x \in U$

Thereby, parallel development of DD and TD tends to minimum and takes less time (t), whereas series development tends to maximum and, consequently, takes more time (t). This means that to optimise and reduce the time spent on DTPP at engineering enterprises, it is necessary to transfer series business processes to parallel series as much as possible. This can be made possible only with a reliable managerial mechanism when design and process engineers possess sufficient qualifications and competence. Objective functions for members of the DTPP system at an engineering enterprise are:

$$F_0(\alpha_k(N,b_k),\alpha_t(x,b_t),b_k,b_t) = G(N,x)-\alpha_k(N,b_k)-\alpha_t(x,b_t) \qquad (3)$$

$$F_k(\alpha_k(N,b_k),\eta_k(b_k),N,b_k) = \alpha_k(N,b_k)-\sum_{i=1}^{n}\eta_k^i(x, b_k^i)-S_k(b_k) \qquad (4)$$

$$F_t(\alpha_t(x,b_t),\eta_t(b_t),x,b_t) = \alpha_t(x,b_t)-\sum_{j=1}^{m}\eta_t^j(b_t^j)-S_t(b_t) \qquad (5)$$

$$f_k^i(\eta_k^i(b_k^i),\eta_{kt}^i(N),N,b_k^i) = \eta_k^i(b_k^i)+\eta_{kt}^i(N)-S_k^i\left(N,b_k^i\right), i \in I \qquad (6)$$

$$f_t^j(\eta_t^j(b_t^j),\ \eta_{tp}^j(x),x,\ b_t^j) = \eta_t^j(b_t^j)+\eta_{tp}^j(x)-S_t^j\left(b_t^j\right), j \in J \qquad (7)$$

where:

$G(N,x)$ is the revenue function of the DTPP system;

$\alpha_k(N,b_k)$, $\alpha_t(x,b_t)$ are funds allocated by the management to the departments of design and technology;

$n_k(b_k)$, $n_t(b_t)$ is a function of motivating departments of design and technology;

$\eta_{kt}^i(N)$ is the function of the influence of the technology department on the performance of the *I*-th design engineer;

$\eta_{tp}^j(x)$ is the function of the influence of production on the performance of the *j*–th process engineer;

$S_k(b_k)$, $S_t(b_t)$ are functions of costs by departments of design and technology;

$S_k^i\left(b_k^i\right), S_t^j\left(b_t^j\right)$ is the function of cost per one employee from the department;

N is the quality of DD and TD while developed;

b_k, b_t are the qualifications of a design engineer or a process engineer.

The decision-making model is:

$$F_0(\alpha_k(N,b_k),\alpha_t(x,b_t),b_k,b_t)=G(N,x)-\alpha_k(N,b_k)-\alpha_t(x,b_t) \xrightarrow{k,x,b_k,b_t} max \qquad (8)$$

$$A_k(N,b_k)=\gamma_k N/b_k+a_k b_k=\gamma_k(1-e^{-m_b\alpha_k})/b_k+a_k b_k \le \alpha_k^z$$

$$A_t(x,b_t)=\gamma_t x^2/2b_t+a_t b_t \le \alpha_t^z$$

$$B_k \le B_k,\ b_t \le B_t,\ \alpha_k \ge 0,\ N \ge N^z,\ x \le \overline{x}$$

The function is effective if $\frac{\Delta F_0}{\Delta N} > 0;\ \frac{\Delta F_0}{\Delta x} > 0;\ \frac{\Delta F_0}{\Delta b_k} > 0;\ \frac{\Delta F_0}{\Delta b_t} > 0$.

As shown in Figure 1, the pre-production timeframe is determined by the time gap formed between the latest and upcoming consumer demand for a product.

$$X = \frac{T_{total}}{Q_{DTPP}} \to max \qquad (9)$$

where X is the value of the DTPP efficiency indicator by a specific item produced {0,1}; T_{total} is the time period for DTPP defined by the contract, and Q_{DTPP} is the volume of the DTPP. If $X \geq 1$, the efficiency of the department for design and technology in DTPP corresponds to the given time period left after meeting the previous consumer demand for a product. If $X < 1$, the efficiency of the department for design and technology in DTPP does not correspond to the given time period left after meeting the previous demand of a consumer for a product.

4. Results

Successful transition from series business processes to parallel ones and further reduction of time required for the DTPP depend on how well the goals and responsibilities of each design and technology facility are defined. According to the structure of the department for design and technology, it should be subdivided into different divisions. The functions and responsibilities of each division, or bureau, derive from production goals and annual workload. An important point here is to make sure that the goal itself is universal and common for all divisions to achieve. The functional responsibilities of the department for design and technology at an engineering enterprise are described in Table 1.

Table 1. Functional responsibilities of the department for design and technology at an engineering enterprise

№	Name of the bureau	Functions	Note
		Registration of preliminary notices	
		3D models design	
		Drawings design	
		Development of temporary design options for parts and assemblies according to production needs	
		Decision-making	
		Execution of work programs	
		Registration of test reports	
		Registration of acts	
		Registration of research certificates	
		Registration of letters	
		Conducting and processing the results details testing, defining the cause of defects. Registration of research certificates	
		Formation of an electronic archive for design documentation. Adjustments of drawings and drafts following feedback	
		Reception and issuance of design and technological documentation in the archive in accordance with the related documentation	
		Accounting and storage of design and technological documentation in the archive in accordance with the related documentation	
		Elaboration of design notices for changes in product drawings	
		Development, coordination and approval of standards for extra materials	
		Development of equipment for the workshop	
		Development of design documentation for assembly of universal equipment and devices	
		Design supervision over the manufacture of non-standard equipment, tooling and fixtures	
		Support for manufacturing of non-standard equipment, fixtures and tools	
		Elaboration of the technical specification for changing the drawings of tools; monitoring timely completion of metal tooling according to the modified drawings	
		Machining of simple parts in the production	
		Evaluation of defects in mechanical production due to the technological order; development of measures to eliminate defects	

		Adjustment of technological processes in mechanical processing	
		Registration of certificates on improvements in technological equipment	
		Development of temporary options for technological processes tailored for specific production needs	
		Introduction of automated forms and registration of acts following the reduction of labour intensity and saving materials	
		Technical guidance of overlays in the development of new technological processes and special equipment	
		Prompt solutions to current issues of technological preparation for the workshop production	
		Registration of permission cards for temporary deviation from design documentation	
		Development of machining processes for complex parts in production	
		Road maps design	
		Formation of the composition of products in the PDM system	
		Introduction of databases (regulatory documentation, tools, equipment, etc.)	
		Development and coordination of workshop layouts	
		Preparation of applications, coordination of equipment supplies and introduction of newly received equipment	
		Development of welding processes for parts when they are put into production	
		Development of welding processes for parts when they are put into production	
		Adjustment of working welding processes	
		Registration of certificates on improvements in technological equipment	
		Development of temporary options for technological processes tailored for specific production needs	
		Technical guidance of overlays in the development of new technological processes and special equipment	
		Prompt solutions to current issues of technological preparation for the workshop production	
		Registration of permission cards for temporary deviation from design documentation	
		Development of technical processes for assembly of components and the product when they are put into production	
		Evaluation of defects in assembly production following the technological order; development of measures to eliminate defects	
		Adjustment of technological processes in assembly	
		Registration of certificates on improvements in technological equipment	
		Development of temporary options for technological processes tailored for specific production needs	
		Technical guidance of overlays in the development of new technological processes and special equipment	
		Prompt solutions to current issues of technological preparation for the workshop production	
		Registration of permission cards for temporary deviation from design documentation	
		Tooling production	
		Scheduling regular inspections of special equipment (in association with the Metrological Laboratory)	
		Supervision over the provision of a monthly plan for production	
		Purchase and storage of instruments and tools	
		Purchase and delivery of measuring equipment	

To evaluate the effectiveness of DTPP carried out in AO Zavod “Universalmash” (JSC “Plant “Universalmash”) in relation to the manufactured products, it is necessary to introduce Formula 9 into calculation. To define the time period T_{total} , we take the timing established by the 3-year contract for manufacturing, bearing in mind that production begins together with the DTPP. Then, to determine the scope of the DTPP, we will Q_{DTPP} sum over the time spent on production preparation in accordance with official standards. The case enterprise observed here carries out the DTPP, starting with the resumption of production of a previously manufactured product after a break, instead of designing a brand new product. Table 2 describes every area of DTPP at the Universalmash Plant.

Table 2. Areas for design and technological pre-production at the Universalmash plant

№	Types of work	Area for DTPP	Time required for a job, hour	Note
1	Reception and accounting of received design documentation from the developer	Design pre-production	130	Assessment of contract for design support
2	Verification of documents on compliance with the inventory of completeness	Design pre-production	16	Based on 17 000 items
3	Analysis of design documentation and its adjustment based on comments; discussion of changes with the developer	Design pre-production	180	Work is carried out in advance, as well as timely
4	Development of drawings with due attention to technological specifications of equipment	Design pre-production	230	
5	Introducing changes to design documentation in accordance with the technological specifications of a manufacturer	Design pre-production	170	
6	Approval of technical conditions for the installation series of the product and their series production	Design pre-production	Not required	
7	Introducing changes to design documentation in accordance with the testing results and capacity of an enterprise	Design pre-production	220	
8	Adjustment of design documentation based on the results of manufacturing and testing of first samples	Design pre-production	120	
9	Introducing changes to design documentation in accordance with the technological pre-production	Design pre-production	170	
10	Technical maintenance for production of an experimental batch	Design pre-production	Not required	
11	Adjustment of design documentation based on the results of manufacturing and testing of a pilot batch	Design pre-production	Not required	
12	Registration and approval of documentation for production of the installation series	Design pre-production	Not required	
13	Technical maintenance for production of the installation series	Design pre-production	Not required	
14	Registration and approval of documentation for series production	Design pre-production	80	

15	Release of documents on repair, export, etc.	Design pre-production	70	Production of operational documentation for the complete set of products
16	Technical maintenance for series production	Design pre-production	During the entire production period	
17	Development of a parts classifier	Technological pre-production	160	
18	Distribution of item identification	Technological pre-production	70	
19	Technological design plans	Technological pre-production	240	
20	Development of automated forms	Technological pre-production	730	
21	Design of route sheets	Technological pre-production	770	
22	Calculation and design of layouts	Technological pre-production	160	
23	Distribution of workshop sections	Technological pre-production	830	
24	Calculation of operational standards	Technological pre-production	410	
25	Calculation of standards for materials	Technological pre-production	370	
26	Determination of planning standards	Technological pre-production	180	
27	Listing of special and standard equipment	Technological pre-production	80	
28	Preparation of a technical enquiry and schedule for the development of non-standard equipment	Technological pre-production	120	
29	Implementation of special and non-standard equipment	Technological pre-production	760	
30	Arranging the order for manufacturing tools, fixtures and non-standard equipment	Technological pre-production	40	
31	Tooling production	Technological pre-production	830	
32	Equipment testing	Technological pre-production	During the entire production period	
Total:			7136	Amount of time by points 1,2,3,4,5,7,8,9,14, 15,17,18,19,20,21,22,23,24, 25,26,27,28,29,30,31

The Universalmash plant outsources design support, and that is why the major activities of the design pre-production are related to interactions with a third-party company, which results in more time spent on obtaining designs from the developer.

The overall time for all the work performed in series amounts to 7136 hours. When divided by 8-hour working day, the total number of working days is 890. An average year contains 252 working days, which means it will take 3.5 years to carry out the entire scope of work when performed in series. Total value Q_{KTPP} = 3.5 years.

Formula 9 is used to determine the value (*X*).

$$X = \frac{T_{total}}{Q_{DTPP}} = \frac{3}{3.5} = 0.85$$

If $X < 1$, the performance of the department for design and technology in the DTPP does not correspond to the time period allotted for pre-production after meeting the previous consumer demand for a certain product. In the case of the Universalmash plant X of $0.85<1$ indicates that their performance in the DTPP is not sufficient to fulfil the contract on time. By applying Formula 9, we can conclude that a full-scale DTPP requires much more time than meeting the requirements of consumers. The amount of work presented in Table 1 is the overall time needed to perform all the work by individual business processes. Their order is described in Figure 3.

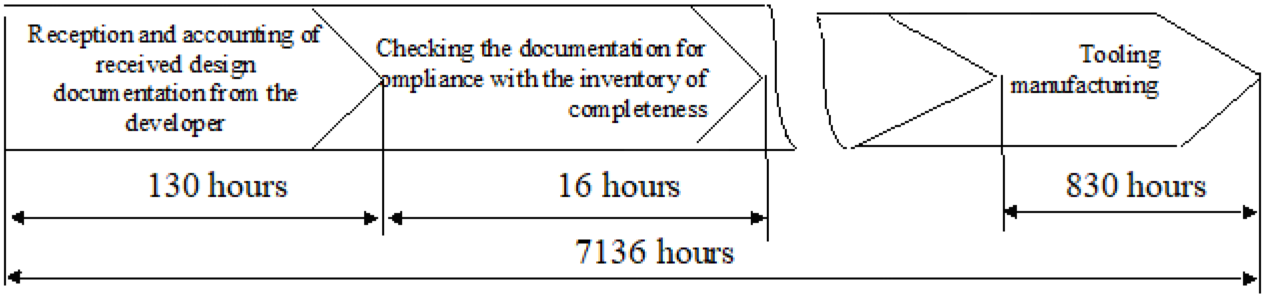

Figure 3. Overall time needed to perform the DTPP, described by business processes on the basis of data from Table 2.

To reduce the time Q_{DTPP}, it is necessary to maximise the transfer from series business processes to parallel ones. It will equalise the entire amount of work Q_{DTPP} to the longest business process or to the sum of a series of business processes that cannot be put into the parallel mode. Figure 4 gives the sum of the business processes with the longest duration.

The overall time for parallel work amounts to 3490 hours. When divided by the 8-hour working time, the total number of working days is 436. An average year contains 252 working days, which means it will take 1.73 years to carry out the entire scope of work when performed in series. Total value Q_{KTPP} = 1.7 years.

Formula 9 is used to determine the value (*X*).

$$X = \frac{T_{total}}{Q_{DTPP}} = \frac{3}{1{,}7} = 1.76$$

Having $1.76 > 1$ means that the performance of the department for design and technology in the DTPP corresponds to the time period allotted for pre-production after meeting the previous consumer demand for a certain product. Such efficiency is sufficient to fulfil the contract on time. When designing enterprise architecture, many practitioners from the industry note that existing framework models are very theoretical and difficult to apply (Plataniotis et al., 2013; Tucci, 2022). Nonetheless, the Zahman matrix allows for obtaining a scrupulous perspective from different stakeholders, thereby raising awareness of more specific data, functions, processes, etc.

With the architectural approach pioneered by Zahman (1987, 1992), it became realistic to systematically optimise the IT architecture and the information systems involved in the DTPP.

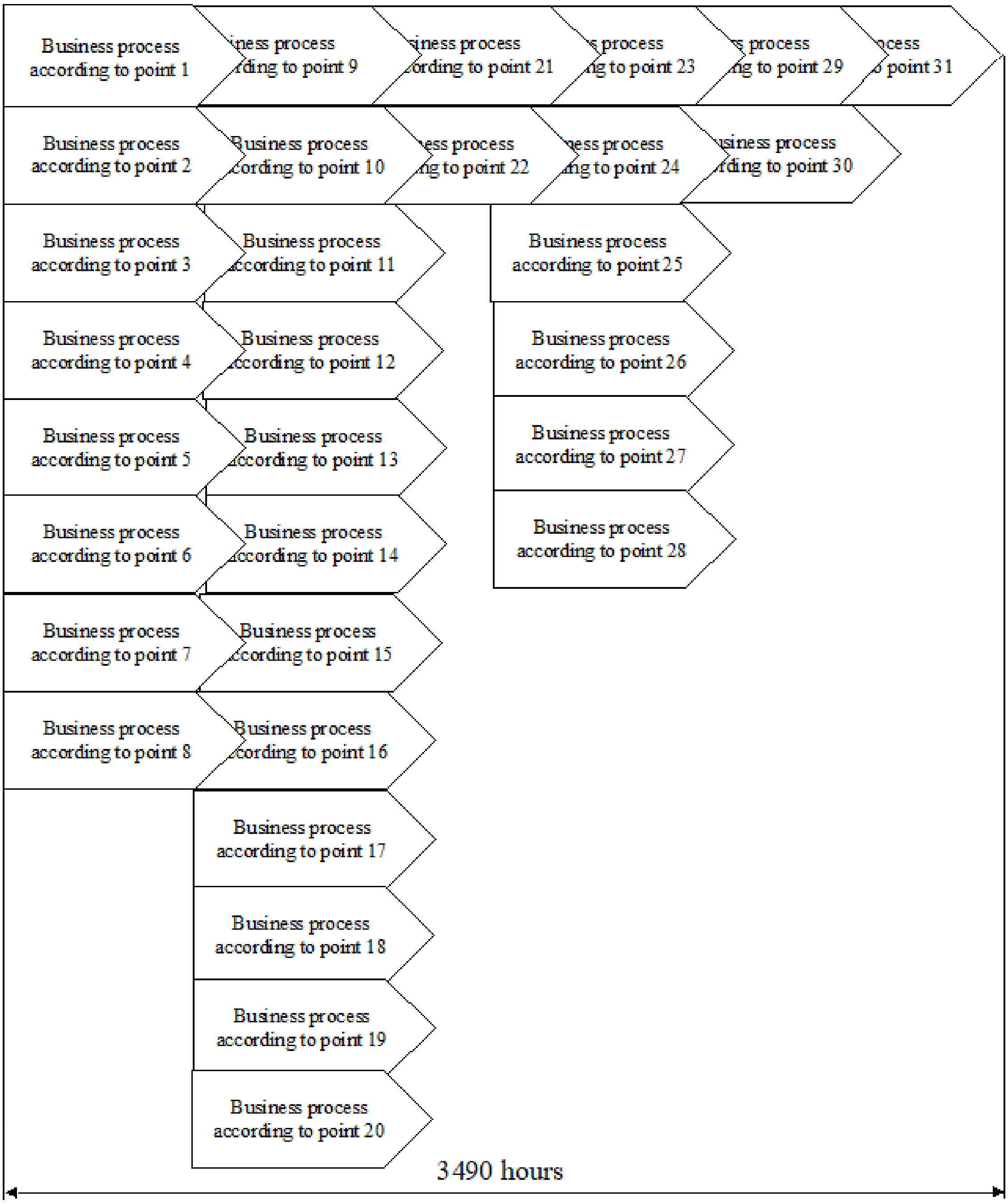

Figure 4. Overall time of all series of business processes required to complete the DTPP, based on the data from Table 2.

5. Discussion

Modelling the DTPP for an engineering enterprise not only aims to reduce time but also to minimise costs associated with this process.

Suppose x_i is the volume of the DTPP for the release of a product of the *i*-th version and k_i is the cost of the DTPP of the *i*-th product, then the amount of funds for the DTPP for the *i*-th product amount to $k_i x_i$ monetary units (MU). The amount of funds required for the DTPP of products manufactured by an engineering enterprise is:

$$K(x_i)=k_1x_1+k_2x_2+\ldots+k_nx_n \tag{10}$$

where $k_n x_n$ *are* the funds for the DTPP of a product.

$K(x_i)$ *is* the sum of funds for the total volume of the DTPP of all products manufactured by an engineering enterprise.

Restrictions are imposed based on the resources necessary for the DTPP of an engineering enterprise to launch a product:

$$d_{j1}x_1+d_{j2}x_2+\ldots+d_{jn}\,x_n \leq h_j,\ j=1,2,\ldots,m \tag{11}$$

$d_{jn}\,x_n$ *are* resources for the DTPP of each product;

h_j is the margin of resources for the DTPP.

Implicit restrictions cannot be negative for the DTPP, which means that the variables are to be non-negative, as follows:

$$x_i \geq 0 \tag{12}$$

A set of mathematical relations for the DTPP of an engineering enterprise (objective function and constraints) represents a mathematical model for the DTPP task to minimise the costs of pre-production for the product release.

$$\begin{cases} K(x_i)=k_1x_1+k_2x_2+\ldots+k_nx_n \rightarrow \min \\ d_{j1}x_1+d_{j2}x_2+\ldots+d_{jn}\,x_n \leq h_j,\ j = 1,2,\ldots,m \\ x_i \geq 0,\ i = 1,2,\ldots,n \end{cases} \tag{13}$$

The matters of top priority when assessing the management prospects at an engineering enterprise are selecting the most suitable design and technological process to meet consumer needs.

6. Conclusion

Growing attention to engineering enterprises is derived from the fact that they play one of the leading roles in our country's economic systems. Among the most significant features, it is worth pinpointing that engineering enterprises:

- are major taxpayers;
- create jobs;
- manufacture products for export;
- produce domestic products;
- contribute to the transition from the commodity economy to the non-commodity export economy;
- boost competitiveness in both domestic and international markets;
- adapt to a new economic realm;
- generate new competencies and qualifications in the workforce (skill, knowledge, and experience);
- develop digital technologies;
- catalogue industrial products at all stages of production and delivery;
- maximise the profit for an enterprise;
- create high added value and consumer value;
- accelerate capitalisation of business.

Further, the availability of information flow via the market-centred DTPP at an engineering enterprise facilitates information exchange across industries.

However, the current situation shows that the majority of measures initiated to carry out the DTPP, DT, or TD are taken on the spot and rely on the available resources only. The reason is rather simple and boils down to the fact that modelling via quantitative indicators is complicated and time-consuming. Another important consideration is that, normally, the management of the department for design and technology does not need to obtain very specific data. In most cases, a general development track is more than enough. For instance, these tracks might weigh the importance of developing standard or group technologies—individual or group work—at a production site.

Another issue to bear in mind is that the transition from series processes to parallel-series ones makes the curve of the design pre-production and technology pre-production change, thus indicating shifts in production timeframe. Generally, the concept of DTPP modelling at an engineering enterprise can be elucidated from the perspective of IT architecture, built via a fuzzy-set approach.

By applying a fuzzy logic approach, we justified the possibility of reducing the DTPP timeframe by introducing a transition from the series processes to the parallel-series ones in the design pre-production and technology pre-production. Overall, proper integration of digital technologies promises to reduce the DTPP timeframe and introduce an IT architecture for engineering enterprises to build end-to-end designs using information systems in development and production.

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The article was submitted 22.04.2022, approved after reviewing 18.07.2022, and accepted for publication 20.07.2022

Статья поступила в редакцию 22.04.2022, одобрена после рецензирования 18.07.2022, принята к публикации 20.07.2022.

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