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Cost management for PLM systems: A way to improve the competitiveness in digital economy

Evgeny Kolbachev [1*], **Vladimir Zharov** [2] **and Vyacheslav Tsukerman** [3]

[1] Platov South-Russian State Polytechnic University, Prosveschenia Str., 132, Novocherkassk, 346428, Russia

[2] Apatity branch of Murmansk Arctic State University, Lesnaya Str., 29, Apatity, 184209, Russia

[3] Luzin Institute for Economic Studies of the Kola Science Centre of the Russian Academy of Sciences (KSC RAS), Fersmana Str., 14, Apatity, 184209, Russia

* E-mail: kolbachev@yandex.ru

Abstract Two of the most efficient ways of increasing digital economy systems' competitiveness are creating digital twins using PLM-based cost management instruments. Determining machinery's cost characteristics on the conceive step of their lifecycle is the most efficient if it's based on probabilistic approach. On the next steps of design process, such as concept design and detailed design, a designed construction's price should be estimated basing on its informational (parametric) complexity indexes. This price is to be compared with earlier estimated approximate parameters. The most efficient way of using presented approach is making it a part of CAx system (first of all, such systems as MCAD and EDA). It may be applied as a part of invariant subsystem of technical and economic parameters for the computer-aided account facilities and for simulation of processes (CAE, CAA). The most appropriate way of organizing design and development processes is to use AGILE ideology. This approach gives a possibility to create an integral system of creating digital twins that is useable on any step of product's lifecycle.

1. Introduction

Creating and using of digital twins is the well-known and efficient way of the production economy's digitalization. Digital twin, first of all, is a virtual replica of physical object's (product's), processes' or systems' operation condition. Using a digital twin means using virtual reality to simulate processes of real product's characteristics changing. Product's characteristics change if one of its elements is replaced with other. They also change during product's lifecycle [1, 2, 3]. Using of digital twins is necessary for well-timed design and production of next-gen customized and competitive products [4].

The cost characteristics of product also change during its lifecycle and should be taken into account during digitalization and reindustrialization. On other hand, using special instruments to manage the product's lifecycle is a way to increase the machine-building corporation's (or other production enterprise's) competitiveness. That's way using production lifecycle management systems (PLM-systems) as an element of digital twins seems to be an appropriate decision [5].

Digitalization is a process that changes not only machinery: a worker is also a part of production system. That's why is so important to avert a negative impact of digital technologies upon humans [6, 7]. The best way to avert a negative impact is to work out human-oriented objects and systems. One of the basic characteristics of human-oriented system is its safety, and that's why systems of this type are more competitive than other.

The mentioned tendencies make especially actual a well-known work [8] by I. Tomotoshi. In this work author reviews production operations and their relation to human factor. The basic idea is that the researcher is to pay attention to the operations' specific features that become apparent when product lifecycle management (PLM) and project management (PM) instruments are used.

There is another important system that is to be worked out in the same time with engineering requirements, quality rating, and economic parameters of the designed product. It's a customer relationship management and requirements management (CRM – RqM) system. It is to be worked out on such steps of product's lifecycle as conceive and conceptual development, and its procedures are to be strictly followed. Using of digital twins is an efficient way to solve this problem. For example: at the Hannover Messe 2018 Siemens Corporation presented an original cloud-based platform MindSphere [9]. It's a new version of operation platform that is used to create digital twins to solve a mentioned problem. A successful user of similar technologies in Russia is UEC-Saturn [10].

In the same time, such problems as created machine's cost determining (and also determining its exploitation cost) and coordination with a customer are to be solved.

In the last decades of the 20th century and in the beginning of the 21st century a number of authors presented researches in the said field and worked out a number of appropriate methodologies [11, 12]. But these works can't give a review of any possible conditions of designing and exploitation of machinery such as determining machinery's cost and constructional characteristics. Machinery lifecycle management is also to take into account social and economic factors.

A number of approaches and ways to solve the mentioned problems are presented below.

2. Research methods

2.1. Determining machinery's cost characteristics on the conceive step of lifecycle

Possibility approach is applicable if the goal of designed product (or of its part) is emergency prevention. Elimination of the consequences of the accident is much more expensive operation than using of the designed product. Situations, in which the said approach is applicable, take place rather often.

A perfect example of the said situation is using of the water conservation systems: it's a way to prevent procurement of provision in other regions if summer is dry. Building of the water conservation system is cheaper than buying provision. It's obvious that dry summer is a probable occasion, but its probability may be determined accurately enough using statistical information.

Functioning of some machinery's parts prevent accidents and make its exploitation safe. Elimination of the consequences (both direct and indirect) of the possible accident would have required significant funds.

Following the idea that human-oriented product is a safe product requires taking into account two basic factors. First of them is operating safety (because any accident is a probable reason for human's health hazard or another safety risk). Second is ecological safety. Taking these factors into account gives a possibility to avoid human health hazard if the product functions sustainably in the correct way.

In the research by D. Gorobets [13] a similar situation is examined by the example of electric locomotives building. Industrial disaster on the railroad is also a probable occasion, but they rarely take place. That's why it's impossible to get representative statistical information to determine their probability accurately enough.

Designing of the specific products to prevent accidents and industrial disasters is not the only way of using possibility approach. Emergency shutdown of any object or system that had a utility potential causes different types of crisis situation that may last short or long.

Evaluation of the designed objects or systems functioning results, based on the decreasing of risks level during their functioning, may be described using an insurance model. The cost parameters during its functioning may be determined by actuarial calculations [14]. This approach requires considering a mass risk insurance as an analog or alternative for designed object's or system's normal functioning. So, a working model is the following: economic result of the designed object's or system's functioning is supposed to be similar to result of specific insurance fund's functioning (the said fund is to give a possibility to carry out numerous measures to eliminate the consequences of object's or system's extinction or dysfunction).

As an analog of insurance rate is to be used an economically grounded level of costs for the designed object's or system's functioning. The yearly cost of its keeping functional is similar to the yearly insurance rate that gives a possibility to compensate the losses with insurance payment if the accident takes place, and designed object doesn't exist anymore.

During the determining of cost level for a designed object's functioning, a number of indexes are to be estimated: an accident frequency; accumulation risk index; loss ratio; average sum insured; severity of the risk; unprofitability of the sum insured; rate of loss; frequency of damage; severity of the damage.

An accident frequency's F_a basic characteristic is a number of accidents and crisis situations in the analyzed period:

$$F_a = \frac{L}{n} \tag{1}$$

F_a is an accident frequency index; L is a number of crisis situations; n is a period duration.

Rate of loss, or the insurance payout ratio R_l is a percentage ratio of the indemnity paid to the amount of insurance premiums:

$$R_l = \frac{B}{S} \cdot 100\% \tag{2}$$

R_l is rate of loss; S is the amount of insurance premiums (rubles); B is a sum of indemnity paid (rubles).

In the analyzed example a calculation may be based on the idea that S amount is similar to a designed object's total service cost in analyzed period, and B is similar to a cost paid to eliminate the consequences of crisis situation.

To predict a designed object's security level (if there's no enough representative statistical information about the object's type to determine this level) it's appropriate to use solution theory and Bayes' formula [15].

In this situation a possibility $P(H_1)$ of object's trouble-free functioning may be determined in the following way:

$$P(H_1) = 1 - K \tag{3}$$

H_1 here is a hypothesis about designed object's trouble-free functioning during the whole lifecycle; K is an estimated probability of the accident, based on the expert knowledge.

The following formula is to be used to determine a probability of the accident in this situation:

$$P(H_2) = K \tag{4}$$

H_2 here is a hypothesis that the accident matters during the object's functioning.

Presented approach was used to substantiate a level of needed costs during the determining of safety level for the functioning of the electric locomotives [13] and mining equipment [16].

Taking as a basis an appropriate cost per function of safe operation securing, and value engineering methodology [17], it becomes possible to determine total cost of the created machinery exploitation. Its price may be determined in the same way. After the consultation with a customer, these parameters become basic principles during the working out of machine's construction and design.

2.2. Methodology of machinery's cost estimation during the concept design and detailed design periods: functions and parameters as a basis

When the designed machinery's cost parameters are determined and coordinated with a customer, they should become a basis for construction working out during the concept design and detailed design periods. In these periods machinery parameters' estimation is to be based on the functional model's parameters. It's also important to take into account an idea that any machine's parameter may be represented as an aggregation of particular indexes, and at the same time, as a component of bigger aggregate. This phenomenon may be represented as a hierarchic structure of the indexes, and the significance level of any index may be determined basing on their weighting factors.

It seems to be appropriate to strike the exploitation safety indexes off any generalized indexes', because they are more important than any other. Weighting factors' system is unable to represent how important they are. That's why exploitation safety indexes are to be represented as a special hierarchic structure, alternative to the basic one.

It's also appropriate to determine construction's cost parameters basing on its tentative parameters set during the concept design and detailed design periods. It's appropriate, because the refined production costs may be determined not earlier than details production technologies are worked out.

There are numerous methods of determining machinery's cost, based on its construction parameters in the early period of design, and for each milestone [18, 19]. We follow the idea that the most appropriate method of cost estimation is based on the construction's parametric cost index [20]. The most appropriate characteristic of the product, which is used for mechanical engineering, is the index of parametric complexity per unit of detail mass.

2.3. Organizational methods for the design processes

Project engineering is an integral part of working out a new technical system. It may be represented as a process of increasing the amount of information about system. Thus, a level of system's entropy decreases in the same time [20].

The level of construction's approximating to the optimum condition may be presented as a level of the construct's entropy. Decreasing of the entropy level means that the construct's conditions become closer to the optimum. We can use this dependence because during the development and analyzing of the different versions of the construct the number of the possible (potential) versions to choose the optimum construct of them decreases. Each of the versions is a step to the optimum.

In the analyzed situation the conditional entropy index, derived by A. Renyi [21] seems to be the most appropriate. The essence of the presented approach is the following.

Let V is a randomly chosen version of the construct, and the probability of the choice is positive; ξ is a random variable that possesses the values $x_1, x_2, \ldots, x_n$. We denote by A_k the derivative of V, a version of construct which's $\xi = x_k$ ($k = 1, 2, \ldots, N$). Then basing on the definition, we determine the conditional entropy of ξ under the condition V as entropy of the random variable ξ, calculated on the base of the conditional probabilities' distribution. It's taken that that the construct version V is created. So we derive the equation.

$$H_V(\xi) = \sum P(A_k|V)\log_2 \frac{1}{P(A_k|V)} \tag{5}$$

$P(A_k|V)$ is a conditional probability of the version A_k under the condition B (B is taken as the initial version).

It's obvious that the most efficient way of using presented approach is making it a part of CAx system (first of all, such systems as MCAD and EDA). It may be applied as a part of invariant subsystem of technical and economic parameters for the computer-aided account facilities and for processes simulation (CAE, CAA) [22]. During the organization of the machinery design processes basing on the economic characteristics it's appropriate to use AGILE ideology.

Following AGILE ideology is the way to respond to changing of the design environment (both internal and external) as promptly as possible. It also gives a possibility to take into account new information that exists during design processes. But following the said ideology requires a coordinated work of developers (mostly, designers) and customers' inspectors. They are to examine each step of the project development process and change a draft proposal if needed.

Some authors [23, 24] represent AGILE ideology as the next step of LEAN methodology's development. This representation seems to be incorrect. The most efficient using of AGILE ideology is possible when the basic problem to be solved is interaction between developers and customers (on any step of development process, including determining product cost). It's appropriate during working out and designing of a new product. In contrast with it, LEAN methodology is the most applicable for mass production processes.

3. Practical use of the concept and instruments, bottom lines and ideas for future research

Presented methodology as an integral concept, or some of its separate ideas and instruments, were used for project engineering during working out locomotives and other railroad engineering, machinery for mining construction, melioration and land reclamation. Information about some of these projects and list of used methods are presented in table 1. Parameters of the worked out products, and presented methodology that's used, are presented in table 2.

Table 1. Projects and project sets realized in SRSPU (NPI) and based on presented methodology.

Worked out objects	Years of realization	Used methods and instruments				
		Actuarial approach	Bayes's method	Parametrical complexity	Construction's entropy	Agile ideology
Electric locomotives	2004-2010	–	+	+	–	–
Material mining equipment	2006-2011	+	+	+	–	–
Waterside structures	2004-2015	+	–	+	+	–
Fish protectors for the weirs and water intakes	2004-2015	+	–	+	+	–
Power installations for the melioration systems	2017-2018	+	–	+	+	+

Table 2. Parameters of some products worked out with the help of presented methodology.

Product	Determined safety costs, thousand rubles	Accident prevention costs function	Product's estimated value on the level of draft proposal, thousand rubles
Electric locomotive (for passenger service, AC)	11611	0.251	46258
Electric locomotive (for cargo transportation, AC, two sections)	18764	0.185	101432

Product	Determined safety costs, thousand rubles	Accident prevention costs function	Product's estimated value on the level of draft proposal, thousand rubles
Electric locomotive (for passenger service, dual standard, AC and DC))	31320	0.294	106534
Electro pulse fish protector	13.6	0.017	798

Summarizing the said, it's possible to present some ideas for future research in this field (developing and improving the probabilistic approach-based methodology for project engineering of technical systems). In other hand, when accident prevention costs certification is based on actuarial approach, a great volume of statistical information is required. Information is required to determine a probability of accident, anthropogenic disaster and other types of technical system's damages. To make using of Bayes's method more reliable, the perfect algorithm of the expert evaluation is needed. Using parametric complexity indexes to determine costs requires working out a legal framework to make a list of evaluated constructions greater, because the existing methodology gives a possibility to determine indexes of details and mounts for mechanical engineering. Solving the said problems should give a possibility to create an integral system of creating digital twins for the products and details that covers any stage of system's lifecycle.

4. Conclusion

Creating and using of digital twins is one of the key features of the production economy's digitalization. Thus, determining of machinery's cost characteristics for PLM systems on the conceive step of their lifecycle is the most efficient if it's based on probabilistic approach. In this situation a possibility of designed machinery's accident-free exploitation is to be estimated basing on actuarial method or using Bayes' formula. This possibility is to be taken into account to estimate the elimination of the consequences of accident costs. It's appropriate to use these costs and value engineering methodology to determine designed machinery's exploitation cost and its release price.

On the next steps of design process, such as concept design and detailed design, a designed construction's price should be estimated basing on its informational (parametric) complexity indexes. This price is to be compared with earlier estimated approximate parameters.

The most efficient way of using presented approach is making it a part of CAx system (first of all, such systems as MCAD and EDA). It may be applied as a part of invariant subsystem of technical and economic parameters for the computer-aided account facilities and for processes simulation (CAE, CAA). The most appropriate way of organizing design and development processes in the system is to use AGILE ideology.

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