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AN ALGORITHM OF SELECTING THE PRICING MODEL FOR A CONSTRUCTION CONTRACT

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Розроблено алгоритм вибору цінової моделі контракту на будівництво. Це важливо, тому що ціна є одним з ключових параметрів контракту. Саме цей параметр визначає, яка частина створюваної в рамках контракту цінності у грошовій формі дістається підряднику (виконавцю, постачальнику), а яка залишається замовникові. В результаті дослідження встановлено, що контрактними драйверами ціноутворення виступають початкова ціна, контроль, стимули (моральний ризик) і фінальна ціна. Така трактовка збігається з основами Теорії контрактів і є передумовою фундаментальної достовірності розробленої системи. Базовими вхідними компонентами алгоритму прийняття рішення щодо найбільш доцільної цінової стратегії є матриця властивостей моделей ціни контракту і метрика питань з оцінювання відповідних пріоритетів Замовника по проекту. Система дозволяє обрати одну з п'яти ключових стратегій ціни: CRC, MC, TC, LS або GMP, які застосовуються міжнародною практикою. Використання системи вибору цінової моделі контракту спільно з системою обрання організаційного профілю виконання проекту дає можливість обрати найбільш доцільну стратегію з 130-ти парних альтернатив. Пропонований підхід кумулятивним чином сприяє успіху будівельних проектів і має уніфікований характер. Формалізований інструментарій порівняльного аналізу альтернатив є цифровим змістом Системи вибору цінової стратегії COMP (Contract Organizational Mechanisms: Pricing). Алгоритм побудований на розрахунку векторів пріоритетів факторів ціноутворення по проекту (на основі визначених множин рангів і рейтингів) з подальшою бальною оцінкою доцільності застосування у проекті кожної з альтернативних моделей ціни. Апробація системи COMP у проекті будівництва Льодової арени в м. Києві показала, що створена концептуальна модель (пропонований алгоритм) дозволяє дійти доцільного рішення щодо цінової стратегії контракту з математичною, високою теоретичною і практичною аргументованістю

Ключові слова: теорія контрактів, багатокритеріальний аналіз, цінові механізми, прийняття стратегічних рішень

1. Introduction

In capital construction, procurement can be considered as the backbone of the entire management structure [1]. In keeping with this figurative terminology, the decision to apply a particular price mechanism (payment profile) is its main vertebra.

Price is one of the key parameters of a contract. It is this parameter that determines what part of the value created by the contract in the form of money is due to the contractor (performer, supplier) and what remains to the client. Construction contracts deal with creating significant (capital) values, and therefore, pricing issues in this area are of particular importance. Acknowledging this challenge, international practice has created a range of pricing models for a construction contract, each of which has its advantages and disadvantages. As to the reverse side of this medal, in the framework of each capital construction project there is a problem of a reasonable choice of a price strategy.

The choice of a pricing structure for a construction contract is still based on acquired empirical experience, without the use of a systematic mathematically formalized procedure. Sometimes the choice is made intuitively and sometimes it is based on considering established traditions or business fashion. The solution to this problem used to be hampered by the lack of a recognized theory that would serve as the basis for creating an appropriate conceptual framework for making the appropriate decision. Fortunately, this hurdle is currently "officially" lifted – the founders of contract theory were awarded the Nobel Prize in 2016 [2]. Thus, now the peak of relevance is the task to develop a formalized apparatus (algorithm) for selecting a price model of a construction contract in the context of contract theory.

2. Literature review and problem statement

The subject of this study has three key projections that are disclosed in published sources, and one of them is the typology of contract price models with considering their characteristics. Capital construction projects are implemented using the following typical price mechanisms:

– lump sum – LS;
– guaranteed maximum price (GMP);
– cost-reimbursement contract (CRC);
– target cost (TC);
– payment according to the measured volumes of work (measurement contract – MC) [3].

Each of these models has a contract price that is convenient and appropriate in the presence of certain conditions for the project. In [3], for each price profile, their characteristic conditions and circumstances are given, but the formalized mechanism of making the corresponding decision is absent.

None of the price models is specific to any particular method of project implementation [4]. Let us say, if the chosen method of project implementation is design-build (DB), then this does not mean that the price model for the contract should be lump sum (LS). Yes, some of the pricing mechanisms really fit into one of the project implementation strategies a bit better while others are a bit worse. However, this is only a "soft" predisposition, and a well-founded choice should be made on the basis of a systematic analysis of a specific project.

Performance of capital construction projects is often associated with high risks, limited trust between contracting parties, and lack of appropriate incentives. Motivational contractual mechanisms contribute to the success of construction projects [5].

Having considered the application of the model of guaranteed maximum price (GMP), the authors of study [5] draw attention to the numerical and significant advantages of this strategy. However, other price mechanisms have their strengths, and therefore, some of them may be more expedient, giving certain priorities for a specific project. Thus, we would like to emphasize again that for each project a separate analysis should be conducted and the most appropriate alternative should be chosen.

The above shows that the classification of price mechanisms has already been highlighted in earlier studies. However, a systematic mathematical apparatus for analysing relevant alternatives on a reliable theoretical basis has not been proposed.

Another, most important projection of this study is the theoretical foundations of contractual relationships. Contract theory deals with the fundamental problem of business cooperation of economic entities. The parties to a contract have a temptation to act selfishly – that is, they try to maximize their own profit, even to the detriment of the total, common benefit of the project. If the parties could conclude a contract that would fully describe any further course of events under the project, then "business selfishness" would not be such an acute threat [2]. However, this is impossible, especially in projects of capital construction, due to their high complexity, long-term duration, the possibility of making further changes to the list of assignments, etc. Consequently, contracts are incomplete. Not all actions of the contractor (and the client) can be made transparent, and consequently, "moral hazard" is an objective feature of contractual relations. In order to solve this problem, contracts use various motivation mechanisms (incentives) that encourage the parties to act more effectively. These issues are the focus of contract theory.

In other words, in reality it is usually impossible in advance to prescribe the contractual obligations of the parties clearly, unambiguously, and comprehensively. Contract theory, in particular, examines the effect of contractual motivational mechanisms that are designed to "compensate for the gaps" of incomplete contracts [6].

Today, the parameter of uncertainty, which naturally can be heated up by a factor of distrust between business entities, is "embedded" with economic theory. The unpredictability greatly complicates the estimating process, especially if we take into account the dependence of the project outcome on the behaviour of individuals [7]. At the same time, rational decisions can be made in the unpredictable world. Choosing the best alternative contract price model for a project is precisely an example of a decision in a situation where to varying degrees there is both unpredictability and distrust. Contract theory can help solve this problem.

Consequently, the literature review shows that contract theory can serve as a methodological basis for creating a reasonable algorithm of choosing a price model for a construction contract.

Another key projection of this topic is the contextual aspects of the subject of research. Determining the pricing strategy is one of the six cumulative facets in the "crystal" of managing the value of capital construction projects [8]. This crystal component acts in synergy primarily with the profiling of contract systems (selecting a project implementation model).

It should also be noted that contextual, technical and *behavioural* competencies are the three groups of factors that improve project and programme management and contribute to their success [9]. Consequently, the conceptual model for making a decision on a contract price profile that takes into account the interests of the parties, the technical aspects of the project, identified priorities, etc., in practice will contribute to the formation of a conflict-free nature of the relationship between project participants.

One of the most important project stages is the initial phase, which lasts from the moment of understanding the business idea until the decision on financing the project is made. At this stage, it is important not only to form a "correct project", but also to determine "the correct mechanism for its implementation". It should take into account the interests of parties concerned as well as any uncertainty, which is an integral feature of the project environment [10]. Consequently, since the pricing strategy of a construction contract is one of the basic prerequisites for the success of the project and a means of proactive regulation of the relationship between the client and the contractor, it is advisable to choose the price model during such stages as the formation of a concept, feasibility study, and project planning. It should also be emphasized that the decision-making procedure can be carried out several times, and the pre-selected strategy may be revised, updated (even during the preparation of tender documents).

Study [11] confirms that the role of payment mechanisms (price models) in construction contracts is very important. Selecting an appropriate price profile from among the available ones has a positive effect on the results of the project. For comparative analysis of some alternatives by *integrated project teams*, the study proposes a simulation of the cash flow of the project. However, for a wider range of options for project work, this toolkit is not recommended. One of the key reasons is the presence of a "moral hazard" in the relationship between independent entities. This again suggests that the solution to the problem should be sought in the field of contract theory.

The foregoing indicates that issues of contract price models are widely discussed in published literature, but the proposed approaches to analysing are of a predictive nature and they do not cover the entire field of possible cases and circumstances.

Consequently, on the one hand, there are a number of contract price models, each of which has its own characteristics, advantages, and disadvantages. It is empirically proven that the use of a particular model is appropriate in the presence of relevant conditions and characteristics of the project. On the other hand, contract theory shows how to solve such problems as, in particular, "moral hazard" and incompleteness of available information on a project. An unfulfilled niche of scientific research still consists in the need to create an algorithm of selecting a proper pricing model based on the foundations of contract theory. The research should be focused on the basic principles of the system being created, the general scheme of making an appropriate decision, and a specific formalized algorithm.

3. The aim and objectives of the study

The aim of the study is to develop an algorithm of selecting a contract price model (payment profile) in the area of the best practices of capital construction and the key factors of contract theory.

To achieve this aim, the research should solve the following objectives:

– to define intra-contract drivers of pricing mechanisms in construction projects;

– to propose the architecture of an algorithm for making the appropriate decision;

– to develop a formalized apparatus for a comparative analysis of alternatives and test it within the framework of an illustrative business case.

4. Drivers (a coordinate system) of pricing mechanisms

Based on [12], in the context of contract theory, the following can be noted. In the course of concluding a construction contract between the client and the contractor that have different information, the interaction is "principal – agent". In this plane, the typical pricing situation is as follows. The target function (utility, value) of the principal (client) will be maximized by strategically choosing a price model for the contract. This model, in particular, involves both certain mechanisms of motivation and the corresponding control processes. After this, the target function (utility) of the agent (contractor), knowing the choice of the principal, will also be maximized.

Consequently, the contractor at the tender or in the course of negotiating will offer a competitive price according to which, in compliance with the model that is applied (selected) by the client, money will be received for the performed construction work. In case of excessive overstatement of the price by the bidder, the contract will go to a competitor. Since the time of signing the contract, the relevant controls and motivations are involved. Ultimately, after completing all payments and work, the final price of the construction project will be formed. Thus, the key pricing drivers, if summed up, can be defined as follows: the initial contract price, the mechanisms of motivation, the control processes, and the final price.

On the basis of the above generalized and summarised definition, let us formulate a wider interpretation of each of the contract pricing drivers.

The initial contract price is determined by the minimum bid from the contract applicants. The price level depends on the risk of the project for the contractor. The lower the financial risk for the contractor, the lower the minimum bid (at the same time, by definition, the starting price must be no less than the expected costs borne by the contractor).

The mechanisms of motivation act in opposition to the "moral hazard", creating the levers for directing the actions of the contractor in the best interests of the project. The more effective the contractual mechanisms of motivation, the less the probability of "moral hazard" on the part of the agent is.

The control processes allow monitoring, whether (and to what extent precisely) the contractor's actions comply with the requirements of the contract. Consequently, this driver depends on the degree of completeness of the contract – the higher the completeness of contractual arrangements and the specification details, the more careful can be the control over the agent's actions.

The final price is formed under the influence of all changes to the project during the construction period, finally fixed at the time of paying the last amount under the contract. Exceeding the final price of a certain level (limit) may or may not be a significant negative factor for the client. This question is related to the "cost-benefit" analysis of the project.

The above-mentioned drivers of pricing mechanisms are a coordinate system in which an analysis of the suitability of each alternative contract price model for any specific capital construction project should be performed.

5. The architecture of an algorithm for finding a solution on the pricing strategy

The starting block of the conceptual model for choosing a price model for a project is the drivers (measurements of the pricing dimension), which are defined above based on the best practices and foundations of contract theory (Fig. 1). This block, together with the typology of key pricing strategies, the matrix of ratings of their properties and the metric of questions for determining the price priorities of the client (the initiator of the project), forms a stable context of the system. The rest of the business process blocks form a moving, dynamic context of the system, reflecting the specifics of a project under consideration and the priorities of a definite client for a construction site.

At the same time, it is noteworthy that by using blocks 8 and 9 of the algorithm, the analysed project is placed in the appropriate "cell" of the field of alternative pricing strategies. Let us briefly define and characterize such key alternatives.

The contractor's *expense recovery and reimbursement* profile (model) allows for a low starting price of the contract, provides for a detailed control by the client, weakly encourages the contractor to seek ways to save money, and is characterized by low predictability of the final price level.

The profile of the *lump sum payment* presupposes a relatively high starting price of the contract, provides for minimal control by the client, encourages the contractor to reduce costs, and has a high predictability of the final price.

The profile of *payment according to the measured work* (measurement payment) by the action of pricing drivers occupies an intermediate position between the two above-mentioned models of the contract price.

Two additional key strategies use incentive mechanisms for the contractor by setting a price threshold.

The *target costing* (TC) specification implies that in the event of a final price deviation from a fixed threshold, the difference (or savings or overrun of costs) in a certain proportion is distributed between the parties to the contract. The TC model gives a relatively low starting price of a contract, which is associated with detailed control as well as encourages the contractor to save and not exceed the threshold of the final price.

The profile of the *guaranteed maximum price* (GMP) differs from TC as the distribution is subject only to cost savings; in case of exceeding the price threshold, all losses are borne by the contractor. Consequently, the GMP model is similar to TC based on the nature of the pricing mechanism; however, the final price driver is more stringent and strong.

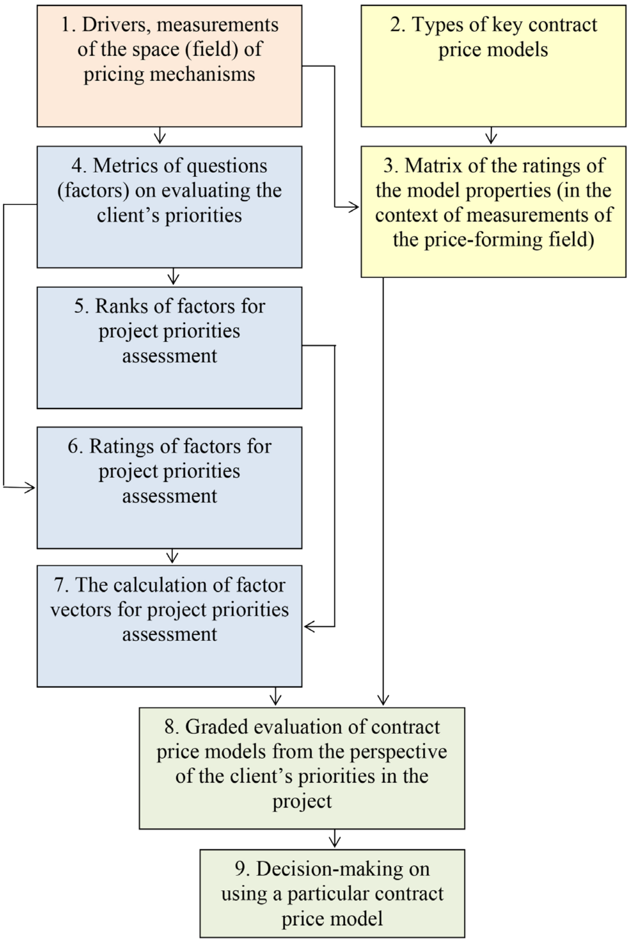

Fig. 1. The conceptual business process (algorithm) of decision-making on the most appropriate model of the contract price for a project

The architecture of the business process lies at the heart of the formalized mathematical apparatus of comparative analysis of alternatives.

6. Formalized content (algorithm) of a conceptual model for choosing a pricing strategy

The above mentioned drivers and structure are the basis of the pricing strategy (COMP – Contract Organizational Mechanisms: Pricing). Additionally, we note that "*comp*" is commonly a short form of the word "*computation*" (estimation, calculation) or "*compensation*" (remuneration, reward).

Drivers of pricing mechanisms are measures of both the properties of price models and the client's respective priorities for a particular project. Consequently, the coordinate system "*initial price – control – incentives / moral hazard – final price*" entails a plurality of properties of contract pricing models:

$$\left\{\begin{matrix}\{S_m\}\\ \{C_m\}\\ \{I_m\}\\ \{F_m\}\end{matrix}\right\} = B, \tag{1}$$

where $\{S_m\}$ is a subset of ratings of the properties of models in relation to the driver of the initial (starting) price; $\{C_m\}$ is the control by the client; $\{I_m\}$ is the moral hazard / incentives; $\{F_m\}$ is the final contract price; m is a serial number of the model from 1 to 5.

The numerical values of the ratings of the properties (Table 1) characterize each model as to in which of the drivers one strategy or another works better or worse. The higher the rating for a particular model, the better is the pricing driver for it in the client's interest.

Table 1

The matrix of ratings of properties of contract price models for capital construction

Contract price model (pricing strategy)	Measurements of contract pricing space			
	Initial price/bid	Control, completeness	"Moral hazard" & incentives	Final price
Guaranteed maximum price (GMP)*	S_1=4	C_1=4	R_1=4	F_1=8
Payment of certain complex amounts (Lump Sum – LS)	S_2=3	C_2=3	R_2=6	F_2=8
Target Cost (TC)*	S_3=5	C_3=5	R_3=5	F_3=5
Payment for measured volumes of work (Measurement Contract – MC)	S_4=8	C_4=4	R_4=5	F_4=3
Compensation of expenses and payment of remuneration (Cost Reimbursable Contract – CRC)	S_5=8	C_5=8	R_5=2	F_5=2

*Note: * – "Threshold" contract price models*

Thus, for example, in the model of compensating expenses and paying remuneration, the strong drivers are the initial price and control whereas the weak ones are incentives and the final price. At the same time, the rating of properties for each of the models is 20 (Table 1). In this way, the conceptual decision-making process does not "discriminate" any of the price strategies while adhering to the principle of "equality of strategies" within the system as a whole. Otherwise, if the total driver ratings for each strategy were not equal to one another, the system would be set up to make biased decisions.

On the other hand, for each project, the client, within the framework of the COMP system, defines priorities for the drivers of the pricing mechanism. Thus, a set of ranks of priorities D^r is formed, and each element belongs to its own group:

$$\left.\begin{bmatrix}\{S_k^r\}\\ \{C_k^r\}\\ \{I_k^r\}\\ \{F_k^r\}\end{bmatrix}\right\}=D^r, \qquad (2)$$

where $\{S_k^r\}$ is a subset of the ranks of the client's priorities regarding the driver of the initial (starting) price; $\{C_k^r\}$ is the control; $\{I_k^r\}$ is the moral hazard / incentives; $\{F_k^r\}$ is the final contract price.

In a single manner from [13], priorities are determined by answering a number of questions (Table 2). For each pricing driver, the COMP system provides three questions, and therefore $k=\overline{1,3}$. For example, as to the driver of the initial price, the first question (k=1) determines whether it is important to have the lowest bidding prices from the tenderers (or in the course of competitive negotiations). Equality of the number of questions in the groups corresponds to the principle of a balanced decision-making system – none of the drivers of pricing mechanisms is a priori or more or less important. Their priority within a particular project is determined by the client by implementing steps 5–7 of the algorithm (Fig. 1).

The rank of each element in formula (2) is a natural number in the range from 1 to 9. An element with the minimum possible priority for the client on the project is assigned rank 1, and the maximum possible is 9.

At the same time, depending on the answer given by the client to the relevant question (Table 2), each item acquires a certain rating. Consequently, a set of ratings of the elements of price priorities within the project is formed as follows:

$$\left.\begin{bmatrix}\{S_k^\rho\}\\ \{C_k^\rho\}\\ \{I_k^\rho\}\\ \{F_k^\rho\}\end{bmatrix}\right\}=D^\rho, \qquad (3)$$

where $\{S_k^\rho\}$ is a subset of ratings of the client's priorities regarding the driver of the initial (starting) price; $\{C_k^\rho\}$ is the control; $\{I_k^\rho\}$ is the moral hazard / incentives; $\{F_k^\rho\}$ is the final contract price.

Thus, the client has three options for answering each of the questions – "A", "B" or "C" (Table 2). If the answer is "A", the corresponding component receives a rating of 3; in the case of option "B", the rating is 2; in the case of option "C", it is 1. For example, if the client believes that due to certain characteristics of the project, the contract tenderers will be able to prepare for it justified price bids (answer option "A"), then the rating of this factor will be equal to 3.

The product of a rank multiplied by the rating for each individual factor shows its vector of priority. In this way, within a separate project, a set of priority vectors is created for all four pricing drivers:

Table 2

The conceptual metric / matrix for determining the client's priorities in choosing a pricing model for a capital construction contract*

Groups (measurements, *drivers* of pricing mechanisms)	Question to evaluate options (contract price models)	Options for answers		
		A	B	C
Initial price/bid	1. Is it important to have the lowest bidding prices from tenderers (or in the course of competitive negotiations)?	Yes	Hard to say	No
	2. Is it feasible for a tenderer to prepare a reasonable price bid?	Yes	Hard to say	No
	3. Is a low starting price more important than the contractor's incentives / interest to look for ways to save (reduce) costs during the performance of the contract?	Yes	Equal	No
Control, completeness	1. What is the client's ability / willingness to control costs (cost management)?	High	Medium	Low
	2. What is the expected level of control influence (on the part of the client) on the level of project costs?	High	Medium	Low
	3. What is the desirable detail of the scope of work and specifications of the project subject to control (the desired degree of the contract completeness)?	High	Medium	Low
"Moral hazard" & incentives	1. Is it important for the client to avoid manifestations of "moral hazard" by the contractor during the performance of the contract?	Yes	Hard to say	No
	2. Is it possible to rely on the contractor's incentives more than on external control of the contractor's actions?	Yes	Hard to say	No
	3. Is it important to increase the contract price above the desired (planned) level?	Yes	Hard to say	No
Final price	1. Does the project go beyond the expediency of the client when exceeding the final contract price of a certain level?**	Yes	Hard to say	No
	2. What is the importance of the agreed final price factor versus the factors of the "initial price" plus the "control"?	High	Medium	Low
	3. Is the limit of the final price more important than the ability to keep the price at an even lower level?	Yes	Equal / Hard to say	No

*Notes: * – depending on the fundamental principles of contract theory; ** – the price threshold is determined on the basis of the "benefit-cost" analysis*

$$\left.\begin{bmatrix}\{S_k^r\}\times\{S_k^\rho\}\rightarrow\{\overrightarrow{S_k}\}\\ \{C_k^r\}\times\{C_k^\rho\}\rightarrow\{\overrightarrow{C_k}\}\\ \{I_k^r\}\times\{I_k^\rho\}\rightarrow\{\overrightarrow{I_k}\}\\ \{F_k^r\}\times\{F_k^\rho\}\rightarrow\{\overrightarrow{F_k}\}\end{bmatrix}\right\}=V, \tag{4}$$

where V is a set of all vectors of price priorities for a project; $\{\overrightarrow{S_k}\}$ is a subset of priority vectors for the driver of the initial (starting) price; $\{\overrightarrow{C_k}\}$ is the control; $\{\overrightarrow{I_k}\}$ is the moral hazard / incentives; $\{\overrightarrow{F_k}\}$ is the final contract price.

The final step for determining the recommended price model for a project is the score of each of the alternatives:

$$S_m\times\sum_{k=1}^{3}\overrightarrow{S_k}+C_m\times\sum_{k=1}^{3}\overrightarrow{C_k}+I_m\times\sum_{k=1}^{3}\overrightarrow{I_k}+F_m\times\sum_{k=1}^{3}\overrightarrow{F_k}=E_m, \tag{5}$$

where $\sum_{k=1}^{3}\overrightarrow{S_k}$ is the sum of the priority vectors for the driver of the initial (starting) price; $\sum_{k=1}^{3}\overrightarrow{C_k}$ is the control; $\sum_{k=1}^{3}\overrightarrow{I_k}$ is the moral hazard / incentives; $\sum_{k=1}^{3}\overrightarrow{F_k}$ is the final contract price.

The contract price model that gains the maximum number of points among all the alternatives analysed is considered to be the most appropriate for using in a particular project.

7. Results of approbating the algorithm of selecting a contract price model

The conceptual formalized model and corresponding computerized COMP tool were applied, in particular, to the Ukrainian-Canadian construction project of the Ice Arena of Kyiv. Thus, let us take a look at this business case for choosing a pricing strategy for the contract.

The client's answers to the unified questions gave starting positions for the numerical evaluation of the design pricing space (Table 3):

Consequently, the total vector of the priority for the driver of the initial (starting) price of the contract is

$$\sum_{k=1}^{3}\overrightarrow{S_k}=S_1^r\times S_1^\rho+S_2^r\times S_2^\rho+S_3^r\times S_3^\rho=$$
$$=6\times2+5\times2+7\times1=29, \tag{6}$$

as to the driver "contract control and completeness":

$$\sum_{k=1}^{3}\overrightarrow{C_k}=C_1^r\times C_1^\rho+C_2^r\times C_2^\rho+C_3^r\times C_3^\rho=$$
$$=5\times2+4\times1+6\times1=20, \tag{7}$$

as to the driver "moral hazard and incentives":

$$\sum_{k=1}^{3}\overrightarrow{I_k}=I_1^r\times I_1^\rho+I_2^r\times I_2^\rho+I_3^r\times I_3^\rho=$$
$$=6\times3+8\times3+3\times2=48, \tag{8}$$

as to the driver "final contract price":

$$\sum_{k=1}^{3}\overrightarrow{F_k}=F_1^r\times F_1^\rho+F_2^r\times F_2^\rho+F_3^r\times F_3^\rho=$$
$$=4\times2+7\times3+3\times2=35. \tag{9}$$

By multiplying the total priority vectors calculated by formulae (6)–(9) for the corresponding ratings of the properties of price models (Table 1), an evaluation was given as to how each of the strategies is relevant in the analysed project (Table 4).

For example, let us consider the graded assessment of using the target costing (TC) strategy in the project:

$$E_3=S_3\times\sum_{k=1}^{3}\overrightarrow{S_k}+C_3\times\sum_{k=1}^{3}\overrightarrow{C_k}+I_3\times$$
$$\times\sum_{k=1}^{3}\overrightarrow{I_k}+F_3\times\sum_{k=1}^{3}\overrightarrow{F_k}=660. \tag{10}$$

The data in Table 4 produce a conclusion that since the LS model has scored the maximum number of points, it is the most appropriate for using in the project from the viewpoint of pricing drivers.

Table 3

The ranks and priority criteria of the client for the project (regarding the drivers of pricing mechanisms)

Measurements, *drivers* of pricing mechanisms	The numbers of the questions for prioritization *	The answer options chosen by the client *	Priority rank	Priority rating
Initial price, price offer	1	B	$S_1^r=6$	$S_1^\rho=2$
	2	B	$S_2^r=5$	$S_2^\rho=2$
	3	C	$S_3^r=7$	$S_3^\rho=1$
Contract control, completeness	1	B	$C_1^r=5$	$C_1^\rho=2$
	2	C	$C_2^r=4$	$C_2^\rho=1$
	3	C	$C_3^r=6$	$C_3^\rho=1$
"Moral hazard" / incentives	1	A	$I_1^r=6$	$I_1^\rho=3$
	2	A	$I_2^r=8$	$I_2^\rho=3$
	3	B	$I_3^r=3$	$I_3^\rho=2$
Final contract price	1	B	$F_1^r=4$	$F_1^\rho=2$
	2	A	$F_2^r=7$	$F_2^\rho=3$
	3	B	$F_3^r=3$	$F_3^\rho=2$

*Note: * – Questions and alternative answers to them in accordance with Table 2*

Table 4

The graded assessment of the price strategies in the context of the project of constructing the Ice Arena

Drivers of price mechanisms	Contract pricing models				
	CRC	MC	TC	LS	GMP
Initial price, price offer	232	232	145	87	116
Contract control, completeness	160	80	100	60	80
“Moral hazard” / incentives	96	240	240	288	192
Final contract price	70	105	175	280	280
Total	558	657	660	715	668

8. Discussion of the results of creating an algorithm for selecting a contract price model

The proposed COMP system is completely self-contained (integral) within the framework of reaching its goal, namely, a reasonable choice of the price profile of the contract. At the same time, the COMP system is a harmonious addition to the conceptual model for deciding on the most appropriate strategy for implementing a COMPAS project, which is detailed in [13]. In order to ensure the fundamental correspondence as well as the convenience of joint application in the practice of these two systems, they are based on considerably laid similar principles of multi-criteria analysis. For example, the number of measurements of decision-making constants in both of these systems is four.

While COMPAS relates to the choice of the proper institutional mechanism for implementing a project (Fig. 2), COMP can choose a contract model to pay for the work to be performed.

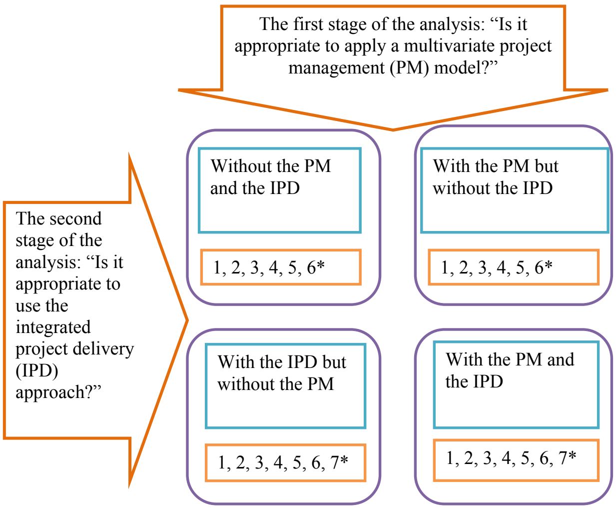

Fig. 2. The typology of strategies for implementing a project in the box-matrix of decision-making according to COMPAS (according to [13]) *Note*: * The model that is determined in the third stage of analysis: 1 — involvement of a number of contractors; 2 — involvement of the contractor in managing construction and subcontractors for implementing individual complexes of work; 3 — involvement of the contractor for construction management at risk (CMAR); 4 — traditional (design—bid—build, DBB); 5 — design—build (DB), including “turnkey”; 6 — step-by-step development; 7 — integrated project delivery (IPD)

Consequently, one of the five key alternative price models can be applied within each institutional mechanism. Thus, the total number of strategic pairwise alternatives in the joint application of COMPAS and COMP is 26×5=130. Some of these pairs of alternatives are relatively common practice. For example, such a pair is CMAR and GMP.

The possibility and convenience of using COMP in conjunction with COMPAS is the strength of this system. As noted above and in accordance with [7], the choice of pricing and the project pricing mechanism is one of the three synergistic pairs that make up the crystal of the cumulative project value management.

At the same time, the most significant advantage and vivid fundamental feature of the COMP system is that it is built on the basis of contract theory. Drivers of pricing mechanisms within the system are (1) the initial price, (2) cost control, (3) motivation mechanisms (incentives) / “moral hazard”, and (4) the final price. The initial price determines the lower boundary of the principal’s costs (agent’s income); the final price is the upper limit. Within these limits, the price level is regulated both through control and through incentives (as to the negative side, it is the factor of moral hazard). Each key pricing model of a construction contract used in international practice (CRC, MC, TC, LS, and GMP) is characterized by its peculiarities of the effect produced by these drivers. The choice of the model follows from the definition of the project priorities by the client (principal) in the same coordinate system “initial price – control – moral hazard / incentives – final price”.

The basis of contract theory gives COMP certain advantages over alternative conceptual models of selecting the pricing strategy, which are built, in particular, on project cash flow estimations [11]. This is primarily due to the fact that the cash flow projection paradigm, unlike contract theory, is not sufficiently related to the factor of the principal-agent relationship.

The limitation of the results of the study is that the COMP system currently implies analysing the five above-mentioned key price models. At the same time, for example, the CRC system has two types: reimbursable cost-plus a percentage-fee and reimbursable cost-plus a fixed-fee. In addition, it should be noted that in some countries of the world, the classification of project pricing strategies has its own characteristics, in particular in the USA [14]. Another limitation of the system lies in the fact that it concerns only internal-contact factors and does not cover the supply and demand or at what stage of the economic cycle (growth, peak / boom, recession, trough / depression) there is a choice of the contract price model. However, the key restriction of COMP is that the purpose of the system is not the validity of the estimates and the predictability of the construction cost but the choice of the most appropriate model of pricing under the project. The reasonableness and predictability of project costs is achieved through building information modelling (BIM) [15], and this tool is another component of the “crystal” of the project value management.

The discussion point of the proposed conceptual model is the number and content (formulation) of unified questions on determining the client’s cost priorities for a specific project.

Further research in this particular field of science should focus primarily on the following:

– development of a formalized apparatus of the theory of the dynamics of project efficiency, which is one of the components of the "crystal" of the cumulative value management;

– conceptual definition of the impact of the market phase (each of the four stages of the economic cycle) on deciding upon the most appropriate pricing strategy for the project;

– development of a number of creative templates for choosing a contract price model for construction projects of various types of objects.

9. Conclusion

1. Drivers of pricing mechanisms in capital construction projects strategically predetermine "frames" in which the price of work under the contract may vary, as well as the key impacts on price formation.

The price bid of the project performer is formed taking into account the financial risks, which are subject to the terms of the contract for the contractor. Each contract price profile determines its financial risks to the contractor, and therefore, the price model of the project affects the *starting contract price*.

Since the start of a project, the costs are controlled by the client, and the more careful the control is, the greater the likelihood that the costs will be lower. At the same time, during the performance of the contact, the contractor is under the influence of some "moral hazard", the actual manifestation of which depends on the contractual incentives to act morally. Each price model of a contract has both its *control depth* and its *power of incentives* (*as a counteraction to moral hazard*), and therefore, these factors actively influence the dynamics of project costs.

Eventually, at the end of the object construction, the price gets its final value. Each pricing model is characterized by its institutional pressure on the final price, and some models even set a certain benchmark for the maximum cost borne by the client for the project.

Based on the above, contract pricing drivers are the initial price, control, incentives (moral hazard), and the final price. This interpretation coincides with the basics of contract theory and is a prerequisite for the fundamental authenticity of the developed system.

2. The basic input components of the decision-making process for the most appropriate pricing strategy is the matrix of the properties of the contract price models and the metric of the questions for assessing the relevant priorities of the project client. Each of these components is constructed in a four-dimensional analytical space "initial price – control – moral hazard / incentives – final price", which reflects the set of pricing drivers in a construction contract. The system allows choosing one of the five key pricing strategies: CRC, MC, TC, LS, or GMP, which are applied internationally. The architecture of the decision-making process (algorithm) is due to the tasks to perform a multi-criteria analysis of the priorities of the project and to assess for which of the price models this priority profile is the best option.

Using the system of choosing the price model for a contract together with the system of selecting the organizational profile for implementing the project helps determine the most expedient strategy of 130 paired alternatives. The proposed approach cumulatively contributes to the success of construction projects, has a unified character, and can be implemented in any country of the world.

3. The formalized process of benchmarking alternatives is the digital content of the Contract Organizational Mechanisms: Pricing (COMP). The algorithm is based on calculating the vectors of priorities of project pricing factors (based on the determined sets of ranks and ratings), followed by a graded assessment of the feasibility of using each of the alternative price models in the project.

The use of the COMP system in the construction of the Ice Arena in Kyiv has shown that the created conceptual model (proposed algorithm) makes it possible to take an appropriate decision on the price model for a contract with mathematical, high theoretical and practical reasoning.

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DEVELOPMENT OF A METHOD TO CALCULATE THE PROBABILITY OF A BERTH FAILURE UNDER VERTICAL STOCHASTIC LOAD

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Розроблено метод визначення ймовірності досягнення граничного значення навантажень від вантажу, що зберігається на складах портового терміналу, на вертикальну стінку причалу в умовах невизначеності моментів прибуття суден та їх навантаження. Передбачається, що процес прибуття суден із вантажем описується моделлю складного пуассонівського процесу, а зі складу вантаж вивозиться за допомогою наземного виду транспорту рівномірно із постійною інтенсивністю. За допомогою методів математичної теорії ризику побудовано ймовірнісну модель роботи системи «склад-причал» як складової портового терміналу. Сформульовано критерій безпечної роботи причалу при дії на його конструктивні елементи випадкового навантаження від вантажу, що зберігається на складі у тилу причалу, з метою визначення ймовірності неперевищення гранично припустимого значення тиску на лицьову стінку причалу (згідно закону Кулона), тобто аварії причалу. Для знаходження ймовірності аварії причалу у сталому режимі його роботи виведено інтегральне рівняння типу згортки. Рішення цього інтегрального рівняння дозволило знайти аналітичний вираз для ймовірності безвідмовної роботи причалу для різних функцій розподілу навантаження суден, що дало змогу кількісно оцінити ризик настання аварії причалу. За допомогою знайденої ймовірності аварії причалу сформульовано та вирішено дві практичні задачі. По-перше, визначено значення інтенсивності вивезення вантажу зі складу, яке забезпечує із достатньо малою ймовірністю відсутність аварії. По-друге, сформульовано критерій економічної доцільності страхування збитків внаслідок аварії причалу (його раптової відмови) внаслідок перевищення навантажень від вантажу припустимого значення у даний проміжок часу.

Запропонований у статті методичний підхід до визначення надійності причальної споруди на портовому терміналі, на відміну від існуючих методів розрахунку причальних споруд, дозволяє більш обґрунтовано оцінювати величину реальних експлуатаційних навантажень (вертикальних та горизонтальних), що діють на основні конструктивні елементи причалу

Ключові слова: портовий термінал, судна з вантажем, граничне навантаження, лицьова стінка причалу, ризик аварії причалу, страхування ризику

1. Introduction

The adequacy of the methods for evaluating the reliability of a structure is known to be determined by reliability and accuracy of the models of loading, models of operation of materials, from which the elements of berth structures are made, and the models of occurrence of failures (accidents). Specification of only separate of the listed models is not likely to give any practically acceptable recommendations, unless the level of accuracy of the other remains insufficient.

As regards berth facilities, in the course of formalization and modeling actual operational loads that influence them, the additional difficulty is to take into consideration the probabilistic nature of loads. The models of failures under