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ORIGINAL ARTICLE

Developing a model of work duration under the influence of risk events in the implementation of life cycle contracts for large energy construction projects

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ABSTRACT

Projects implemented under life cycle contracts have become increasingly common in recent years to ensure the quality of construction and maintenance of energy infrastructure facilities. A key parameter for energy facility construction projects implemented under life cycle contracts is their duration and deadlines. Therefore, the systematic identification, monitoring, and comprehensive assessment of risks affecting the timing of work on the design and construction is an urgent practical task. The purpose of this work is to study the strength of the influence of various risks on the duration of a project implemented on the terms of a life cycle contract. The use of the expert assessment method allows for identifying the most likely risks for the design and construction phases, as well as determining the ranges of deviations from the baseline indicator. Using the obtained expert evaluations, a model reflecting the range and the most probable duration of the design and construction works under the influence of risk events was built by the Monte-Carlo statistical method. The results obtained allow monitoring and promptly detecting deviations in the actual duration of work from the basic deadlines set in the life cycle contract. This will give an opportunity to accurately respond to emerging risks and build a mutually beneficial relationship between the parties to life cycle contracts.

KEYWORDS

life cycle contract; risk; design phase; construction; duration of work; breach of schedule; strength of risk impact

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1. Introduction

In the face of a developing economic recession, which is exacerbated by the COVID-19 pandemic and financial restrictions, state authorities of the Russian Federation are faced with a budget deficit and the problems of long-term management of large infrastructure projects (Beermann and Austin, 2021; Yembergenov et al., 2022). The new economic conditions force public authorities (acting as customers) to seek and apply in practice new forms of interaction with the performer (contractor) in the construction of energy facilities in the Russian Federation (Ilin et al., 2022; Zhilenko et al., 2021). One such form of interaction that has proven effective in international practice life cycle contracts (LCC) (Barbos, 2022; HM Treasury, 2012). The term LCC is also sometimes substituted by the term design-build-finance-maintain (DBFM) (Fadyushin, 2019; Tatibekova et al., 2022).

The contractor not only builds the system but also commits to maintaining it throughout its lifetime at a cost agreed upon in advance by the customer and the contractor. The contractor receives payment in installments in accordance with the schedule defined in the contract. Thus, it is the contractor who is interested in choosing the best solutions and ensuring the quality of the work.

As a result, the value of the total project costs for the creation of the systems, their development, and maintenance, in the long run, is often lower than in standard contractual approaches. The construction of energy facilities and other infrastructure projects is always tied to the implementation of social objectives (Janjua et al., 2019). Thus, the use of LCC contributes to the social responsibility of the business through long-term cooperation between the customer and the contractor (Darendeli et al., 2022). The construction of an energy facility and its maintenance is carried out by one contractor. On the one hand, the contractor's motivation increases owing to the long-term employment contract, which ensures a higher quality of the project and its further maintenance (Dai et al., 2021). Guaranteeing the permanent employment of personnel will ensure stable interaction, which is unattainable with one-time contracts. On the other hand, for the project implementation system itself, the introduction of an LCC will lead to a reduction in costs due to the elimination of intermediaries and an increase in service quality.

The use of LCC is thus an example of how social responsibility is mutually beneficial for all parties: contractors receive guaranteed sales of their services, and customers receive long-term guarantees for the uninterrupted and long-term operation of the facility and equipment (Sekerin et al., 2014).

However, due to the long duration and the dynamic environment of construction projects, changes in the implementation of LCC are inevitable. That is why all changes must be considered during the project implementation (Demirel et al., 2019). Typically, such projects require expensive equipment, significant overhead, manpower, and large budget payments to customers and contractors. The longer the work takes, the higher the budgetary costs and the greater the likelihood of litigation. Thus, flexibility in construction projects is now becoming a more important tool for dealing with unpredictable circumstances (Demirel et al., 2017). For this reason, when entering into an LCC, the contractor should assess the risks associated with possible delays in design and construction as best as possible (Alimbekova et al., 2021). Fines and penalties may be imposed on the contractor for improper performance of obligations to comply with work schedules and, ultimately, may lead to early termination of the contract.

Analysis of the impact of risk events on the duration of work under an LCC project will allow the contractor to estimate the actual duration of the design and construction phases and objectively assess their ability to participate in the project. Risk assessment methods need to be developed to obtain more accurate and objective indicators.

As a research hypothesis, it is argued that the duration of the design and construction phases of the LCC depends on the strength of influence and the likelihood of risks, which ultimately lead to an increase in the established deadlines for the project.

To address these research hypotheses, the study used a mixed-method approach based on the methodology of a single case study (Ciasullo et al., 2022), the expert assessment method, and Monte Carlo statistical modeling as the best combination of methods to obtain quantitative results. Our study attempts to research the detection of the main risks and their impact on the duration of a Russian power construction project implemented under an LCC. In addition, it was necessary to identify the main risk factors that arise in the design and construction of facilities under an LCC (Liu and Qian, 2019).

The findings reveal the potential for applying LCC that reflects the range and most likely duration of design and construction activities under the influence of risk events. This data adds to the existing literature based on the developed model for the analysis of risks affecting the implementation of projects in the energy sector. In particular, the results obtained allow tracking and timely detecting the deviation of the actual duration of work from the baseline deadlines set in the LCC. This will enable a clear response to emerging risks and build mutually beneficial relationships between customers and project executors under the LCC.

The next section provides a literature review. Particular attention is paid to the study of the risks affecting construction, the distribution of risks among the participants in public private partnerships (PPP), as well as the methodological principles of research in this area in the study, which allows for determining the likely duration of each type of work in the LCC. Next, the methods and results of the study are presented and substantiated. Finally, the study's theoretical and practical conclusions and limitations are described.

2. Literature review

Theoretical issues of LCC in the implementation of PPP have been studied by many scientists, including Kireeva (2020), Andrada-Félix (2022), Yescombe and Farquharson (2018), and Delmon (2011).

A significant part of the research is devoted to the study and development of the concept of risk sharing between participants in PPP as the main driving force of infrastructure projects (Cui et al., 2018; Macwan and Pitroda, 2018; Wu and Wei, 2009).

Studies focusing on the realization of LCC projects (Peng and Liu, 2013) indicate that the intensity of construction increases with each stage of construction. In the project, some processes need to be implemented in parallel with limited resources and a production base. The uncertainty of the external environment is not decreasing but tends to grow. In such a situation it becomes crucial to solve the tasks of risk monitoring of LCC projects.

Monitoring of the problem (Gharaee et al., 2019; Strasser et al., 2021) demonstrates that participants in PPP projects cite as the most critical problems violations of deadlines for the design and construction of infrastructure facilities, as well as the actual cost of works exceeding the planned ones (Ahmad et al., 2019; Hameed et al., 2018; Jiang et al., 2022; Zimmermann and Eber, 2014).

The duration of work is the most important indicator of construction because the time spent on construction increases the cost of the project due to inflation, interest rate, and opportunity costs (Alagboso, 2019).

In the context of our study, of scientific interest are primarily works related to the assessment of the impact of risk events on the duration of infrastructure construction (Aarthipriya et al., 2020; Berdibekova et al., 2022). The main factors of risk highlighted are the stability of funding, the professionalism of the contractor, the complexity of the project, weather conditions, and disagreements between the contractor and the customer (Hatem et al., 2021; Ngoma et al., 2014; Ram and Paul, 2015; Taraziya and Ali, 2020).

The most common methods of modeling the risks of construction projects are the Monte Carlo quantitative analysis, sensitivity analysis, and "what if" analysis (Eskander, 2018; Korytárová and Hromádka, 2020; Qazi, Daghfous, and Khan, 2021; Qazi, Dikmen, and Birgonul, 2020). As a rule, such empirical studies are conducted with the use of special software tools.

Several researchers note that "what if" analysis does not consider the probability of the scenario, the variety of values that the input data can assume, or the combinations of values that can constitute a scenario (Pham, 2020; Roberts and Tonna, 2022).

Monte Carlo simulations replace the values of uncertain variables in the model with functions that generate random samples from defined distributions. The resulting simulation outputs are analyzed, and then the probability of the outputs being above (or below) some specified target value is determined (Benton, 2018).

Although the methodological basis of quantitative risk assessment and modeling is sufficiently developed in scientific literature, we believe that the empirical studies examining the impact of risk factors on the duration and cost of infrastructure construction projects implemented based on LCC are extremely insufficient. This is because there are many factors ranging from national legislation to the internal features of the company, and the situation can change.

3. Methods

3.1. Research approach

The research design strategy included the use of qualitative and quantitative methods of analysis, which provides us with an opportunity to interpret and conduct a more in-depth study of risk assessment problems in large energy projects under LCC conditions, as well as generate new ideas for future research.

Qualitative methods were used to gather information for quantitative analysis. The qualitative methods employed in our study included the use of document analysis, the case study method, and an expert survey by the Delphi method. After collecting the information, using the concordance coefficient, the consistency of expert opinions was tested and risk modeling was performed via the Monte Carlo method.

3.2. Empirical context and case selection

Complete and reliable information on projects offered for implementation in various sectors of the Russian economy is available in the unified information system (UIS) in the field of procurement (Federal'noye kaznacheystvo, n.d.).

In the area of interest of the potential contractor are projects that meet the following criteria:

Implementation area—electric power industry.

Conditions of implementation—LCC (in accordance with Federal Law No. 44-FZ (State Duma of the Federal Assembly of the Russian Federation, 2013)).

The customer's location is territorially the same as the contractor's location.

From the consolidated registry (Federal'noye kaznacheystvo, n.d.), only one project fully met all of the above criteria and was taken for review.

The project under consideration is being implemented under an LCC to perform a set of works on the design, construction, and subsequent maintenance of outdoor lighting facilities in a settlement in the Moscow region.

Since information about the customer is not freely available, our study uses the code name of the customer the "Sluzhba zakazchika gorodskogo khoziaistva" ("Service of the Customer of the Municipal Property") Municipal Budgetary Institution.

The initial maximum contract price (IMCP) is set in accordance with the Order of the Ministry of Economic Development of the Russian Federation and is currently 12,296,560,680 rubles. Hereinafter we proceed from the currency rate of 1 USD = 70 rubles.

Start of the work from the date of the Contract. Completion of work: in 25 years from the date of commissioning of the object, but no later than 31 December 2050.

The project is implemented in three stages:

First stage. Design of outdoor lighting facilities (2022–2023). The duration of the stage is 77 weeks.

Second stage. Construction of outdoor lighting facilities (2023–2025).

Third stage. Maintenance of outdoor lighting facilities (25 years).

According to the LCC project, it is allowed to violate the terms of design and construction, but not more than six months for each of the stages.

Currently, the customer has already conducted work on the selection and approval of the new construction site, performed the necessary engineering surveys, and developed a design assignment.

The most important condition for the execution of the municipal LCC is the contractor's compliance with the design and construction deadlines. According to the LCC project, if the design or construction deadlines are violated for more than six months through the fault of the contractor, the contract is terminated.

3.3. Data collection

Stage 1. Developing a network diagram of the project.

The network diagram for the project was developed according to the regulatory and legal documents of the Ministry of Energy of the Russian Federation (Ministry of Energy of the Russian Federation, 2019) and the methodological developments and standards of the "FSK EES" OJSC (FSK EES OJSC, 2012; NTC FSK EES OJSC, 2014).

Step 2. Expert evaluation of project uncertainties and risk factors.

To assess uncertainties and identify the most significant risks and exclude less significant hazards from further analysis, we used methods of checklist analysis, analysis of experimental data on the frequency of man-made accidents at the construction site, and analysis of available chronological data on past events in the implementation of similar energy projects.

These tools provide accounting indicators on the frequency of risk events associated with accidents and failures on construction sites, which allows for quantifying the probability and strength of the impact of these risks on construction work.

The above methods were supplemented by qualitative research in the form of an expert survey by the Delphi method. Experts were selected within two weeks based on a preliminary analysis of available information on their professional training, academic degree and/or title, practical work experience of five years or more, and involvement in expertise for other energy projects.

The study involved 22 experts from research, contracting, and design organizations in the field of electric power.

The expert survey was conducted in February–March 2022 and involved a combination of expert uncertainty and risk assessment methods, including randomized individual questionnaires and the Delphi method. The expert survey by the Delphi method was conducted in two rounds. In the first round of the study, experts were asked to answer questions without any arguments or substantiation of their opinions.

The questionnaire developed for the study included two sets of questions aimed at:

Block 1. Identifying the most important risk events that pose threats to the implementation of the energy infrastructure project;

Block 2. Assessment of the level of uncertainty (in the actual timing of individual works and percentage deviations from the established costs of individual works).

3.4. Data analysis

The responses received were processed and the level of expert consistency was determined using the concordance coefficient.

The dispersion coefficient of concordance is determined using the formula:

$$w = \frac{12 * S}{m^2 * (n^3 - n)} \tag{1}$$

where,

w—expert opinion concordance coefficient,

n—number of risk events,

m—number of experts,

S—deviation of the sum of ranks from the average sum of squares of ranks, calculated using the formula:

$$S = \sum_{i=1}^{n} (\sum_{j=1}^{m} r_{ij} - \bar{r})^2 \tag{2}$$

r_{ij}—the rank of the *j*-th risk assigned to it by the *i*-th expert,

$\bar{r}$—average value of the sum of the squares of ranks.

The degree of consistency of the experts' opinions was interpreted according to the following scale (Lin et al., 2012):

$w < 0.3$—expert opinions are not consistent and expert evaluation is not accepted,
$0.3 < w < 0.7$—average consistency of opinions,
$w > 0.7$—high consistency of expert opinions.

Stage 3. Risk modeling using the Monte Carlo method.

The model was constructed using a special add-in MODELRISK in the Excel environment.

The input data used were spreadsheets with expert estimates of the minimum, most likely, and maximum values for each variable. The PERT distribution, which is the beta distribution that uses the assumption of the mean, was used to model expert opinions. The result of the analysis is the most likely range of duration of the design and construction phases, considering the impact of the identified risks on the execution time of individual works.

4. Results

As a result of the assessment of expert opinions, the most probable minimum and maximum time frames for the work were determined (**Table 1**).

From the formed list of risks, the experts identified the most significant ones that may have an impact on the timeline of the project. **Table 2** presents statistical data on the consistency of expert assessments regarding the significance of risks for the project phase and the construction phase.

The baseline duration of the design phase amounts to 77 weeks. The works are performed sequentially, the completion of a certain type of work being the start of other design work. The network model of the design phase is given in **Figure 1**.

Table 1. Results of expert assessment of deadlines, weeks.

Name of work	Min.	Prescribed base period	Max.
Design phase			
1. Development of main technical solutions	2	3	6
2. Review and approval of the main technical solutions (MTS) with MES, SO EES, and FSK EES departments	6	8	12
3. Development of the full set of project documentation materials	21	35	42
4. Expert review of PD by the State Expert Review Board	7	8	10
5. Development of working documentation	20	23	29
Construction phase			
1. Dismantling of abandoned equipment and materials	3	4	8
2. Installation of outdoor lighting poles	95	112	120
3. Installation of brackets with lights	81	86	100
4. Installation of outdoor lighting input and distribution cabinets (IDC) in the extension to the transformer substation (TS)	24	26	32
5. Installation of the IDC outside	25	28	36
6. Installation of supply networks from the IDCs to the support in the ground	21	27	30
7. Installation of package transformer substations (PTS)	34	40	48
8. Testing of equipment and commissioning of the object	56	61	65

Table 2. Most significant risks.

Phase	Most significant risks	Expert consistency coefficient
Design phase	1. Failure of the customer to provide the necessary input data in due time 2. Loss of work time due to violations of labor discipline 3. Lack of experience in the design of energy facilities 4. Increase in the standard time costs for the preparation of project documentation 5. Extension of the established time frame for state expert review 6. Extension of the deadline for approving the draft design assignment	0.811
Construction phase	1. Lack of workers with the required specialties and the necessary qualification level (category) 2. Poor communication and coordination between contractors 3. Customer's failure to pay for the work under the contract in due time 4. Low automation of the contractor's business processes 5. Delayed delivery of structures, materials, equipment 6. Low mechanization of the contractor, the lack or shortage of modern equipment 7. Unfavorable weather conditions 8. Changes in design decisions during construction 9. Loss of work time due to violations of labor discipline 10. Irrational organization of construction sites and work schedules 11. The COVID-19 pandemic	0.805

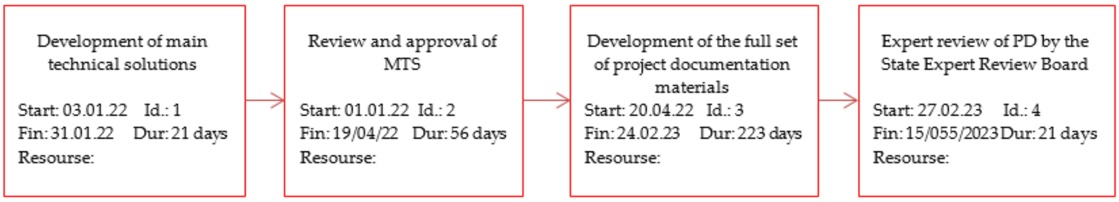

Figure 1. Network model of works in the design phase.

The results regarding the probability of occurrence and the strength of the impact of the identified risks on the duration of work in the design phase are shown in **Table 3**.

Table 3. The power of influence and probability of risks on the duration of works in the design phase.

N	Types of design phase works, subject to the risk of delays	Power of influence			Risk probability
		Min.	Most real	Max.	
1	Development of main technical solutions	15%	25%	40%	50%
	Development of the full set of project documentation materials	15%	25%	40%	20%
	Development of working documentation	10%	20%	30%	15%
2	Development of main technical solutions	1%	3%	5%	5%
	Development of the full set of project documentation materials	1%	3%	5%	5%
	Development of working documentation	1%	3%	5%	5%
3	Development of main technical solutions	20%	30%	50%	10%
	Development of the full set of project documentation materials	25%	35%	50%	10%
	Development of working documentation	20%	30%	40%	10%
4	Development of the full set of project documentation materials	3%	5%	7%	40%
5	Expert review of PD	10%	20%	30%	50%
6	Review and approval of MTS with MES, SO EES, and FSK EES departments	5%	10%	15%	40%

The most significant in terms of their impact on the duration of the project phase are the risks of the customer's failure to provide input data on time, the contractor's lack of experience in designing electric power projects, and the duration of the state expert review of project documentation. The risks of untimely provision of initial information and failure to meet the deadline for the expert review are considered by experts to be the most likely risks in the implementation of project work.

The results of modeling the schedule of the design phase, considering the uncertainties of realization of the identified risks, allow for determining the probable timing of the implementation of each type of work. **Table 4** shows the results of modeling the duration of work, with consideration of the established probabilities of risk occurrence for the design phase.

Table 4. The results of modeling the duration of the design work, accounting for the occurrence of risks.

	Duration of work, weeks			**Distribution**	**Start**	**Total duration, weeks**
	Min.	**Basic**	**Max.**			
Development of MTS	2	3	6	2.276	0	2.276
realization of risk 1	2	3	6	2.988	0	3.734
realization of risk 2	2	3	6	2.387	0	2.387
realization of risk 3	2	3	6	2.938	0	2.938
Maximum duration of the development of the main technical solutions considering the probable risks, weeks						3.734
Review and approval of MTS without risks	6	8	12	7.654	3.734	11.388
Realization of risk 6	6	8	12	9.514	3.734	14.441
Maximum duration of works on the coordination of MTS, considering the realization of probable risks, weeks						14.441
Development of PD	21	35	42	39.885	14.441	54.326
realization of risk 1	21	35	42	35.837	14.441	50.279
realization of risk 2	21	35	42	35.491	14.441	50.863
realization of risk 3	21	35	42	34.560	14.441	58.603
Maximum duration of work on the development of project documentation considering the realization of probable risks, weeks						58.603
Expert review of PD without risks	7	8	10	8.443	58.603	67.047
Realization of risk 5	7	8	10	8.936	58.603	67.539
Maximum duration of project documentation review considering the risks						67.539
Development of PD without risks	20	23	29	25.884	67.539	89.409
Realization of risk 4	20	23	29	22.660	67.539	98.484
Total duration of works on the development of risk-adjusted working documentation, weeks						98.484

The distribution of simulation results on the duration of the design phase is illustrated in **Figure 2**.

Figure 2 shows that the baseline time of 77 weeks established for the design phase is far from the desired. There is only a 0.22% probability of the total duration of the design phase being less than or equal to 77 weeks. The probability that the duration of the design phase will be between less than 81.6 weeks and more than 105.2 weeks is only 5%. The peak of the histogram is at 87.4 weeks, which can be taken as the most probable duration of the design phase if the identified risks are realized.

Thus, if risk events occur, the actual duration of the design phase will exceed the baseline by 10.4 weeks, or about 2.5 months (i.e., less than six months), which cannot be a reason to terminate the contract.

Since the risks highlighted are characteristic of all types of construction work, we consider their impact on the duration of the construction phase as a whole, without detailing by type of work. The degree of influence and uncertainty of the risks during the construction phase, which may lead to a breach of contract terms, are presented in **Table 5**.

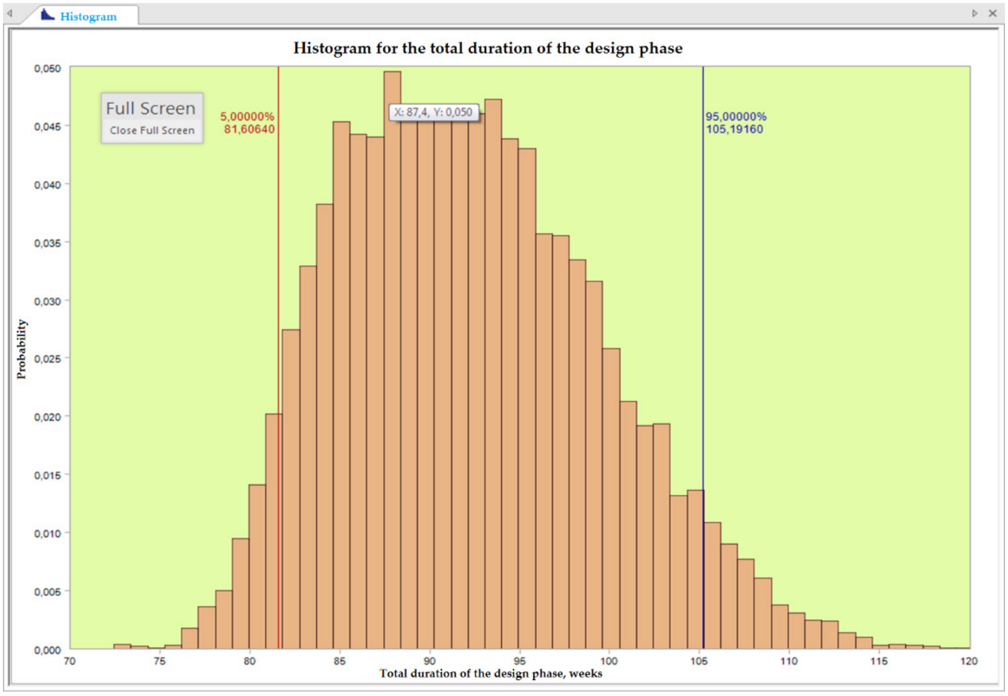

Figure 2. Histogram for the total duration of the design phase.

Table 5. Degree of influence and uncertainty of risks during the construction phase.

Construction phase risk	Power of risk impact			Risk probability
	Min.	Most real	Max.	
Lack of workers with the required specialties and the necessary qualification level (category)	20%	40%	60%	5%
Poor communication and coordination between contractors	10%	20%	30%	35%
Customer's failure to pay for the work under the contract in due time	80%	90%	100%	30%
Low automation of the contractor's business processes	20%	25%	30%	5%
Delayed delivery of structures, materials, and equipment	40%	60%	80%	30%
Low mechanization of the contractor, the lack or shortage of modern equipment	50%	70%	90%	60%
Unfavorable weather conditions	5%	10%	15%	100%
Changes in design decisions during construction	40%	50%	60%	15%
Loss of work time due to violations of labor discipline	20%	30%	40%	15%
Irrational organization of construction sites and work schedules	10%	15%	20%	25%
COVID-19 pandemic	70%	80%	90%	15%

The baseline duration for the construction phase is set at 156 weeks from the completion of the design phase. In this case, all work may not begin until all abandoned equipment and materials are dismantled. Works on the installation of outdoor lighting poles and brackets with lighting fixtures are carried out in parallel. Installation of PTS begins 25 weeks after the dismantling of abandoned equipment is completed. Work on the installation of IDC and supply networks can begin only after the completion of work on the installation of PTS. The network diagram of the construction phase is shown in **Figure 3**.

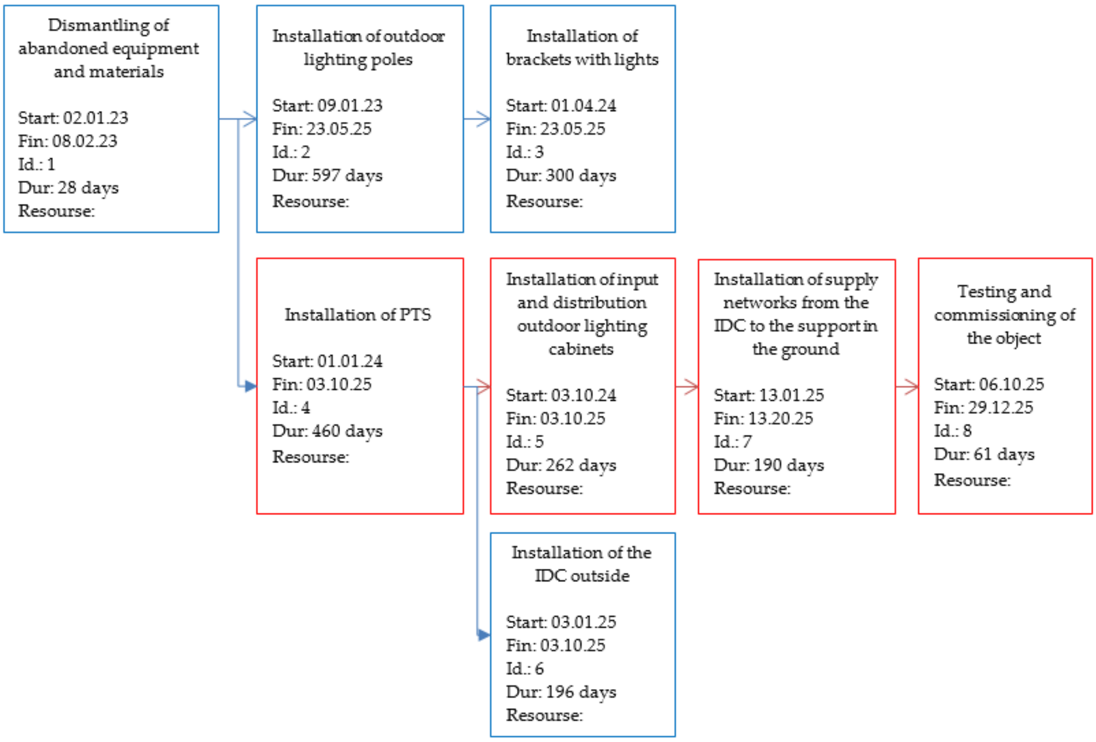

Figure 3. Network diagram of the construction phase.

The distribution of simulation results on the duration of the construction phase is presented in **Figure 4**.

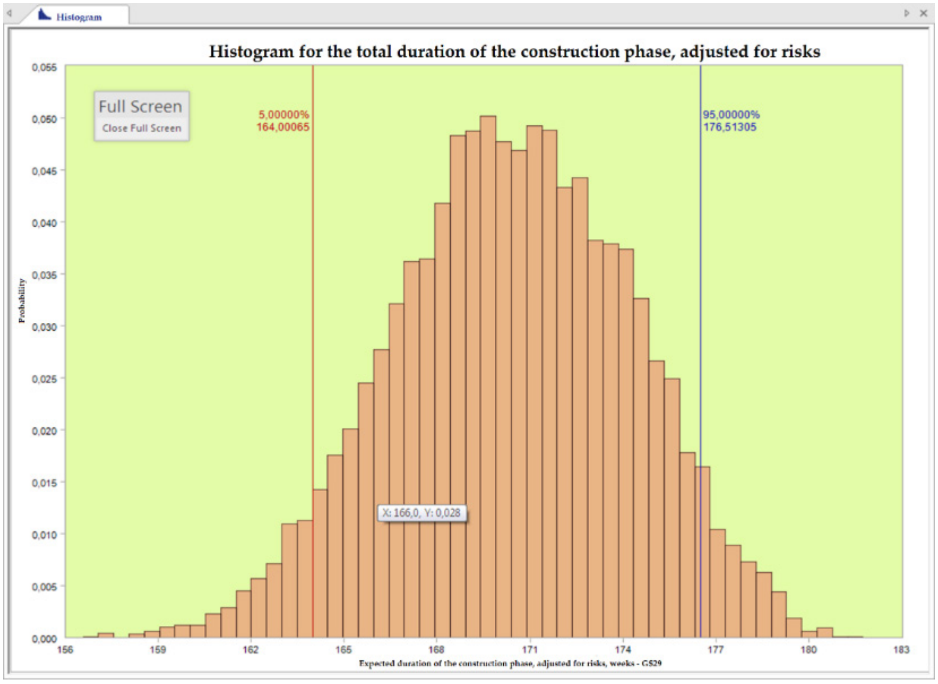

Figure 4. Histogram for the total duration of the construction phase.

The histogram shows the most realistic timing of the construction work, considering the impact of risk events upon them. The probability that the construction phase will be shorter than 164 weeks or longer than 176.5 weeks is only 5%. The most likely period of the construction phase considering the risks is 169.4 weeks.

Thus, if the risks were to come true, the actual duration of the construction phase would most likely exceed the established time by 13.4 weeks, or 3.5 months. The maximum probable duration of construction adjusted for the realization of risks exceeds the base indicator by 20.5 weeks. In both cases, the actual duration will not surpass the limit for deviation from the baseline of six months.

5. Discussion and conclusion

We concur with the opinion of many experts that all parties involved in construction projects are interested in the timely execution and payment of contract work (Lorman Education, 2018). That said, delays in design and construction work are among the frequently disputed issues associated with LCC infrastructure projects.

As a result of the study, the combination of expert evaluation and the Monte Carlo statistical method provided data that enable conclusions about the range of risk uncertainties and the duration of the design and construction phases of the case study of the “Sluzhba zakazchika gorodskogo khoziaistva” (“Service of the Customer of the Municipal Property”) Municipal Budgetary Institution. We determined the likelihood of a potential project contractor exceeding the baseline time frame for the work at the facility.

The models built allow determining the likely timing of design and construction work for the customer, “Service of the Customer of the Municipal Property” considering the occurrence of risk events. It is found that for the project phase, the most likely duration of work will be 87.4 weeks, which exceeds the baseline by 2.5 months.

The findings regarding the duration of the construction phase show that, as a result of the risks identified, the construction work would take 164 to 176.5 weeks instead of the 156 weeks required by the LCC project.

In both the design and construction phases, the contractor’s breach of schedule will not exceed the maximum period of six months outlined in the LCC, which constitutes grounds for breach of contract for violation of the schedule.

Our conclusions align with previous research (Taraziya and Ali, 2020) indicating that in the design phase, the most probable significant risk for the contractors in the project with “Service of the Customer of the Municipal Property” that affects the time and quality of works on the development of main technical solutions and project and working documentation is the timely provision of initial data to the contractor by the customer. This factor needs to be considered by “Service of the Customer of the Municipal Property” in working with contractors to lower the risk of project failure.

On the other hand, the results of the study support the conclusions of other empirical research on the impact of the contractor’s experience in design on the duration of work on the development of the project and working documentation (Ram and Paul, 2015). Lack of experience in designing the objects of energy infrastructure on the part of the contractor increases the overall labor intensity of design work. Thus, quality initial data provided by the customer and the experience of the contractor minimize risks in the design stage. In our study, experts noted that despite this conclusion being seemingly obvious, in practice, late submission of initial data by the customer, the contractor's lack of experience in designing electric power projects, and the duration of the state expert review of project documentation remain the highest risks in Russian practice at the design and approval stage.

Concerning the stage of project implementation, our results confirm the conclusions of previous empirical research that the most significant risks are the low mechanization of construction work (Hwang et al., 2020) along with the lack or absence of modern construction equipment necessary for the construction of energy facilities in the contractor's possession, which affect the choice of the contractor for the project of "Service of the Customer of the Municipal Property".

Furthermore, we agree with earlier conclusions that for the contractor, the most probable risk increasing the duration of construction is the customer's failure to pay for LCC work on time (Boussabaine, 2013; Hatem et al., 2021; Macwan and Pitroda, 2018; Zhang et al., 2020). In the case of a decrease in the limits of budgetary obligations, brought to the customer as a recipient of budgetary funds, the customer may become temporarily insolvent. This problem is especially acute given the financial and technological constraints faced by companies operating in Russia.

To solve this issue, the executives of "Service of the Customer of the Municipal Property" and the potential contractor in the project are recommended to account for situations involving a reduction in the contract price in the terms of the contract, including by reducing the time of performance and (or) the volume of services provided by the LCC.

The study does not provide convincing support for the conclusions of some researchers who argue that the duration of the design phase is substantially extended by the loss of working time due to violations of labor discipline on the part of the contractor's staff (Business Bliss Consultants FZE, 2018). Our findings suggest that with an average probability of occurrence of this risk, the strength of its impact on the duration of work is low.

Furthermore, the present study reveals that the lockdown tied to the return of COVID-19 may have a fairly strong impact on the duration of construction. This impact is confirmed by the results of other studies. The experts interviewed assess the risks of a return of the pandemic as low. Even if any restrictions related to COVID-19 are introduced, experience has already been accumulated to help minimize the risks of project failure by the contractor due to the spread of this dangerous disease.

Thus, the combination of the expert survey method and statistical modeling by the Monte Carlo method allowed us to determine with a high degree of probability the actual range of the possible duration of each stage of the project. Putting the results into practice will allow LCC members to build flexible but effective relationships.

This study entails some theoretical and practical conclusions. In particular, the article presents two theoretical implications:

(1) The present study enriches the existing literature on the development of a conceptual cost management system model in agricultural enterprises. At present, this topic is being actively

developed in the context of the development of modern managerial construction methods aimed at reducing various risks. However, further research is needed to consider the national specifics of business. As far as we know, this study presents one of the first attempts to conceptualize the accumulated international experience island and demonstrate the functional characteristics of elements in the proposed LCC management system as applied to the Russian experience. We urge other researchers to actively engage in the development of business process management technologies for agricultural enterprises with the opportunity of their practical implementation.

This brings us to the second theoretical conclusion (2) that integration of diverse methods improves the overall performance of the model. In developing the model of the duration of works under the influence of risk events in the realization of LCC for large energy construction projects, we proposed the use of a complex of methods, which allows for calculating the time interval of each stage. The employed practices can be used by other researchers and specialists in calculating the duration of the stages of work on other objects in the energy industry as part of LLC execution.

The article also provides certain practical conclusions. Specifically, we suggest that the results of the study should be considered at the legislative level since Russia does not have an exhaustive list of initial data that must be provided to the contractor. In addition, the practice of work under LCC shows that in most cases the parties do not agree on comprehensive lists (Anurov, 2021), which largely causes the violation of the timing and quality of development of project documentation, as well as subsequent litigation between the parties.

We concur with Ameyaw and Alfen (2017) that the LCC needs to enshrine a specific list of such input data. Agreement by the parties to a comprehensive list of initial data for the design and a clear time frame for their submission to the contractor will secure the interests of parties in the LCC. In addition, at the conclusion of the LCC, it is deemed expedient to include a clause obligating the designer (contractor) to give written notice to the customer about the lack of baseline data within 10 working days after the conclusion of the contract.

We also share the opinion of researchers that the duration of the design stage is heavily affected by the terms of state expertise. In particular, by Russian law, the term of the state examination of design documentation and engineering studies is determined by the contract and depends on the complexity of the facility to be erected. However, it must not exceed 42 working days, although, from March 2022, these deadlines may be extended by up to 20 working days (Government of the Russian Federation, 2021).

The adoption of Resolution 579 (Government of the Russian Federation, 2022), which establishes a simplified procedure for expertise, opens up new possibilities for shortening the design phase. For example, the resolution eliminates the requirement of a second expert review of the PD if the contractor replaces the building materials specified in the project with analogs not inferior in quality, without increasing the cost of construction by more than 30%, or without exceeding 100 million rubles. However, we argue that there is no need to require project documentation with state expert review, at least during the decision to provide federal co-financing, because, despite some simplification of the procedure, this process remains quite complicated in Russian practice in the implementation of LCC.

This study did not consider the risk factors for LCC associated with the operational phase. In addition, the influence of risks on the total cost of an LCC remained outside the scope of this study. These issues require detailed study and are promising areas for further research.

This study, however, did not consider the risks associated with the special war operation in Ukraine, which commenced on 24 February 2022. The execution of such an operation induces numerous risks for the implementation of LCC, each demanding comprehensive examination. First, the process of importing products from foreign nations via parallel imports presents a two-fold problem: the escalating costs accompanying an extended supply chain and the increased timeframes required to procure these products. Second, the potential violation of licensing rights, especially in instances where production continues at the facilities of companies no longer in operation, represents a significant hazard. This risk not only infringes on legal boundaries, but it also surfaces ethical concerns within the wider framework of business operations. Third, there is the risk of producing subpar products. Given the urgent constraints of tight deadlines and scarce resources, there is a pronounced tendency to manufacture substandard, imitative products that fall short of the industry standards. The situation further escalates due to the dynamics of a closed-market economy and the declining inter-organizational relationships, potentially undermining competitive advantages and overall project effectiveness. These risks, both individually and collectively, highlight the intricacies and challenges associated with the implementation of LCC for large energy construction projects, especially in contexts influenced by special war operations. Therefore, it becomes imperative to study these risks further and consult with experts in international trade, licensing, product quality management, and economics for a more precise understanding of these risks in the future.

Author contributions

Conceptualization, VB and SL; methodology, LG and DF; software, SA; validation, SL, DF and LG; formal analysis, LG; data curation, VB; writing—original draft preparation, VB and SL; writing—review and editing, LG, DF and SA; visualization, SA; supervision, VB; project administration, LG. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare no conflict of interest.

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