UDC 69,055:69,003

Optimization of shopping center construction under organizational and financial constraints

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The article presents the results of optimizing the construction duration of the object and the average monthly financing intensity of the shopping center construction under organizational and financial constraints, namely: the work processes alignment – 68-76%; the maximum monthly financing intensity – 40 million UAN; number of work brigades – 1-2; the maximum construction duration – 360 days. There were developed the method for optimizing and the results of numerical modeling of organizational and financial decisions were obtained. The most efficient models of construction were identified by graphical way under limited conditions of their implementation.

Keywords: organization of construction, civil engineering, trade and entertainment center, the duration, the intensity of the funding.

Оптимізація моделі будівництва торгово-розважального центру при організаційно-фінансових обмеженнях

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Представлено результати оптимізації тривалості зведення об'єкта і середньомісячної інтенсивності фінансування будівництва торговельно-розважального центру в умовах організаційно-фінансових обмежень, а саме: сумісність процесів – 68-76%; максимальна місячна інтенсивність фінансування – 40 млн. грн.; кількість бригад – 1-2; максимальна тривалість робіт – 360 днів. Аналіз інформаційних джерел показав, що умови житлового будівництва надзвичайно мінливі, тому важливо дослідити вплив зміни організаційних рішень на основні показники, насамперед на тривалість будівництва та інтенсивність фінансування. Розроблено методику оптимізації організаційних рішень будівництва торговельно-розважального центру із використанням сучасних програмних продуктів з галузі управління проектами. Шляхом організаційного моделювання у програмі MS Project та економіко-математичного моделювання у пакеті MS Excel побудовані достовірні моделі процесу будівництва. Згідно плану експерименту зафіксовані значення наступних показників: тривалість виконання будівельно-монтажних робіт, максимальна місячна інтенсивність фінансування проекту та середньомісячна інтенсивність фінансування будівельних робіт.Для подальших досліджень була вибрана поліноміальна модель другого ступеню, що відповідає плану експериментів. На цій основі побудовані експериментально-статистичні моделі зміни показників від факторів, що варіюються: інтенсивність використання робочого часу, кількість робочих бригад та суміщення робіт. Графічним способом визначені найбільш ефективні моделі будівництва в обмежених умовах їх реалізації: «тривалість виконання будівельно-монтажних робіт» дорівнює 244 дні (60 робочих годин у тиждень, 2 робочі бригади, суміщення робіт 68%); «середньомісячна інтенсивність фінансування» дорівнює 15000 тис. грн. (80 робочих годин на тиждень, 1 робоча бригада, суміщення робіт 68%).

Ключові слова: організація будівництва, цивільне будівництво, торговельно-розважальний центр, тривалість, інтенсивність фінансування.

Introduction

The volume of civil construction in Ukraine was increased by 3.4 times (from 19 659,1 million UAN to 66 791,6 million UAN) for the period 2010-18 years. At the same time, the conditions of the civil construction are more complex than other types of construction for two main reasons: complicated engineering facilities as well as the instability of the financial situation at the macro and microeconomic levels. In the examination of the regulatory and reference literature comprehensive systematic recommendations for the choice of organizational and financial decisions on the topic has not been found. Research topic is extremely relevant, given the high social, economic and technical effect of solving the problem of rational selection of organizational solutions for civil construction.

Review of research sources and publications

Now there are 144 shopping centers in Ukraine with the corresponding lease area of 2.5 million m^2 by ICSC standards [1]. ICSC Ukraine Research Group has identified a concept of "shopping center" – an object of commercial real estate, which is planned, built and operated as a single entity, including shops and gross leasable area (GLA) of not less than 5000 m^2. According to the study, most of the retail space in the largest cities of Ukraine is presented in the format of "traditional/large" (27.9% of gross leasable area of shopping centers), "traditional/average" (23.2%), and the "traditional/small/with day to day – trade dominant" (24.7%). Another 15.8% have a format of "specialized/thematic center/entertainment without dominant" [2-3]. Shopping centers` market development has its own logic, and from year to year it is becoming more diverse. Under these conditions, the study of organizational and financial decisions of new shopping centers construction is relevant [4].

Analysis of works devoted to the optimization of organizational and technological solutions of construction and reconstruction [5-7] leads to the conclusion that the use of experimental statistical modeling is an effective way to solve such problems and can be used for modeling and optimization of operating activity of the construction companies. The papers [8-13] are devoted to optimization techniques applied by experimental statistical modeling. It is expedient [5-7] to create operating models of construction enterprise using specialized software for project management.

Definition of unsolved aspects of the problem

There is not considered the combined effect of a variety of organizational factors on the performance of the construction project in numerous studies aimed at the selection of efficient organizational and technological solutions. The study task is proposed to be solved by numerical simulation of construction processes and optimization of organizational solutions considering existing constraints, using modern software, theory of experiment planning and statistical processing of experimental results.

Problem statement

Purpose of the article is to optimize the construction duration and the average monthly financing intensity of the shopping center construction under the organizational and financial constraints. The following tasks were set to achieve this goal:

– Development of optimization method of indicators of shopping center construction project.

– Construction of experimental statistical dependencies of construction duration and average monthly financing intensity from the working time use intensity, the number of work brigades and the work processes alignment.

– Analysis and graphic interpretation of the numerical experiment`s results.

Basic material and results

There was proposed to use experimental statistical modeling for effectiveness evaluation of the organizational solutions of the shopping center construction. The essence of this simulation is to monitor the system under consideration by fixing the values of the outgoing parameters when specifying input values parameters. Thus, in the present study, the system is represented as a time schedule. Experimental statistical modeling algorithm is shown on Fig. 1.
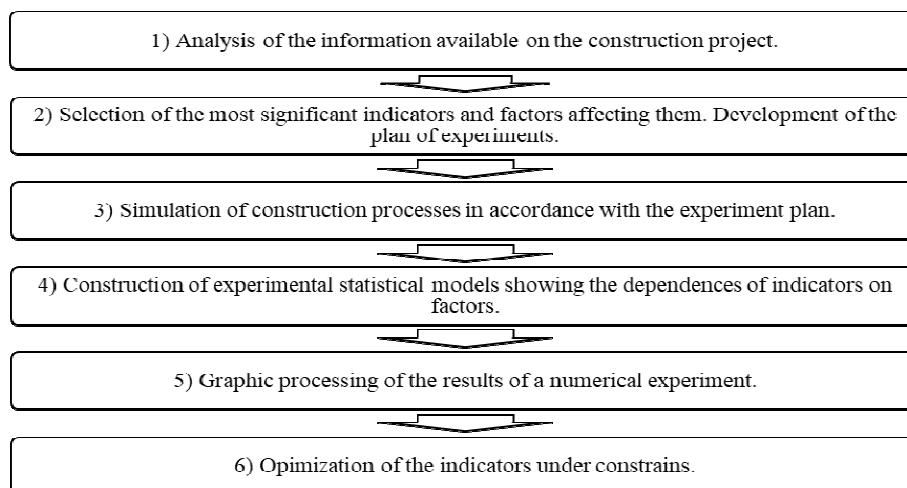

> 1) Analysis of the information available on the construction project.
>
> 2) Selection of the most significant indicators and factors affecting them. Development of the plan of experiments.
>
> 3) Simulation of construction processes in accordance with the experiment plan.
>
> 4) Construction of experimental statistical models showing the dependences of indicators on factors.
>
> 5) Graphic processing of the results of a numerical experiment.
>
> 6) Opimization of the indicators under constrains.

Figure 1 – Research algorithm

The key indicators are as follows:

– Y_1 – construction duration – the number of calendar time from the start of the first work until the end of the last work at all sections considering the schedule of construction works.

– Y_2 – maximum monthly financing intensity – the maximum amount of the monthly financing for the entire period of construction. It is defined as follows: construction of the work schedule with a cash distribution equal to month period; the resulting financing schedule is analyzed and month with a maximum funding is selected.

– Y_3 – average monthly financing intensity – the funds allocated for the construction of a facility are deleted on the duration of the construction work, expressed in months.

The selected indicators are most affected by the following factors:

– X_1 – working time use intensity – there was provided the following in the development of the experimental design: 40, 60, 80 hours per week;

– X_2 – number of work brigades –there was considered embodiment of the workflow involving 1, 2 or 3 brigades simultaneously;

– X_3 – work processes alignment – the ratio of the length of the construction period T_c to the total value of the working time of all the processes on all work sections $\Sigma_1^N \Sigma_1^N t_1$ (formula 1).

The transition to the coded factor levels was performed according to the standard formula 2, where:

– x_i – predetermined level of factor in its normalized form;

– X_i – predetermined level of factor in its natural form;

– $X_{i\,max}$ – maximum level of factor in its natural form;

– $X_{i\,min}$ – minimum level of factor in its natural form.

The polynomial experimental statistical model was selected to solve the problems of the present study. It is general form presented in formula 3. Numerical results of the experiment are shown in table 1. The results of the experimental statistical models calculation for the selected indicators are shown in formulas 4-6.

One of the tasks set by the customer was to determine the minimum duration of the construction work. The following restrictions were imposed while solving this problem:

– Work processes alignment – 68-76%;

– Maximum monthly financing intensity – 40 million UAN

$$K_s = \frac{T_c}{\Sigma_1^N \Sigma_1^n t_i} - 1 \; ; \tag{1}$$

$$x_i = \frac{X_i - \dfrac{X_{i\cdot max} + X_{i\cdot min}}{2}}{\dfrac{X_{i\cdot max} + X_{i\cdot min}}{2}} \; . \tag{2}$$

The restrictions are shown on the diagram by shading of following isosurfaces of construction duration and maximum monthly financing intensity values (Fig. 2). It enables to analyze these restrictions.

The effective value of the indicator "construction duration", equal to $C_{1\,limit}$ = 244 days, was found after examining the diagram with restrictions. This model is possible at: X_1 = 60 hours per week, X_2 = 2 working brigades, X_3 = 68%. The indicator reduces by the increasing of the working time use intensity (X_1), the number of work brigades (X_2) and the work processes alignment (X_3).

$$
\begin{aligned}
Y_1 = 243{,}64 &- 73{,}3\,X_1 + 35{,}94\,X_1^2 + 47\,X_1 X_2 + 19{,}5\,X_1 X_3 \\
&+ 121{,}3\,X_2 + 57{,}94\,X_2^2 \qquad\quad + 31\,X_2 X_3 \\
&+ 63{,}8\,X_3 \;\; + 9{,}56\,X_3^2
\end{aligned}
\tag{4}
$$

$$
\begin{aligned}
Y_2 = 36692{,}83 &+ 5619{,}81\,X_1 - 2047{,}95\,X_1^2 + 618{,}65\,X_1 X_2 + 1407{,}68\,X_1 X_3 \\
&+ 11427{,}04\,X_2 - 1998{,}13\,X_2^2 \qquad\qquad + 2043{,}24\,X_2 X_3 \\
&+ 6450{,}97\,X_3 \;\; + 209{,}38\,X_3^2
\end{aligned}
\tag{5}
$$

$$
\begin{aligned}
Y_3 = 20377{,}52 &+ 3106{,}2\,X_1 - 1812{,}37\,X_1^2 - 282{,}55\,X_1 X_2 + 23{,}64\,X_1 X_3 \\
&+ 6104{,}18\,X_2 - 1470{,}06\,X_2^2 \qquad\qquad + 438{,}58\,X_2 X_3 \\
&+ 3227{,}25\,X_3 + 1575{,}09\,X_3^2
\end{aligned}
\tag{6}
$$

The general form of the polynomial model:

$$
\begin{aligned}
Y_i = b_0 &+ b_1 X_1 + b_{11} X_1^2 + b_{12} X_1 X_2 + b_{13} X_1 X_3 \\
&+ b_2 X_2 + b_{22} X_2^2 \qquad\quad + b_{23} X_2 X_3 \\
&+ b_3 X_3 + b_{33} X_3^2
\end{aligned}
\tag{3}
$$

Table 1 – The results of a numerical experiment

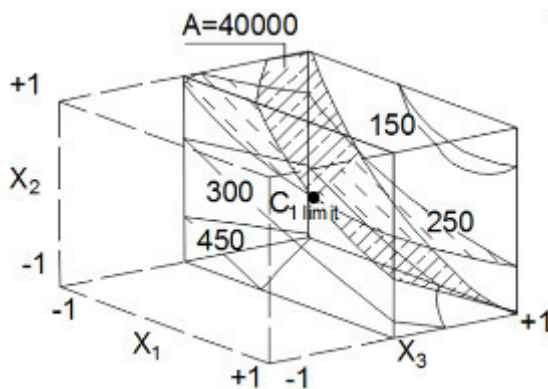| #	Working time use intensity, hours a week (X_1)	Number of work brigades, (X_2)	Work processes alignment, % (X_3)	Construction duration, days, (Y_1)	Maximum monthly financing intensity, thsd. UAH, (Y_2)	Average monthly financing intensity, thsd. UAH, (Y_3)
1	40	1	61	710	15 171, 713	7247, 944
2	40	1	76	445	20 788 647	11 487 308
3	40	3	61	278	32 012, 947	18 039 328
4	80	1	61	395	21 591 218	12 817, 417
5	40	3	76	190	43 728 903	25 907, 546
6	80	1	76	261	30 764, 955	19 025, 854
7	80	3	61	204	38 833 149	24 353, 094
8	80	3	76	141	58 253 785	30 441 367
9	80	2	68	224	44 725 436	22 139 176
10	40	2	68	335	26 268 165	15 032 774
11	60	3	68	194	50 425 694	25 367 806
12	60	1	68	409	20 667, 557	12 488, 766
13	60	2	76	190	47 045 372	25 907, 546
14	60	2	61	278	28 462 916	18 039 328
15	60	2	68	244	33 285 173	20 294 245

Figure 2 – Optimization of the construction duration under limitations of the work processes alignment and the maximum monthly financing intensity
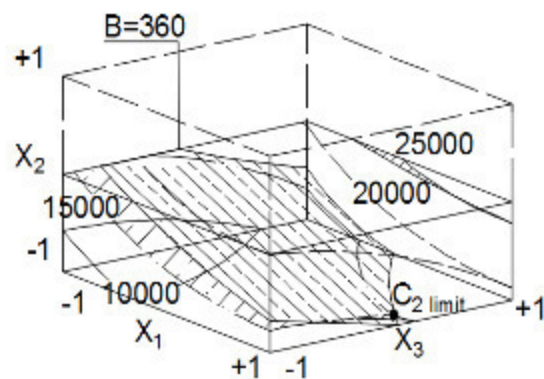

Figure 3 – Optimization of the average monthly financing intensity under limitations of the number of work brigades and the maximum construction duration

Next task, set by the customer, was to determine the minimum of the average monthly financing intensity. The restrictions for this task were:

– the number of work brigades – 1-2;

– the maximum construction duration – 360 working days.

These restrictions were shown on the diagram of the average monthly financing intensity (Fig. 3).

The minimal value of the indicator "average monthly financing intensity", equal to $C_{2\ limit}$ = 15,000 thsd. UAN was found after considering the limitations. This model is available when X_1 = 80 hours per week, X_2 = 1 operating brigade, X_3 = 68%. The average monthly financing intensity reduces with increasing levels of working time use intensity (X_1), the number of work brigades (X_2) and the work processes alignment (X_3).

Conclusions

1. The developed methodology and the obtained results confirm the possibility of using the proposed approach to the optimization of the construction duration and average monthly financing intensity for the facilities under consideration.

2. The efficient construction model into the investigated range of the factors has the following parameters: duration of construction – 244 days, the maximum monthly financing intensity – 40 million UAN, the average monthly financing intensity – 15 million UAN. These rates are achieved at 60 working hours a week, using two working brigades, with work processes alignment equal to 68% under constraints (work processes alignment – 68-76%; maximum monthly financing intensity – 40 million USD; number of working brigades no more than 2; construction duration – 360 working days).

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