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Modelling of Efficiency Evaluation of Traditional Project Delivery Methods and Integrated Project Delivery (IPD)

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Abstract. The classic triad "owner-architect-general contractor" are the main participants of traditional projects. They make contracts that regulate the rights and obligations of the parties and establish procedures for solving the entire range of issues during the operation of contractual relations. However, modern projects, especially large ones, require a wide range of participants. Taking into account the large number of project participants, it becomes very important to optimize the cooperation between them. The problems with communication leads to the division of the construction process to the stages, the significant number of changes and non-operating costs, and as a result to the increased project duration and increased costs. The research analyzes the core, characteristics and principles of the Integrated Project Delivery (IPD) and establishes the connection between it and the traditional project delivery methods. The IPD accumulates some of their special features and becomes the next stage in the evolution of the construction industry. One of the main characteristics of the Integrated Project Delivery is an early involvement of key participants, based on the following principles: early involvement, early goal definition, intensified planning, and organization and leadership. The aim of the research is to compare the effectiveness of the traditional project delivery methods and the Integrated Project Delivery by the criterion of the total cost for project modification. Methods of mathematical modeling were used to compare the effectiveness of the various project delivery methods. Thus, such curves and functions of dependence were modeled: between the increase in the cost of the project modifications and the period of their delivery; between the intensity of changes made to the project and the time when traditional project delivery methods are used; between the intensity of project modifications and the time on application of the Integrated Project Delivery. By means of the integral calculus (Simpson's rule) it was determined the total cost of the project modifications, which is a function of the method of project delivery and the cost of making the appropriate changes. The result of the calculations proves that the use of the integrated project delivery model reduces the total cost of making changes by 33%.

1. Introduction

A project team consists of the project main stakeholders as follows: owners, architects, engineers, general contractors, main sub-contractors, suppliers, and manufacturers [1]. At a very early stage (project development, pre-draft phase) the entire planning (design) is carried out by a team that involves not only an architect and a structural engineer, but also consultants in the areas of construction management, MEP engineering, energy technology, building physics, acoustics, facade construction and, depending on the type of project, other specialists [2].

Taking into account the large number of project participants, it becomes very important to optimize the cooperation between them. The problems with communication leads to the division of the construction process to the stages, the significant number of changes and non-operating costs, and as a result to the increased project duration and increased costs [3, 4]. The building design and construction industry needs to move towards a better coordination of participants and more collaborative approaches to overcome problems [5].

The questions of cooperation and integration during the delivery process was a great concern of scientists for a long period. For instance, recalls how the separation of the design and construction phases of projects was identified as a problem by government industry reports in the UK as early as 1962 by Emerson, who identified how removed the responsibility for design is from the responsibility of production [6]. He suggests that procurement models that omit the contractor can increase risk, reduce communications between team members, cause delays and create incorrect information which can lead to disputes and claims. The importance of the integration processes was emphasized by Chinowski [7] who have developed what they call an „Integration Matrix". The four quadrants of the matrix refer to varying levels of trust and communication. The final state is that of integration, where both trust and communication levels are high. They note that this is the preferred state for collaboration to occur. The concept of high performance is routinely implemented in diverse industries but has received little attention in the construction industry, where success is typically measured using traditional indicators, such as time, cost and quality. Authors suggests that the problem can be addressed by viewing the construction team as an integrated group of participants within a network, rather than as a group of participants. The team needs to consist of a cohesive network where members focus on building long term relationships that are transferred from activity to activity.

The project delivery method is selected by the owner of the construction project, this method establishes the preconditions for the realization of the project, such as the roles and responsibilities of the participants, including the legal agreements between the parties by setting project target and payment method. This tends to be a critical factor so that if selected correctly, it enables the successful implementation of a construction project.

2. Materials and methods

The most popular delivery methods today include Design-Bid-Build (DBB), Design-Build (DB), and Construction Manager at Risk (CM at Risk).

DBB is the construction delivery method this allows the owner to enter into separate contracts with the designer, which is generally the architect, and the contractor. After the design is complete the project is released for bid by contractors. The owner selects from these competitive bids to award the contract for construction. The lack of integration between the designer and contractor in this process often results in problems that do not get recognized or resolved until after the construction process is under way.

The reason the owner would choose DB over another construction delivery method is to have one contractual agreement to help transfer risk from the owner to the design-build team and increase coordination between disciplines. This method of design and construction follows the same approach as DBB but takes out the "bid" step. This allows for the design and construction entities to be more coordinated and integrated throughout the project. This method allows for the design and construction entities to be more coordinated and integrated throughout the project.

CM at Risk has the same contractual agreement as DBB and the early cost commitment like that of the DB method. CM at Risk is a project delivery method in which the "construction manager is hired early in the process to deliver an early cost commitment and to manage issues of schedule, cost, construction and building technology".

Having analyzed the most popular methods of projects delivery, we can conclude that the IPD accumulates some of their particular factors and becomes the next stage of evolution in the construction process organization. For instance, from the Design-Build method, the IPD "received" design and construction entities to be more coordinated and integrated throughout the project. In its turn, the CM at Risk method involves the earlier involvement of stakeholders in the construction project.

One of the reasons that IPD is being brought into the industry is because these traditional methods of project delivery "suffer because participant success and project success are not necessarily related" [8]. The disconnect between the parties can cause a separation between the design phase and the construction phase of a project in the traditional design methods [9].

The essence of the integration in the construction process is fully described by the definition of IPD, from the American Institute of Architects [8]: IPD as a project delivery approach that integrates people, organizations, business structures and exercises into a process that collaboratively harnesses the talents and insights of all project participants to optimize the results, increase value to the owner, reduce waste, and maximize efficiency through all stages of design, manufacturing and building.
Having analyzed a number of definitions for IPD, the similarities of its characteristics are adduced in table 1.

Table 1. The similarities in characteristics of IPD.

Similarity / Scholars	Early involvement	Integration	Collaborative	Shared risks / rewards
AIA California Council (2007) [8]	x	x	x	x
NASFA (2010) [10]	x	x	x	x
Rahim (2015) [11]	x	x	x	
Hardin (2009) [12]	x	x	x	x
Nofera (2011) [13]		x	x	x
Johnson (2013) [14]	x	x		x
Gultekin (2014)[15]	x	x	x	

The main principles of IPD are formed on the base of its characteristics. Principles are critical for effective business implementation and the construction industry is no exception. If all of these are implemented and used together better collaboration is created, which in turn creates a better project output both in design and construction.

The authors point out different number of IPD basic principles and benefits. Thus, according to NASFA [10] eleven principles of IPD are divided into two categories - contractual and behavioral; the American Institute of Architects [8] and Kent & Becerik-Gerber [16] used nine principles of IPD; according to Hassan are ten principles of IPD [17]. In our opinion, analyzing the principles of the IPD, it is not so important to allocate the maximum of their number, but the clear segment and the distinguish of specific areas make a point. To realize the aim of this study, the most interesting is the study of N. Azhar [18] in which the author identified six main principles of the IPD:

- early involvement of key participants;
- shared risk and reward;
- multi-party contract;
- collaborative decision-making and control;
- liability waivers among key participants;
- jointly developed and validated project goals.

In addition, in the above-mentioned study, a survey was conducted among US construction industry companies. One of the questions was to identify the most important IPD principle. Thus, the survey participants identified the early involvement of stakeholders as one of the most important factors. The principles that embody idea of early involvement are: early involvement, early goal definition, intensified planning, and organization and leadership. Although this is pretty selfexplanatory, it is the most important principle of IPD. Early involvement is referring to the fact that in pure IPD all disciplines involved in the process are involved and make decisions from the project's beginning. This moves directly into early goal definition. If the goals of the project are set early on everyone will be on the same page and know what is expected of them throughout the entirety of the project.

Complexity of the project in recent times has increased the importance of early involvement of key participants. The American Institute of Architects [8] has highlighted its importance as follows "Building upon early contributions of individual expertise, these teams are guided by principles of trust, transparent processes, effective collaboration, open information sharing, team success tied to project success, shared risk and reward, value-based decision making, and utilization of full technological capabilities and support. The outcome is the opportunity to design, build, and operate as efficiently as possible".

The questions of the early involvement of stakeholders during the delivery process was a great concern of scientists for a long period. One of the first to start the research was B. Paulson [19]. He found that the level of influence is high during the early stages of construction and gradually reduces over the project life. Similar well-known preposition was made by P. MacLeamy, CEO, HOK at the 2004 Construction Users Roundtable to illustrate advantages of IPD [20].

The MacLeamy curve (figure 1) plots correlation between cost of making changes when using the traditional project delivery methods and integrated project delivery over the successive timeline of a project. This hypothesis has been tested and proved true several times by several researchers over number of years. Collaborative project delivery gives the owners benefit of having major role players of projects involved in early stages of design and construction. The integrated processes, thus, reduce time delays, waste of motion, material and labor and save money as they are driven by collaboration and teamwork [21].

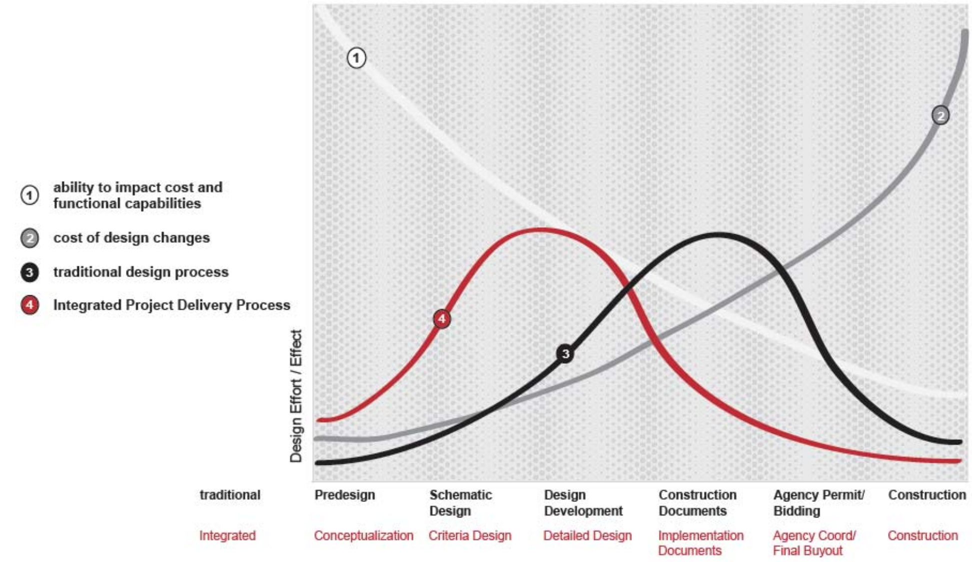

Figure 1. The "MacLeamy Curve" illustrates the advantages of Integrated Project Delivery.

The owner is able to reduce costs and increase the quality of a design if compared with traditional project delivery. The advantages of MacLeamy's curve are specifically for project owners who are complex and innovative with fast-track requirements, or for owners who have not clearly defined a program and/or its terms. With the introduction of a builder to the conceptual phase of an early design, the contractor can collaborate with the designer to adopt efficient methods [22].

Consequently, one of the main advantages of Integrated Project Delivery over traditional project delivery methods is the early involvement of stakeholders. It enables to identify the conflicts and errors ahead and to introduce the project modification in the early stages of its delivery.

The study aims to compare the effectiveness of the traditional project delivery methods and the Integrated Project Delivery (IPD) method by the criterion of the total cost for project modification.

To compare the effectiveness of different projects delivery methods, we used the methods of mathematical modelling and numerical integration (Simpson's rule).

3. Results and discussions

At the first stage, we simulate the dependence of the cost growth for changes made to the project from the period of their delivery. To do this, we construct an exponential function g (t) (figure 2)

$$g(t) = \exp(bt) \quad (1)$$

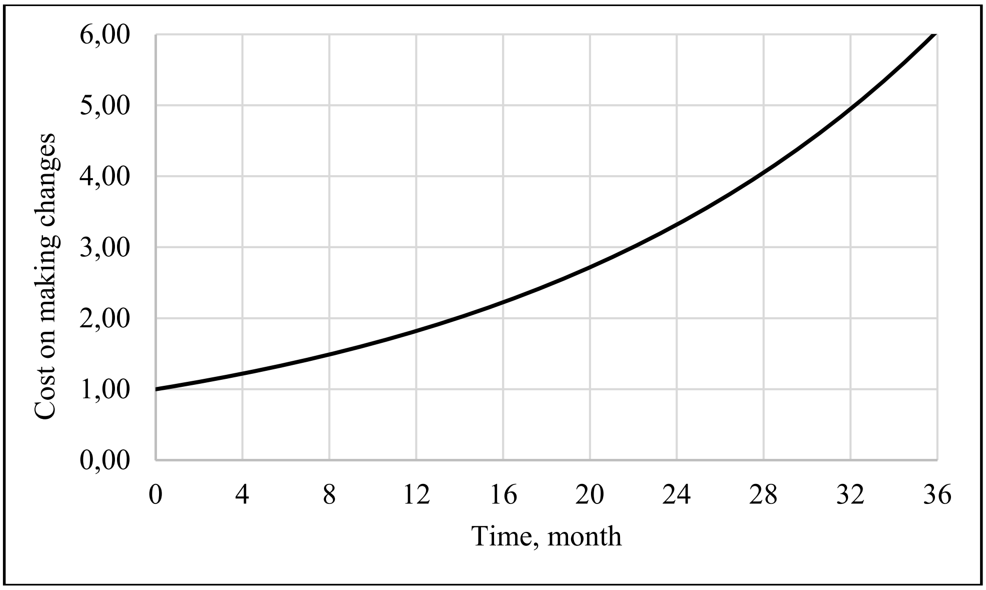

Figure 2. Dependence of cost growth on making changes from the time of project delivery.

where *t* - is the current time, expressed in months, $b = 0.05$ - is the parameter that reflects the rate of cost growth for project modifications. The period of the construction project is *36* months.

The next step is to simulate the curve and the function of dependence between the intensity of changes made to the project and the time when traditional project delivery methods are used. On application of traditional project delivery methods, the greatest changes to the project are made at the middle stage of project implementation. This hypothesis is illustrated by a symmetrical bell-shaped line (Gauss curve), figure 3.

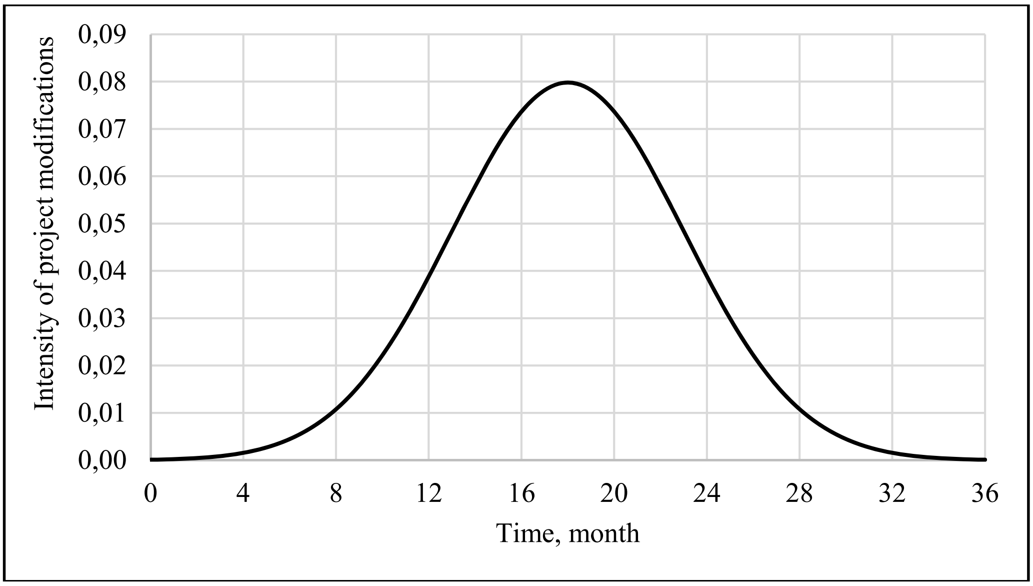

Figure 3. Dependence between the intensity of project modifications and the time on application of the traditional project delivery methods.

The process of changes making on application of traditional project delivery methods we model using symmetric Gaussian function

$$f_1(t) = k \exp\left[-a\left(\frac{t-m}{\sigma}\right)^2\right] \quad (2)$$

Where *t* - is the current time expressed in months, *m* is the parameter that reflects the time frame of the project delivery, σ is the parameter that has the content of the mean square deviation, *a* is the parameter that determines the slope of the curve, *k* is the factor that normalizes the amplitude of the function $f_1(t)$. The parameters for this model of the decision-making process are as follows: *a = 0.5, m = 18, σ = 5, T = 36*. The normalizing factor *k* is chosen so that the area of the curve (S_1) under the decision-making curve is equals one

$$S_1 = \int_o^T k \exp\left[-a\left(\frac{t-m}{\sigma}\right)^2\right] dt = 1 \quad (3)$$

From (3) we determine that the value of the parameter is *k = 0.0798*. The subject-matter of normalizing is that the area of the curve reflects the number of the project modifications (in percentages - 100%). With different methods of project delivery, the number of modifications will be roughly the same, but their basic mass will focus on the various stages of project.

We modulate the curve and the function of dependence between the intensity of the changes made to the project and the time when the Integrated Project Delivery (IPD) is used. The process of changes making on application of Integrated Project Delivery (IPD) is modelled using the following function $f_2(t)$ (figure 4)

$$f_2(t) = kt^3 \exp(-bt) \quad (4)$$

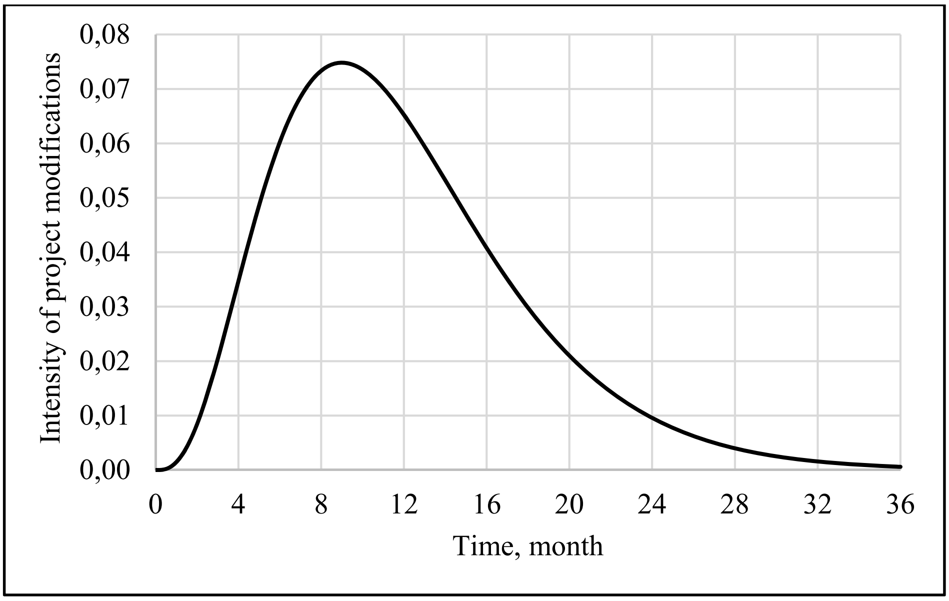

Figure 4. Dependence between the intensity of changes made to the project and the time on application of the Integrated Project Delivery (IPD).

Where *t* is the current time expressed in months, *b* is the parameter that represents the period of project implementation, which has the largest number of changes, *k* is the factor that normalizes the amplitude of the function $f_2(t)$. The parameters of this decision-making process model are as follows: *b = 1/3, T = 36*.

As it can be seen from the chart, on application of the Integrated Project Delivery, the biggest part of proposals and decisions regarding project improvement are concentrated in the initial period of the project delivery that saves time and money for their implementation.
The normalizing factor *k* was chosen in such a way that the area of the curve (S_2) under the decision-making curve equals one (*k = 0.00206*).

$$S_2 = \int_o^T kt^3 \exp(-bt)\, dt = 1 \tag{5}$$

To evaluate the benefits of the Integrated Project Delivery concept the integral calculus methods are put into practice. The total cost of project modifications depends on the chosen method of project delivery (traditional methods or integrated delivery) and the outlay of making the appropriate changes. So, in order to calculate the total cost of correcting all identified defects you need:

1. Find the product of the curve that shows the intensity of proposals submitting $f(t)$ and the exponent $g(t)$, which reflects the increase in the cost of making changes with time.
2. Calculate the area of the figure, which is between the graph of the function $f(t) \cdot g(t)$ and the axis OX. This area (defined integral) shows the total cost of making changes to the project.

Thus, the total cost of project modifications is defined by the time schedule for making changes (the function $f(t)$) and the cost changes implementation (the function $g(t)$) and expressed by the functional *W(f, g)* of the following form

$$W(f,g) = \int_0^T f(t) \cdot g(t) dt \tag{6}$$

Consequently, the total cost of making changes is expressed by the ratio:

- with traditional methods of project delivery

$$W_1 = \int_0^T f_1(t) \cdot g(t)dt \tag{7}$$

- with Integrated Project Delivery

$$W_2 = \int_0^T f_2(t) \cdot g(t)dt \tag{8}$$

Numerical integration of expressions (7) and (8) was performed using the Simpson's rule (step $h = 0{,}1$ *months*) [23]. The calculations were carried out in a spreadsheet and contain 361 records. As a result, the following amounts of expenses for project modifications were received:

$W_1 = 2.537,$
$W_2 = 1.903.$

Thus, we can make a conclusion that the application of integrated project delivery allows to save 33,3% of financial resources. Really

$$\frac{2.537 - 1.903}{1.903} = 0.333$$

4. Conclusions

The research analyzes the essence, characteristics and principles of the Integrated Project Delivery (IPD) and establishes the connection between it and the traditional project delivery methods. The IPD accumulates some of their special features and becomes the next stage in the evolution of the construction industry. Efficiency is investigated of the traditional project delivery methods and the Integrated Project Delivery by the criterion of the total cost for project modification. Methods of mathematical modelling were used to compare the effectiveness of the various project delivery methods. Thus, such curves and functions of dependence were modelled: between the increase in the cost of the project modifications and the period of their delivery; between the intensity of changes made to the project and the time when traditional project delivery methods are used; between the intensity of project modifications and the time on application of the Integrated Project Delivery. By means of the integral calculus (Simpson's rule) it was determined the total cost of the project modifications, which is a function of the method of project delivery and the cost of making the appropriate changes. The result of the calculations proves that the use of the integrated project delivery model reduces the total cost of making changes by 33%.

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