

Optimization of inventory costs management in the construction enterprise

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Abstract. During planning the execution of each construction project, the factors that may affect the effectiveness of its realization should be analyzed in detail. The costs of execution construction projects are significantly influenced by (apart from technical factors) decisions in the field of inventory management, among others, variability of environmental conditions, prices of construction products, the ability to acquire local suppliers, distance of transport, limited size of storage for construction products as well as the individual character of the project. In projects related to the buildings erection and other construction works, there are many logistical tasks in the area of supply in construction products, raw materials, equipment, as well as in the area of financial and information flow. Taking into account the large share of material costs, inventory management in the costs of projects realization and the high potential for their reduction, every enterprise operating in the construction industry should pay a great importance to the supply logistics sector. Determination of the size and delivery times of construction products, as well as the transport routes, storage and reloading locations are decision-making problems that are solved by management of both the enterprise and the construction projects. The paper presents a proposal for a methodology, which allows to determination and comparison of the inventory management costs in enterprise conducting parallel works on several construction sites. Mathematical models have been developed which simulate the functioning of supply logistics systems and allow, through their solution, to determination of the minimum logistics costs with optimal arrangements for the supply schedule (delivery volumes in subsequent periods of the project execution). This is the foundation for the selection of the optimal variant of a supply chain management. The practical application of the methodology proposed is illustrated using an example.

1. Introduction

The execution of construction projects is burdened with the impact of many risk factors that may have a negative influence on the time and cost of its realization. Therefore, the ability to make optimal decisions is a key element of the effective management of construction projects [1]. Identification of risk factors and assessment of the impact of their effects allows for an effective reduction of the duration of individual processes [2], as well as costs related to the execution of construction works [3]. Such costs include expenses incurred as a part of logistic tasks.

There are many logistic tasks in the field of supplying construction products, raw materials, equipment as well as in the area of financial and information flows in projects related to the



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construction and execution of other construction works. Logistics of the construction production also includes land removal from excavations, waste disposal, maintenance of vertical and horizontal transport equipment, internal communication at the construction site, coordination of dates and places of delivery, safety and health protection in logistic processes [4]. Taking into account the scope of tasks and the great potential to reduce the costs of their realization, every enterprise operating in the construction industry should pay a lot of attention to the supply logistic sector.

Due to the individual character of each project (venue, communication conditions), it is not possible to indicate a universal system that will meet the needs of many construction projects in an optimal way. Processes related to the supplies, purchases or deliveries determine the undisturbed course of the construction project execution. Appropriate inventory management, efficiency of supply units or timeliness of deliveries are one of many factors that affect the efficiency of construction works. Ensuring adequate inventory of products, in quantities and times corresponding to the demand for them, guarantees compliance with deadlines for the realization of works. Therefore, it is important to choose the right model of the logistic supply system in order to ensure the continuity of construction production as well as to reduce logistic costs [5].

Logistic systems of construction enterprises are diverse in terms of structure and objectives of the activity. Due to the location and number of elements, they can be divided into:

- one-stage (deliveries are directed directly to the recipient).
- two-stage with an auxiliary warehouse (supplies are directed first to the recipients, and surplus goods are stored in the warehouse).
- two-stage with a central warehouse (recipients are supplied by the warehouse) [6].

The logistic system should meet the objectives set out in the contract strategy and in the construction company in which the system operates. For example, it can be the optimization of costs related to the logistics (inventory management, transport, storage) through consolidation of supplies in central warehouses and modernization of infrastructure.

The strategies of many enterprises also assume concentration on key business areas and outsourcing of other services, e.g., to the logistic centers. The logistic center is an institution offering services for a wide range of logistic functions and processes. It can be an integral part of the supply chain of the logistic system in construction, which allows its optimal functioning and is the focal point for products flow streams. In the literature, an attempts to conduct a cost analysis can be meet, together with simulations and multi-criteria analyzes of the impact of a logistic system choice on the inventory management [4], [7].

Arashpour et al. [8] investigated the impact of decision parameters, such as the ability to enable and disable certain suppliers, and the use of multiple vendor configurations on the inventory management cost. To this end, they have developed the optimization models that have positively influenced the efficiency of the supply chain in the production of prefabricated products. The research results showed that minimizing the risk of uncertain deliveries by the configuration of many suppliers increases the costs related to the inventory management.

Supply chains in the construction usually consist of many participants and they are characterized by a complex construction structure. Cheng et al. [9] propose to present the supply chain using a network model that can facilitate the identification of bottlenecks and is the basis for the supply chain modification. On the example of installation processes, they developed models based on the Supply Chain Operations References (SCOR) model, which deals with planning, acquisition, production, and

execution of supply chain activities. The proposed models complement the SCOR with issues related to the design, sales administration, technology development, and customer service. Research shows that such a configuration contributes to the improvement of strategic planning and performance monitoring in the supply chain management.

Jaśkowski et al. [10] propose the linear programming model for supplies optimization of unevenly consumed materials, which aims to minimize the inventory management costs. The use of the fuzzy numbers made it possible to take into account the materials prices fluctuations over time. The model developed allows to determine the optimal quantities of deliveries as well as select appropriate delivery channels for a given material.

Tomczak and Rzepecki [11] compared various supply chain management systems using the modified AHP method in Mikhailov's approach. Thanks to this, it was possible to take into account the differences between experts' assessments and a small number of the decision-makers. In this way, a scale vector was obtained, which prioritizes the supply chain management systems in order of their suitability for the set criteria.

Researchers also point to the great importance of the information exchange and integration of the supply chain participants. A significant impact of social aspects on the supply chain management was noted [12]–[14]. Xue et al. [15] compared the level of information exchange in different inventory management strategies. They developed a comparative method for two inventory management policies: the optional replenishment (s, S) and the periodic review (PR). In this way, the impact of the deliveries number information on the level of services provided by the general contractor of the construction project was measured. The results confirmed higher effectiveness of the (s, S) policy in improving the quality of services provided and minimizing the costs of the inventory management in the case of the no information sharing. On the other hand, in a situation where there was an information sharing between the supply chain participants, the PR policy turned out to be better but it contributed to the increase of logistic costs.

Another aspect that experts are paying particular attention is the impact of the construction industrialization on the supply chain management [16]. Currently, many construction sites are supplied by the same supplier of materials or prefabricated products. For this reason, manufacturers often work in a multi-project environment. Considering the need to match the production process and logistics to the overall schedule of each project, a coordination and information sharing between all participants in the supply chain is very important in this case [17].

Due to the trend of shift from the stick-built construction to the modular construction, the supply chains currently used, which focus mainly on the supply of products directly to construction sites, are becoming less useful. Hsu et al. [18] developed a mathematical model to establish optimal plans for production, transport, and inventory management in the modular construction, covering three levels of operation: production, storage, and assembly. Thanks to the model, it was possible to determine how the production and inventory management should react to changes in the demand at the construction sites.

The paper analyzes the problem of determining the logistic system structure for the construction enterprise supply. Three variants were considered for the logistic system construction for ceramic blocks supply for the execution of three identical facilities in different locations by one enterprise. The methodology proposed aims to determine the optimal volume of supplies and looks for the minimum costs of the inventory management, which form the basis of comparisons. Mathematical models mapping these systems were developed. The solution of these models will allow to choose a logistic system of supply, for which the inventory management costs are the smallest.

2. Case study

The subject of each of the projects analyzed is the execution of a multi-storey residential building. The building has 4 floors, which walls are executed in the traditional, modernized technology. Works on all three investments, carried out in various locations (distance of about 20 km from each other), start on the same day and are carried out simultaneously.

The first variant of the logistic system predicts supplies directed directly to the construction sites from independent wholesalers located near each investment. In the second option, the supply of materials is provided by the manufacturer located in the vicinity of one of the investments. In the third option, deliveries are made using a central warehouse belonging to an enterprise, which undertakes construction works. The repository is supplied by a representative of a construction products manufacturer.

Assumptions adopted for calculations:

- The period of executing masonry works, which is equal to 44 days, has been divided into 11 periods lasting 4 days each.
- It was assumed that materials deliveries will be made at the beginning of periods.
- The material inventory at the beginning of the period, without taking into account the size of the new supply, is the difference between the material inventory in the previous period (increased by the delivery amount) and the planned material consumption.
- At the beginning of the period, the inventory of construction products is equal to zero.
- The material delivery quantities have been determined taking into account the following conditions:
 - they must adopt non-negative values,
 - the material supply batch (including the accumulated inventory at the beginning of the period) should cover the demand in a given period and ensure maintenance of the reserve created due to the risk factors and uncertainties, which cause random fluctuations in demand, and to eliminate material shortages as well as breaks in the construction production (shortage of material is unacceptable) [19].
- The amount of the reserve was set at 10% of the demand value in a given period.
- The landfill area has been designed in such a way that it would be possible to accumulate the maximum amount of the total inventory at the beginning of the period and the size of the delivery.
- Total costs of material purchase and freezing of current assets in inventories, assuming that payment of remuneration to the enterprise, which performs construction works and purchases materials, takes place after the construction is completed, taking into account the change in the value of frozen capital in that period.
- The interest rate was calculated on the basis of an annual lending rate for companies, amounting to 18%, and it was assumed to be 0.2% for a 4-day period.
- The unit price was adopted from the catalog of the manufacturer of the Alfa 1/1 expanded clay hollow block in the amount of 1.00 EUR/piece gross.
- The price is fixed and it is valid throughout the entire investment period.
- In the second and third variant, a discount of 10% was added to the price due to the purchase of larger quantities of products.
- It has been assumed that the storage costs of construction products, including fixed costs of organizing the warehouse, are approximately proportional to its surface.
- A temporary warehouse with a storage capacity equal to 1500 blocks will be created on each construction site.
- The cost of making a square from multi-hole road slabs was calculated for 6 EUR/m².

- In the case of the central warehouse, it was assumed that its storage capacity is limited to 5000 pieces of hollow bricks.
- The cost of each delivery – independent of its size – was adopted at the level of 3 EUR.
- In the third variant, it will be added only to deliveries from the manufacturer to the central warehouse, while for deliveries for particular constructions, it will be included in every delivery.
- The cost related to the transport of the products ordered was calculated as the product of the transport distance, the rate for 1 km of transport equal to 1.00 EUR, and the number of individual courses making up the whole delivery in particular periods.
- Transport of products for the construction sites will be carried out with platform cars with a capacity of up to 21 tons, equipped with the HDS type loading crane.
- The maximum load size will therefore be 950 items (19 pallets of 50 blocks each).
- In the case of delivery to the central warehouse and from one manufacturer for all construction sites, a car with a capacity of 27 tons will be used for the transport (maximum load size – 1250 items).

Figure 1 illustrates the steps taken to select a variant.

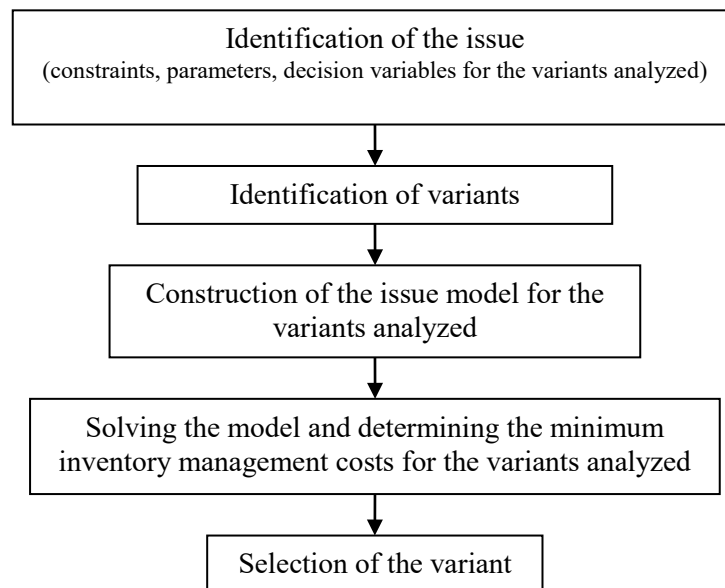


Figure 1. The proposed methodology for the variants selection of the logistics system

3. Mathematical model of the problem

The mathematical model of the issue of determining economically justified deliveries includes the function of purpose and limitations, which were discussed in detail in publications [6], [20]; they are recorded using linear analytical relationships shown in the table 1.

Table 1. Model of the problem with formulas explanation

Formula	Application
$\min C : C = \sum_{i=1}^n D_i \cdot p_i \cdot (1 + r \cdot \Delta t_i) + A \cdot c_s + \sum_{i=1}^n d_j \cdot c_i \cdot (k_i + x_i) + \sum_{i=1}^n c_r \cdot y_i$	Objective function
$\Delta t_i = \sum_{k=i}^n t_k, \quad i = 1, 2, \dots, n$	The freezing period of current assets in inventories

$s_1 = 0$	Inventory in the first period
$s_{i+1} = s_i + D_i - q_i, i = 1, 2, \dots, n-1$	Inventory in the subsequent periods
$D_i + s_i \geq q_i + R_i, i = 1, 2, \dots, n$	The amount of delivery during the i period including the supply must cover the demand (with reserve)
$B \geq D_i + s_i, i = 1, 2, \dots, n$	Limiting the amount of material stored
$A = \frac{B}{N_{sm}} \cdot \alpha$	Necessary area of the warehouse
$k_i = \frac{D_i}{l} - g_i$	The number of courses for delivery during the i period
$D_i \leq M \cdot y_i, i = 1, 2, \dots, n-1, D_i \geq 0, i = 1, 2, \dots, n$	Terms of delivery
$g_i \leq M \cdot x_i, g_i < 1, g_i \geq 0$	Condition of delivery with incomplete use of the transport mean

$$k_i \geq 0, k_i \in I \quad i = 1, 2, \dots, n,$$

$$j \in \{1, 2, 3, 4\},$$

$$x_i, y_i \in \{0, 1\}, i = 1, 2, \dots, n,$$

where:

D_i – the size of the delivery part in the i period,

p_i – unit price of material in the i period,

r – interest rate for the unit period,

Δt_i – the freezing period of current assets in inventories,

s_i – inventory in the i period,

q_i – material consumption planned in the i period,

B – amount of material stored,

A – necessary area of the warehouse,

k_i – the number of courses for delivery during the i period,

d_j – the j construction site distance from the manufacturer's warehouse,

c_i – cost of one kilometer of transport,

l – vehicle load capacity,

g_i – auxiliary variable meaning delivery with incomplete use of the load capacity of the transport mean,

c_s – unit cost of organizing a material repository,

x_i, y_i – binary variables,
 c_r – the cost of one material delivery,
 t_k – duration of a single period,
 R_i – reserve of the material during the i period,
 N_{sm} – storage standards,
 α – factor of increase,
 M – a sufficiently large number,
 C – objective function.

Mathematical models of the problem, constructed for three sets of parameters values (for all variants), were solved using the LINGO 12.0 Optimization Modeling Software. The optimal solution of the cost minimization is shown in table 2.

Table 2. Statement of the minimum cost of supplies.

Variant number	Recipient of deliveries	Minimal inventory costs	
		Cost of delivery C_i [EUR]	The sum of delivery costs for the variant [EUR]
Variant I	Construction I	13314.08	35893.57
	Construction II	11311.21	
	Construction III	11268.28	
Variant II	Construction I	12058.91	36368.31
	Construction II	12164.70	
	Construction III	12144.70	
Variant III	Central warehouse	30377.65	33531.58
	Construction I	1089.31	
	Construction II	1031.31	
	Construction III	1033.31	

A detailed analysis of three variants of the logistic system has shown that the variant using the central warehouse is cheaper in terms of costs related to the inventory management. Direct deliveries to construction sites have been found to be more expensive by 2361.99 EUR for three independent suppliers and by 2836.73 EUR for one supplier, which is approx. 7% and 8.5% of all logistic costs.

4. Conclusions

Logistic processes related to the supply and purchase of construction products are an inherent element of the functioning of every construction enterprise, and their well-thought-out management leads to costs reduction of the entire project. The configuration of the supply chain is influenced by factors such as the common practice of participants, the scale and budget of the project, as well as the type of construction project.

The use of logistic systems with elements allowing for concentration of supplies (central warehouses, logistic centers) is economically advantageous, especially for large and complex investments characterized by complexity of tasks and processes.

The main obstacle in creating models analyzed in the paper is the difficulty in obtaining data from construction enterprises. Therefore, it is reasonable to analyze the sensitivity of logistic systems to changes in decision parameters.

The proper operation of every construction company is often disturbed by the appearance of many decision problems, which certainly include difficulties related to the purchase and supply of building materials and raw materials.

The analysis carried out does not fully solve the decision problem which is the selection of logistic systems due to the fact that it does not concern the supply of the entire construction project and only a part of it – masonry works. It is therefore justified to carry out further analyzes examining the impact of the type of construction products supplied on the selection of a logistic system.

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