Aspects of the System Approach to Inventory Management

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Abstract. Transport construction, including road construction, consumes a huge amount of materials, including new materials of a wide range: stone materials, sand and sand-gravel mixtures, mineral and organic binders, metal, etc. In the direct costs (cost of materials, operation of machines, wages of road workers), the share of the cost of materials reaches 60%. Often, the region in which the road is being built does not have its own standard materials, and these materials have to be delivered from other regions. For example, many regions of the Central region of Russia are forced to import crushed stone of hard rock from Karelia and the Leningrad region, and bitumen - from the Volga region. For the Moscow region, the shortage of building sand is more acutely felt in recent years, and this is only one side of the problem of material support of construction.

1. Introduction
There are a number of factors that cannot be ignored:
   1. Cost of materials from the supplier and its economic stability (one can enter into a contract for cheap products with a supplier who is at the stage of bankruptcy);
   2. Supplier discipline in the fulfillment of contractual obligations (permanent disruptions in the delivery of crushed stone and bitumen can lead to large losses due to forced downtime of the spread);
   3. Presence or absence of warehousing for the storage of stocks of building materials in the construction organization (this is important for such materials as cement, bitumen, fuels and lubricants, varnishes and paints);
   4. Possible schemes for the transportation of materials (only by truck or by a combined method: rail, road, water, air, etc.).

All this proves the complexity and diversity of the problem of the material support of construction due to the solution of a number of interrelated private problems. The models of inventory management allow optimizing the plans of material support of construction. The study of these models is the subject of research in this paper [1-9].

2. Materials and methods
Inventory management models allow solving the following problems in a complex:
   1) the choice of suppliers of materials and structures for construction objects;
   2) justification of the rational option of transporting materials;
   3) gathering procurement and transport units of the optimal (rational) composition that ensures the required rate of supply of materials to the line and the lowest cost of transportation;
4) feasibility study of the value of stocks of the main types of materials and structures, guaranteeing the rhythm of construction (minimizing the risk of line unit downtime due to the lack of materials).

The first and second problems are solved using linear programming models, the third - using queuing models. The fourth problem is solved by the methods of the inventory management theory. Inventory management models allow calculating volumes of stocks, at which the total costs for the creation and storage of stocks will be minimal, as well as the frequency of replenishment of stocks [1-9].

3. Results
Stock size directly affects the pace of construction and completion time. The late commissioning of the object is fraught with penalties, and early commissioning is rewarded.

The economic formulation of the problem in terms of risk minimization can be formulated as follows:

1) with an increase in stocks of materials in the construction company's own warehouses, the probability of not only timely but also early commissioning of the object (P) increases. As a result, the organization can get the effect from the early commissioning ($E_e$):

$$E_e = 0.1E_{st}C_{ost}\left(\frac{T_d-T_a}{T_d}\right)\cdot P$$

where $E_{st}C_{ost}$ - estimated cost of the commissioned object; $T_d$ and $T_a$ - the directive and the actual dates of commissioning of the object, respectively;

2) the reduction of stocks leads to the risk of failure of the directive period for putting an object into operation and paying a fine. If we denote the probability of violation of the term of putting an object into operation through $Q$ ($Q = 1-P$), then the probability of damage from the payment of the fine will be:

$$C_{fine} = \alpha E_{st}C_{ost}\left(\frac{T_d-T_a}{T_d}\right)\cdot Q$$

where $\alpha$ - percentage (share) of the fine from the estimated cost of construction (usually specified in the contract between the customer and the contractor).

Since $T_a > T_d$, then the value of $C_{fine}$ will be negative;

3) it is obvious that with an increase in the cost of stockpiling ($C_{S}$), $P$ increases, and $Q$ decreases (Figure 1, a, b, c). It is necessary to find such costs ($C_{S}$), with which the difference between the effect $E_e$ and losses from fines $C_{fine}$ will be non-negative, i.e. the following condition is met:

$$E_e - C_{fine} \geq 0$$

The point of intersection of graphs $E_e = f(C_{S})$ and $C_{fine} = f(C_{S})$ is called the break-even point from the position of the risk of a fine for late performance of work. On the other hand, there is a risk of economic losses from overspending on the delivery or storage of materials. From this point of view, the total costs of the functioning of the inventory management system can be expressed by the objective function:

$$C_{S} = C_{pur} + C_{tr} + C_{st} + C_{fine} - E_e \rightarrow \min$$

where $C_{pur}$ - the cost of purchasing materials; $C_{tr}$ - transportation costs; $C_{st}$ - the cost of storing materials; $C_{fine}$ - losses from fines; $E_e$ - the effect of early commissioning of an object.
The cost of purchasing material usually does not depend on the size of one-time stored stocks, but in some cases, there may be bulk discounts when the price of materials decreases with an increase in the volume of the order.

4. Discussion
Transportation costs depend on the batch size (it is more expensive to transport materials in small batches).

The cost of storing materials always increases with the size of the stock (storage costs, depreciation costs, and operating costs).

The influence of all components of dependence (3) on total costs is illustrated in Figure 2.

![Figure 1](image1.png)

**Figure 1.** a) Dependence $p=f(C_{ΣS})$; b) Dependence $Q=ϕ(C_{ΣS})$; c) Principled approach to finding $C_{ΣS opt}$

At first glance, with sufficient simplicity, the generalized model described by dependence (3) allows us to construct many specific models presented in Figure 3.

![Figure 2](image2.png)

**Figure 2.** The dependence of the total cost of the inventory management system on the cost components.
It is obvious that the nature of demand can most accurately be described by probabilistic models, but they are rather complex from a mathematical point of view. Therefore, to understand the essence of inventory management models, simple deterministic models are more in demand. The value of the stock can be in the range from zero (stocks are not created, and construction is carried out “just in time”) to the value equal to the total demand for material for the construction season (such stocks are created in the northern areas, when building materials are supplied to the construction site during the navigation period for the entire construction season). Boundary conditions should be considered as exceptional. The theory of inventory management studies the situation when optimal stocks are calculated, taking into account both the costs of creating and storing stocks and the costs of unmet demand for materials. To do this, models of inventory management are use [1-9].

5. Conclusions
When building a model, the following prerequisites are taken into account:

1) The demand for materials can be constant or variable (the latter is typical at a variable pace of work or at a constant pace of work, but different material needs per 1 km of road); deterministic or probabilistic;

2) The construction organization should have stocks of materials (structures). Their replenishment can be carried out periodically, at equal predetermined intervals, or as the necessity arises in accordance with the rate of exhaustion of the stock;

3) The costs of creating and storing stocks, as well as the costs of production of unmet demand, can be combined into a certain objective function that needs to be minimized.

4) A mathematical model of inventory management can be expressed by dependence:

\[ C_{\Sigma S} = C_{CS} + C_{XS} \rightarrow \text{min} \]  \hspace{1cm} (5)

where \( C_{CS} \) – the cost of creating stocks.

Graphic interpretation of the model is given in Figure 4.
**Figure 4.** Graphs of consumption and replenishment of stocks:

a) periodic replenishment of stocks; b) non-periodic replenishment of stocks.

The following notation is used in the graphs:

- $S_{\text{max}}$ – the maximum level of stock in the delivery batch of the material (usually the capacity of the warehouse is determined, but it may be due to economic feasibility - a minimum of reduced costs for delivery and storage);
- $S_{\text{min}}$ – the minimum stock level, $S_{\text{max}} - S_{\text{min}}$ is called the safety stock level;
- $S_{\text{crit}}$ – the critical level of stock, from which it is still possible to make the next replenishment of a stock before it is fully exhausted;
- $T_i$ – the time period for which a batch of material is consumed until its next replenishment;
- $\tau$ – the time spent on submitting an application and delivering a new batch of material to the warehouse.

Each of the stock consumption schemes presented in Figure 4 has its advantages and disadvantages.
In the first scheme, $T_1 = T_2 = \ldots = T_n$, i.e., replenishment of the stock takes place at equal intervals preestablished in the supply contract. This facilitates the organization of transportation (for example, when replenishing stock at the end of each month, it is possible to plan in advance the allocation of vehicles, workers), payment to the supplier and the railway. At the same time, at a variable pace of work, part of the stock may remain unspent, and a new batch of material may not be fully stocked. Another situation is possible, when with a sharp increase in the pace of work, the stock may not be enough, or the rest of the material may fall below the critical level. The advantage of a non-periodic replenishment scheme is the rational use of warehousing, a higher guarantee of preserving the critical reserve (risk insurance), but this scheme is more difficult for inventory management (the “at any time” application may be unsatisfied by the supplier in a timely manner) [1-9].

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