The potentials and limitations of just in time (JIT)

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An important aim of the material and stock management is to satisfy continuously the material needs according to the pace of production. Knowing the production plan, the material norms and the supply sources, it is possible to plan with precision the amount of material needed for the production of a given period. Nevertheless, problems can arise in the process of acquisition and provision of material. On the one hand, such problems can occur due to unforeseen and unplanned changes in the production plan and due to uncontrollable factors of the supply sources on the other.

Introduction

The classical production management systems ensure continuous production by acquisition and building of stocks. Although stockpiling provides security for the organisation, it is also well known that more security means more expenditure. The task of stock management, therefore, is to establish a balanced system that is both reasonably secure and financially viable.

There is other solution for the problem when we do not increase the stock levels, but rather reduce the insecurities of the production in both input and output sides and in the production itself. In theory, in case of appropriate supply sources and infrastructure, it is possible that secure production can be achieved by a few hour stock-level. This is the so-called Just In Time (JIT) system which is often referred to as stock management without stock or stock management without storehouse

The objective of the JIT system is to ensure delivery and/or arrival of materials and products at the right place, at the right time. Theoretically, it can result in "zero stock" which does not allow of delivery failures. Subsequently, one of the neuralgic points of JIT is delivery. We can summarize the changes in demand towards supply sources in the following way: the size of deliveries decreases, the frequency of deliveries increases, demand for better availability of supply services increases, quality of delivery improves (reliability gets better, probability of product damages diminishes).

Demand for an increasingly efficient supply system will, inevitably, means an increase in cost for organisations wishing to use such services. The question arises whether the reduced cost in stock-keeping justifies or compensates for the increasing cost of delivery services. Unfortunately, managers and decision-makers do not often concern themselves with such questions.

For a proper analysis, one should take into account all the cost factors from dispatch as far as destination, irrespective of, who is the cost bearer, the supplier, the customer or somebody else. If we examine the route a product from the manufacturer to the customer we will encounter the following logistical operations: movement of the product from the manufacture to the warehouse, stock-keeping prior to transportation, loading the product onto the vehicle, transport to destination, unloading the product at destination, movement and stock-keeping until consumption takes place.

Throughout these logistical operations, costs are incurred as a consequence of **movement** (the movement is proportionate with its quantity and distance) and **stock-keeping** (this is proportionate with the stored quantity and the storage period). In this paper, the term **cost of movement** refers to the totality of **costs of materials handling** and **transport costs** (in variance with both the distance of movement and the quantity of material being moved). **Storage cost** consists of **rental** and **stock-keeping** costs. Rental cost amounts to all the costs incurred in storage, including the rent of storage space, the rent of storage machines, the cost of upkeep (for example insurance and the cost of public utility). Stock-keeping (waiting) costs cover the delayed arrival of goods, the locked-up capital and all other losses that are incurred during waiting time.

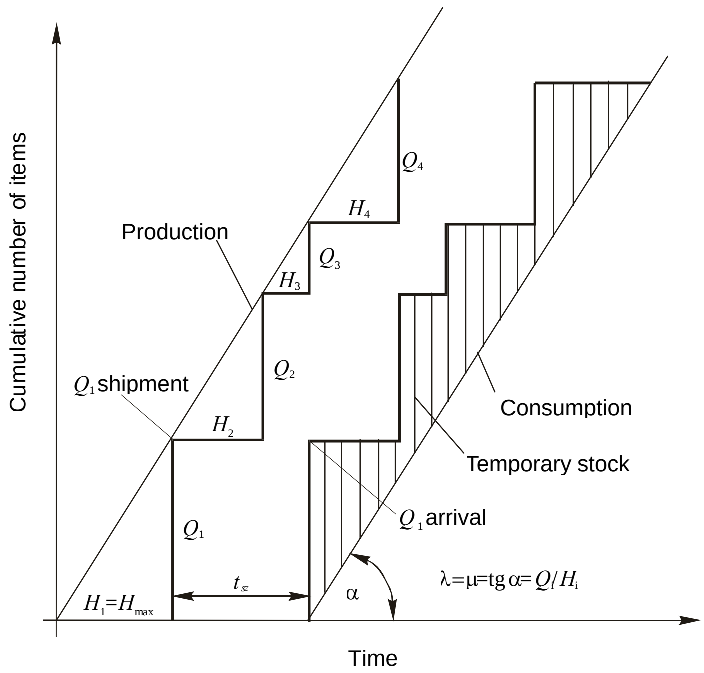

Figure 1.: Changes in stock in different logistical phases

For analysing the costs Figure 1 depicts the production and the consumption of a product in the function of time. The cumulative quantity of production and consumption varies linearly according to the two parallel lines of (production) and (consumption). The quantity of product (batch of goods) can be determined by mass, volume, piece number, unit etc. The direction of the lines is determined by the rate of production (λ) and the rate of consumption (μ) which, as depicted in Figure 1, are equal to one another, therefore $\lambda=\mu=Q_i/H_i$. The stepped horizontal and vertical functions illustrate the time horizons and the quantity of the dispatched and received goods. As the quantity is depicted accumulatively on the vertical axis, it can be clearly seen how much has been produced, transported, received and consumed in a given time frame.

The cumulative functions have been not well-known yet in the theory of stockpiling. These cumulative functions can be easily used in tracking of product lots in the sequential phases of logistics as you can illustrate the change of quantity in different logistical situations (waiting for delivery, transport, waiting for consumption) on one diagram. The vertical section in between the production line and the stepped function on the left hand side represents the quantity of product to be dispatched at a given time. The length of the vertical section relating to the commencement of delivery time represents the quantity of delivered goods. Similarly, at a given time, the vertical sections in between the stepped functions on the right hand side and the consumption line represent the quantity of products to be consumed.

It is also important to understand the horizontal sections of the stepped functions and the areas bordered by the functions. If, within the system, the product quantities flow according to the principles of FIFO, then the i-th product quantity will be equal at each monitoring point. The horizontal section in between the two stepped functions represents the time the product spends moving between those two interdependent points. For instance, the notation t_{sz} on Figure 1 represents the delivery time. The sum of the areas in between the lines and the stepped functions is proportional with the total waiting time of the product quantities. The lined area at the right hand side of the diagram, for example, is proportionate with the time spent at the arrival point of the consumption. The horizontal distance in between the parallel lines of production and consumption depicts the average waiting time between production and consumption. This is the sum of the delivery time (t_{sz}) and the maximum time interval between the dispatches of two consecutive product quantities ($H_{\max}=\max\{H_i\}$), that is, the average waiting time:

(1) $$\overline{W} = H_{\max} + t_{sz} \quad \text{[hour]}$$

The length of the average cycle, if the number of cycles equals m:

(2) $$\overline{H} = \frac{1}{m}\sum_{i=1}^{m} H_i \, ,$$

the average dispatched and received amount per cycle

(3) $$\overline{Q} = \mu \overline{H} \, .$$

The size of storage space ($S_{\max}$) has to be at least as large as the maximum product quantity ($Q_{\max}$). In Figure 1 this is represented by the longest vertical section of the stepped functions. Vehicles transport all products manufactured in the given period at the same time; and this is the reason the necessary storage spaces at departure and arrival should be proportionate with $H_{\max}$ and also with the maximum time interval between dispatches, and therefore the required storage capacity is:

(4) $$S_{\max} = Q_{\max} = \mu H_{\max} \quad \text{[piece]}.$$

Figure 1 demonstrates that the maximum stock level is identical at the points of order and dispatch.

The above mentioned four cost categories [rental (storage) costs, stock-keeping (waiting) costs, the costs of material handlings and the transport costs] are all related to the maximum stock level and the average waiting time. And then, the notations for average waiting time and maximum stock level can be converted by cost-conversion factors into cost per unit and cost per time dimensions.

Rental (storage) cost

The rental cost comprises the cost of storing space for the maximum stock level and the cost of tools necessary for handling the product. This cost is proportionate to the maximum stock level ($S_{\max}$). The value of the proportionate factor (c_b) depends on the size of the quantity, the storing requirements and the rental fees. If the buildings and the tools are privately owned (not leased), then the costs of investment varies linearly with the sizes. Knowing the lifetime of the buildings and the fixed assets to be depreciated it is possible to calculate an equivalent rental cost, which is roughly proportionate to the maximum stock level.

The rental cost for one cycle, if c_b [HUF/unit-time] was the specific of rental cost, $\overline{H}$ the length of the average cycle and $S_{\max}$ the size of the storage space:

(5) $$K_b = c_b \overline{H} S_{\max} \quad \text{[HUF]}$$

The rental cost for a time unit:

(6) $$K_{bi} = \frac{K_b}{\overline{H}} = c_b S_{\max} = c_b Q_{\max} = c_b \mu H_{\max} \quad \text{[HUF/time]}.$$

The rental cost per piece number can also be calculated:

(7) $$K_{bd} = \frac{K_b}{\overline{Q}} = \frac{c_b \overline{H} S_{max}}{\overline{Q}} = c_b H_{max} \quad \text{[HUF/piece]}.$$

It can be seen from the above relationships that the rental cost per time unit or piece number is proportionate to the maximum time interval between deliveries. Quite simply, if we order more rarely bigger quantities, then stock levels are larger, requiring larger storing space as well. This is one of the reasons why we try to keep stock level as low as possible.

Stock-keeping (waiting) cost

The stock-keeping cost (also referred to as waiting cost) is in connection with the delay of the product and it is based on the time difference between production and consumption. The specific cost of the stock-keeping for the examined time period (one cycle) is (c_v) [HUF/piece-time], the average period of stock-keeping is ($\overline{W} = H_{max} + t_{sz}$) and the average stock level is ($\overline{Q}$), from which the stock-keeping (waiting) cost for one cycle is:

(8) $$K_v = c_v \overline{W}\,\overline{Q} = c_v (H_{max} + t_{sz}) \overline{Q} \quad \text{[HUF]}.$$

The stock-keeping cost per unit time, if the length of the average cycle is $\overline{H}$:

(9) $$K_{vi} = \frac{K_v}{\overline{H}} = c_v (H_{max} + t_{sz}) \frac{\overline{Q}}{\overline{H}} = c_v \mu (H_{max} + t_{sz}) \quad \text{[HUF/time]}.$$

The waiting cost of one piece:

(10) $$K_{vd} = \frac{K_v}{\overline{Q}} = c_v (H_{max} + t_{sz}) \frac{\overline{Q}}{\overline{Q}} = c_v (H_{max} + t_{sz}) \quad \text{[HUF/piece]}.$$

In formula (9) the specific waiting cost (c_v) is multiplied by the piece number $\mu(H_{max} + t_{sz})$ produced (consumed) during the average stock-keeping time $(\overline{W})$, while in formula (10) the specific waiting cost (c_v) is multiplied by the time period elapsed between manufacture and consumption. The latter is the same as defined for average waiting time in (1).

Transport and loading costs

For analysing the transport and loading costs adequately, let us take an example. If we entrust a forwarding agent or a carrier with the organisation of the transports, then the transport cost for a given period will equal the total costs of individual transports. The most often used method for the settlement of individual transports is the so called hour-kilometre cost calculation, which is proportionate to the length of transport time and the distance.

(11) $$K_{szf} = c_t(v)t + c_s(v)s \quad \text{[HUF]}$$

where: c_t is hour rate [HUF/hour], t *is* the time involved in rate calculation, c_s is kilometre rate [HUF/km], s *is* the distance [km] and v *is* the capacity of the vehicle [t], [piece], [m^3].

The first member of (11) includes the costs of loading and unloading, the cost of wasted and waiting time in connection with the loading and the driver's wage. The c_t [HUF/hour], which is proportionate to transport time, is present in all transport costs irrespective of the cargo content and the distance. The coefficient of the second member (c_s [HUF/km]), the so called kilometre rate, is the specific cost for a unit distance. This member covers all the costs proportionate to the distance, the vehicle performed (maintenance, repair, fuel).

Both c_t and c_s specific costs depend on the delivered quantity, more precisely on the vehicle capacity, which can be depicted with the following linear functions:

$$c_t = c_{t0} + c_{tv} v \text{ and } c_s = c_{s0} + c_{sv} v.$$

The constants in the equations are positive numbers, from which follows that the bigger the vehicle is, the larger the specific costs are. (In practice, freight rates are classified according to vehicle capacities and hour rates and the kilometre rates are added accordingly.)

Placing the functions into (11):

(12) $$K_{szf} = (c_{t0} + c_{tv} v)\, t + (c_{s0} + c_{sv} v) s \quad \text{[HUF]}.$$

All variables (time, distance and mass) appear in the transport cost function that influences transportation.

The proportion between the average delivered quantity and the vehicle capacities determines the number of vehicles necessary:

$$n = \frac{\overline{Q}}{v} = \frac{\mu \overline{H}}{v},$$

from which $v = \mu \overline{H} / n$, and the length of time of a round is $t = 2t_{sz}$ (*Figure 1.*). Replacing them into (12), the cost of a round is:

$$K_{szf} = (c_{t0} + c_{tv} \frac{\mu \overline{H}}{n}) 2t_{sz} + (c_{s0} + c_{sv} \frac{\mu \overline{H}}{n}) s = 2c_{t0} t_{sz} + c_{s0} s + 2c_{tv} t_{sz} \frac{\mu \overline{H}}{n} + c_{sv} s \frac{\mu \overline{H}}{n} \quad \text{[HUF]},$$

from which the cost of n rounds is:

(13) $$K_{sz} = n(2\, c_{t0} t_{sz} + c_{s0} s) + 2\, c_{tv} t_{sz} \mu \overline{H} + c_{sv} s \mu \overline{H} \quad \text{[HUF]}.$$

Dividing each member of the equation by the average cycle time, the transport cost per time unit is:

(14) $$K_{szi} = \frac{K_{sz}}{\overline{H}} = (c_{t0}\, 2t_{sz} + c_{s0} s) \frac{n}{\overline{H}} + (2c_{tv} t_{sz} + c_{sv} s) \mu \quad \text{[HUF/time]}.$$

Dividing (13) by $\mu \overline{H}$, which is the average moved quantity per cycle,: we arrive at the transport cost per unit quantity:

(15) $$K_{szd} = \frac{K_{sz}}{\mu \overline{H}} = (c_{t0}\, 2t_{sz} + c_{s0} s) \frac{n}{\mu \overline{H}} + 2c_{tv} t_{sz} + c_{sv} s \quad \text{[HUF/unit]}.$$

Results

For further investigation let us look at the total of sub costs per unit time (rental, stock-keeping, transport and loading costs).

(16) $$K_{öi} = K_{bi} + K_{vi} + K_{szi}$$

Replacing the results of (6), (9) and (14) the total cost is:

$$K_{öi} = c_b \mu H_{\max} + c_v \mu (H_{\max} + t_{sz}) + (2c_{t0} t_{sz} + c_{s0} s) \frac{n}{\overline{H}} + (2\, c_{tv} t_{sz} + c_{sv} s) \mu\, .$$

For the sake of simplicity, let us assume that the length of cycles (length of time between two deliveries) and the quantity of product manufactured in one cycle are constant, that is $H = \overline{H} = H_{\max}$, and then

$$K_{öi} = c_b \mu H + c_v \mu (H + t_{sz}) + (2c_{t0} t_{sz} + c_{s0} s) \frac{n}{H} + (2c_{tv} t_{sz} + c_{sv} s) \mu$$

After the $H = Q/\mu$ replacement and organisation, the total cost per unit time is:

(17) $$K_{öi} = (c_v\, t_{sz} + 2c_{tv} t_{sz} + c_{sv} s) \mu + (c_b + c_v)\, Q + (2c_{t0} t_{sz} + c_{s0} s) \frac{\mu\, n}{Q}$$

Figure 2 depicts the (17) total cost function and the sub costs.

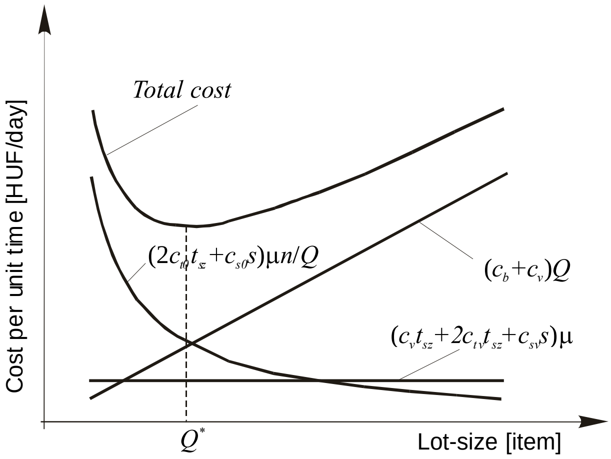

Figure 2. Changes in sub and total costs per unit time as a function of ordered quantities

Knowing the sub costs we can predict the quantity to be ordered (Q^*) (*Figure 2*) that minimises the total cost, that is, we look for the extreme value of the function (17):

$$\frac{dK_{öi}}{dQ} = c_b + c_v - (2c_{t0}t_{sz} + c_{s0}s)\frac{\mu n}{Q^2} = 0,$$

from which

(18) $$Q^* = \sqrt{\frac{\mu n(2c_{t0}t_{sz} + c_{s0}s)}{c_b + c_v}},$$

or the optimal cycle time of ordering:

(19) $$H^* = \frac{Q^*}{\mu} = \sqrt{\frac{n(2c_{t0}t_{sz} + c_{s0}s)}{\mu(c_b + c_v)}}$$

From the results of (17), (18) and (19) it is obvious that the economic lot-size and the optimal cycle time depend on the parameters of the sub costs and the proportions among them. It is also clear that zero stock could only be achieved, even in theory, if the transport cost was zero, which is impossible under normal business circumstances. Furthermore, stock level can be decreased when we can reduce the elements of transport costs in the counter of (18) and (19). However, it is not easy, as reduction of the freight sizes increases the number of transports (n) and in proportion with the number of transports it increases the length of transport and the length of time as well (the same route has to be done on more occasions), which according to (13) leads to an obvious cost increase. The question is to what extent the cost increase can be compensated by smaller vehicles' smaller constant costs.

The above calculations prove that the introduction of JIT needs a careful preparation with an accurate cost accounting.

IRODALOM

[1] **CSELÉNYI, J.-BÁNYAI Á.:** Planung von JIT-Zulieferersystemen. Modelling and Optimisation of Logistic Systems, University of Miskolc, 1999. 58-70 p.

[2] **DAGANZO, C. F.:** Logistics systems analysis. Springer-Verlag Berlin Heidelberg 1991.

[3] **KOTLER, P.:** Marketing management. Analysis, planning, implementation, and control. Seventh edition, Prentice-Hall International Editions, 1991.

[4] **SZEGEDI Z.:** A "Just In Time" szállítási-raktározási rendszertermelési és közlekedési kihatásai. Közlekedéstudományi Szemle, XXXIX évf. 10. sz. 433-437 p.

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