Integrated method of analysing logistics costs in supply chain

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Abstract: Logistics and supply chain management (SCM) is in its development process, progressing stage after stage. The development process at the very first stage considers an evaluation criterion for evaluating effectiveness using minimum total logistics costs (TLC), which underlines the fact that, an important criterion in the development process is complete customers’ satisfaction in services, or the ‘level of service’ (SL). At the same time, the question remains open as to how to quantify the impact of logistics operations and functions on the performance results of TLC and SL. The main aim of this paper is to develop a methodical approach and to come up with a computational approach to assessing the impact of different logistics operations factors (for example, transportation, storage, orders, etc.), on TLC and SL.

Keywords: total logistics costs concept; total logistics cost model; economic analysis integral method; supply chain; supply chain efficiency evaluation.


Biographical notes: Valery Sergeyevich Lukinskiy is an honoured science worker of Russia, a Doctor of Technical Sciences (1986), a Professor (1989), and a Scientific Adviser of Scientific Laboratory Research in the field of logistics. He is a Professor in the Department of Logistics Higher School of Economics National Research University, Saint Petersburg. He trained more than 70 candidates and 15 doctors of science. He is expert of a range of projects (strategy for the development of transport-transit policy of St. Petersburg, LogOnBaltic, Logistics for Life). He studied in Leningrad Polytechnic Institute (1964), Scientific-Research Institute ‘Transport machine building’ (1964–1976), St. Petersburg State University of Engineering and Economics, ENGECON (1976–2013), Higher School of Economics National Research University Saint Petersburg (2013). He has more than 300 scientific and educational works. His fields of research are methodology (models and methods) of logistics theory; transport logistics; inventory management; reliability, forecasting and modelling of transport and logistics systems.
1 Introduction

According to statistical data, total logistics costs (TLC) in supply chain (SC) in different countries make up from 10% (for example, in the USA) to 20% of GDP (Singapore, Russian Federation). Aggregate analysis enables us to expand these costs to basic components, including the following logistic functions and operations: transportation (40%–55%), storage and maintenance of stocks (30%–40%), administration and management (15%) (Ballou, 1999; Bowersox and Closs, 1996; Jonsson, 2008).

These rates are average and relate to individual countries or groups of countries; they characterise the flow of global economic processes and can subsequently be used for long-term forecasts at the macro level and for the development of SC strategies of transnational companies, etc. However, it is very difficult and not very effective to use in the organisation and management of logistics operations at the micro level.

Another field of research is connected to the collection, systematisation and analysis of costs in SC at the micro level (Christopher, 2004; Stock and Lambert, 2001; Waters, 2003). Here, the description fits specific logistics companies (such as terminals, transport and logistics centres, transport infrastructure) or industrial enterprises (focus companies), indulging in different kinds of logistics activity. One researcher (Waters, 2003), cites the results of the warehouses studies of the company ‘Konigshaven Suppliers’, where the logistics costs as a percentage of net income is as follows: transportation (inputs and outputs) – 8%; warehousing, cargo processing, storage – 7%; product returns – 0.5%, staff salaries – 12%, data processing – 2% and some others.
An empirical approach of estimating logistics business operations costs in SC has undoubted advantages, but it also has some significant shortcomings. Firstly, it does not consider or analyse the connections between the main factors influencing logistic processes and their results. Secondly, the usage of this data, for example, in reengineering of business, requires a repeated collection and analysis of information.

To overcome these shortcomings, the balanced scorecard (BSC) method is widely used (Kaplan and Norton, 2006; Nils-Goran et al., 1999). The idea behind BSC is to express the company’s strategy in a certain format, combining a very limited set of parameters characterising the activity of four perspectives: financial, customer, internal processes, learning and development.

BSC is not a measuring tool. It serves to support management processes. To evaluate the effectiveness of decision-making in logistics and in SC, as well as in other areas, the key performance indicators (KPI) are implemented (Bowersox and Closs, 1996; Christopher, 2004; Sergeev, 2013; Waters, 2003). Despite the transparency and representativeness of KPIs methodical approach, its active application is limited, which in our opinion is due to the following reasons:

- KPI is a set of individual indicators, which are not interconnected or related implicitly
- diverse measurement of KPI reflecting in financial, material, time, probability and other indicators, do not provide definitive assessments of the effectiveness of SC
- KPI is unable to show the relationship between indicators (factors) and the resulting factor
- the transition from the existing business processes to the projected ones – is hypothetical and is not confirmed by the economic effectiveness of these activities.

Thorough analysis and synthesis of scientific publications, monographs, textbooks on logistics and SC management enabled us to arrive at the following conclusions:

1. here has been a stable tendency of the development of analytic tools, which can be used to manage and improve SC business processes efficiency. This efficiency is characterised in particular, by the growing number of indicators and variables that exist in models of transportation and inventory management.

2. distinctive feature of models used to describe transport operations is that, most of them are based only on classical transportation problems (optimal organisation of transportation), their modifications, as well as network models (Duskin, 1995; Lukinskiy et al., 2007; Taha, 2005). In most cases, these models take into consideration the storage costs or transportation rates instead of the whole variety of logistics operations indicators (Li and Pang, 2011; Langevin and Riopel, 2005).

3. The models (methods) associated with inventory management are based on the TLC theory and on the classical Harris and Wilson formula modifications (Ballou, 1999; Chopra and Meindi, 2007; Harris, 1913).
The search for real SC efficiency formulas is difficult and it increases with the development of the theory. Therefore, quantitative methods and SCs modelling are actively developing on modern information systems and information technologies (ISaIT) (Bruzzone et al., 2004; Ivanov et al., 2011; Ivanov and Sokolov, 2012; Langevin and Riopel, 2005).

Analysis techniques and quantitative evaluation of the influence of factors on the total costs and SC efficiency has become more popular. In recent times, empirical approach as benchmarking and ‘best practice’ decisions has become widespread. However, it does not correspond to the new principles of SC formation and does not reflect its robustness, flexibility, adaptability and reliability (Behrends and Floden, 2012; Curcio and Longo, 2009; Kaplan and Norton, 2006; Lukinskiy and Shulzenko, 2011; Lukinskiy et al., 2007; Stock and Lambert, 2001).

Therefore, to improve the efficiency and to reduce costs, we need to continue developing quantitative assessment methods of different logistics operations and the logistic systems results relationships.

2 TLC models for a simple supply chain

Currently, two main classifications of SCs are described in various scientific publications. In the first variant, SC is represented as a block diagram, which defines the main objects (participants), but it lacks the logistical operations, for example, suppliers at the second level, suppliers at the first level, the focus company, consumer at the first level, etc. (Bowersox and Closs 1996; Christopher, 2004). In the second variant, SC is represented by the two or three-tier system, considering the principal transport and logistics operations between levels.

Our research has shown that it is necessary to use simple supply chain (SSC) for calculating transport and logistics operations efficiency.

Under the SSC, we consider:

- a part of the logistics chain (channel) that includes at least two main units of logistics system (ULS) – ‘supplier’ and ‘consumer’ interconnected by multiple logistic operations: purchasing, order processing, transportation, storage, etc.
- extending major intermediaries (‘third party’ in logistics): carriers, freight forwarders, warehouses (terminals), etc.
- one of the main factors linking the elements of ULS and SSC is an added value of logistics operations (functions)
- each SC may be represented as several SSC.

Let us consider the problem of TLC for SSC description. Our analysis of numerous scientific publications has revealed that there are three main stages of TLC concept development (Table 1).
Table 1  Conceptual development stages of TLC

<table>
<thead>
<tr>
<th>Stage</th>
<th>Model</th>
<th>Determination</th>
</tr>
</thead>
<tbody>
<tr>
<td>First stage (1913–1940)</td>
<td>$C_z = C_o + C_s$, $Q = \frac{2A \cdot C_o}{C_z}$</td>
<td></td>
</tr>
<tr>
<td>components of the TLC model are independent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second stage (1940–1970)</td>
<td>$C_z = C_p + C_o + C_r$, $C_x = C_x + C_{so}$</td>
<td>For example, for the strategy with a fixed order</td>
</tr>
<tr>
<td>There is a relationship between different elements of the models when considering the various strategies of inventory management</td>
<td>$\frac{\partial C_z}{\partial S} = 0$</td>
<td></td>
</tr>
<tr>
<td>Third stage (1970 – present day)</td>
<td>$C_z = C_{so} + C_{so} + C_{so}$</td>
<td>$\frac{\partial C_z}{\partial R} = 0$</td>
</tr>
<tr>
<td>Elements of the models show an interdependency and interaction between KPI of logistics, total costs and customer service</td>
<td>$\frac{\partial C_z}{\partial P_i} = 0, i = 1, \ldots, n$</td>
<td></td>
</tr>
</tbody>
</table>

Note: $C_t$ – transportation costs, $C_l$ – latent costs.

The first stage (1913–1940). The first reference of the equation ‘total costs’ (TLC) and model EOQ, is dated back to articles published in 1913. They considered two components, including ordering costs ($C_o$) and the cost of production storage ($C_s$):

$$C_z = C_o + C_s.$$  \hspace{1cm} (1)

In the course of our research, we discovered a distinct formula, proposed by Harris (1913), which defined the relationship of total costs as:

$$y = \frac{M}{2} \left( \frac{cr}{x} + s + \frac{c}{x} \right) = \frac{cr + s + c}{x}.$$  \hspace{1cm} (2)

where $M$ is the monthly consumption of products in units, the cost per unit is represented by $C$, $S$ defines the costs associated with the ordering organisation and $X$ is the unknown order quantity, in units.

The second phase covers the period from 1940 to 1970. In the course of the evolution of logistics, there have been methodical changes to the approaches of cost analysis: from the analysis of measures to rationalise the individual elements of turnover and production spheres to TLC.

According to Hadley and Whiting (1969), in 1951 (Errow, Harris and Marschak) published an academic work, which gave a mathematical analysis of a simple model of inventory management, and in 1953 Whiting developed a stochastic version of this model. These studies introduced a new version of the TLC equation:
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\[ C_{\Sigma} = C_p + C_o + C_s + C_{so}, \] (3)

where \( C_p, C_o, C_s, C_{so} \) are costs for purchasing, ordering, inventory storage and loss by stock shortages respectively.

Some researchers in the field of inventory management write this formula as:

\[ C_{\Sigma} = C_o + C_{ss} + C_{ss} + C_{so}. \] (4)

where \( C_{ss}, C_{so} \) are respectively the storage costs of the current stocks and safety stocks.

A comparison of models (1), (3) and (4) shows that:

1. The number of cost elements increases as time passes by.
2. We see the differences in the models of the second stage, for example, the formula (3) includes the cost of \( C_p \), and model (4) does not consider these costs, but instead of the total storage costs model (3) the current storage costs and insurance stocks costs separately (4) is introduced.
3. The main difference between the second stage of the TLC concept development is that, the concept of ‘inventory control strategy’ was introduced.

Strategic inventory management leads to the fact that the models have an additional variable \( \tau \) – turnaround time. For example, the rate in the model with fixed order quantity \( \tau \) is seen in the value of the ‘reorder point (ROP)’ or ‘order level’ \( R \). Setting up the equation to determine the optimal values of two variables – the order stock (\( S \)) and the ROP (\( R \)) we get:

\[
\frac{\partial C_S}{\partial S} = 0 \\
\frac{\partial C_S}{\partial R} = 0
\] (5)

The third stage extends from 1970 to present day. The special feature of this stage is composed of the formation of a synthesised model, which includes not only logistics operations costs, but also the costs associated with complete consumer satisfaction. Our study proved that, the model should include the maximum number of indicators (factors), such as: ordering costs (\( C_o \)), current storage costs (\( C_{ss} \)) and insurance (\( C_{so} \)) stocks. Others include transportation costs (\( C_t \)) and storage of stock in the delivery process, cost of loading and unloading (\( C_{l-u} \)), value added during transportation (\( \Delta C \)), loss of stock shortages (\( C_{so} \)), penalties for late delivery (\( C_{pld} \)) and costs for product returns.

Table 1 shows how the TLC-model (III stage) incorporates the I and II stages in the development process. It represents a possible break down (decomposition) of logistics costs at different levels, for example, the ordering costs \( C_o \) (I level) decomposes at the 2nd level into costs of organising the order \( C_{o1} \) and transportation costs, \( C_t \), etc.

Below, we summarise all of this and create a TLC-model (Lukinskiy et al., 2013) as follows:
\[ C_L = C_p \cdot A \cdot C_s \cdot f + \frac{1}{2} C_p \cdot f \cdot S + \frac{1}{2} C_t \cdot f + C_p \cdot f^* \cdot K_p \cdot \sigma_p \cdot \sigma_t \cdot \sqrt{\tau} \]
\[ + \frac{C_t}{S} \cdot f^* \cdot K_p \cdot \sigma_t \cdot \sqrt{\tau} + \frac{C_p \cdot \tau \cdot A \cdot j}{D} + \frac{A}{S} \cdot C_{so} \cdot \sigma_t \cdot \sqrt{\tau} \cdot E(K_p) \]
\[ + \frac{A}{S} \cdot C_{pld} \cdot F(\tau > \tau_0) + \frac{C_t}{S} \cdot \gamma \cdot A \cdot C^* \cdot \phi \]

where \( C_p \) is the price from the supplier per unit in USD, \( A \) represents the consumption (products) in units, \( C_o \) is ordering costs in USD, \( S \) is order stock in units, \( C_t \) is transportation costs in USD, \( f \) is storage costs of the current stock, in total price of products (share), \( f^* \) is storage costs of an insurance stock, in total price of products (share), \( j \) is storage costs of the stock in the delivery process, in total price of products (share), \( K_p \) is the ratio of the normal law of distribution (Math), \( \sigma_t \) is average quadratic deviation of daily consumption in products, units, \( \tau \) is delivery time (or transportation period), days, \( D \) is money settlements, days, \( C_{so} \) is loss of stock shortages in USD (costs of products shortages), \( E(K_p) \) is the integral of losses; \( C_{pld} \) is the average penalty for late delivery in USD, \( F(\tau > \tau_0) \) is probability of exceeding the optimum transportation time, \( \lambda \) is the proportion of returnable to all (requirement) products, \( C_{t}^* \) is transportation costs of returnable products in USD, \( S^* \) is returnable products, units and \( \phi \) is the size or weight of products, m³ or tones.

When constructing the model (6), a number of points were considered:

1. Costs of loading and unloading operations are included in transportation costs.
2. Delivery time \( \tau < T \), where \( T \) is the periodicity of delivery, in days. Turn around time \( \theta \approx \tau \).
3. We chose inventory management strategy ‘\( S, R \)’, where the order makes out in ROP.
4. The safety stock is subject to a normal distribution (math).

We use the following criteria to optimise the model indicators:

\[ \begin{align*}
C_L (C_s, S, \gamma) & \rightarrow \min \\
SL (C_s, S, \gamma) & \rightarrow \max
\end{align*} \]

where \( C_L \) – TLC [formula (6)] and SL is the customer service ratio, or satisfaction of demand.

In so doing, our model includes the largest number of indicators (factors) that represent logistic functions and operations in the SC. This model determines better costs for various SCs, but also gives room to performing impact analysis of indicators to TLC.

3 Integral analysis method OF TLC for evaluating SC effectiveness

It is evident that the analysis of the influence of factors included in equation (6), on the TLC \( C_L \) result can be carried out using KPI of KPI. Systematic analysis of scientific articles showed that besides using comparison methods (index, benchmarking, etc.) for evaluating KPI (Bowersox and Closs 1996; Christopher, 2004) it is actually advisable to
use the following methods of economic analysis (EAM, Table 2), in particular the integral method of analysis (IMA).

Table 2: Economic analysis methods (EAM)

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Differential method</td>
<td>This method is a theoretical framework for quantifying the role of individual factors in generalising indicators.</td>
</tr>
<tr>
<td>Method of chain substitutions</td>
<td>This method is used for the calculation of the influence of individual factors on the corresponding aggregate, when the relationship between the studied phenomena has a strictly functional characteristic.</td>
</tr>
<tr>
<td>Integral method</td>
<td>This method provides a general approach to solving problems, regardless of the number of elements and forms of connection between them; the method also eliminates the ambiguity estimation of impact factors.</td>
</tr>
<tr>
<td>Method of ratios</td>
<td>It is based on the comparison of numerical values of the same economic indicators under different conditions.</td>
</tr>
<tr>
<td>Method of weighted finite differences</td>
<td>It takes into account all possible substitution but here, quantitative assessment of individual factors is impossible.</td>
</tr>
</tbody>
</table>

Source: Bakanov and Sheremet (1994)

The IMA determines the effect of factors on the result in any form of relationship and with any number of factors. It provides unambiguous results after calculations irrespective of the sequence of analysis parameters. IMA uses an integral function \( f(x) \) (an interval from \( a \) to \( b \)) as an increment of this function \( f(x) \), that is \( F(b) - F(a) \).

Below, we illustrate the nature of the IMA by analysing the influence of factors on the function \( v = C \cdot S \). To define the influence of factor \( C \) on the function \( v_c \), let us look at a definitive integral as:

\[
    v_c = \int_{M_0}^{M_1} \frac{\partial v}{\partial C} \, dc,
\]

where the partial derivative of the function \( v \) at point \( M \) by factor \( C \) is defined by

\[
    \frac{\partial v}{\partial C} \bigg|_{M_c}
\]

with \( M_0M_1 \) representing the rectilinear segment.

In formula (8) point \( M \) – shows the coordinate variables as:

\[
    C = C_0 + \Delta C \cdot t; S = S_0 + \Delta S \cdot t,
\]

where \( C_0, S_0 \) is the baseline values in \( t = 0, \Delta C, \Delta S \) respectively are the increments of factors (for example, \( \Delta C = C_1 - C_0 \) and \( C_1 \) is the value of factor in \( t = 1 \). As a result, the formula for \( v = C \cdot S \) using the formula (8) comes to:

\[
    v_c = \int_{0}^{1} (S_0 + \Delta S \cdot t) \Delta C dt = 0, 5\Delta C \left[ S_0 + S_1 \right].
\]

A similar formula is used to calculate \( v_s \). The sum \( v_c \) and \( v_s \) gives us an estimate for the result \( \Delta v \).

Table 3 shows the main dependencies obtained by using IMA.
<table>
<thead>
<tr>
<th>No.</th>
<th>Function</th>
<th>Model</th>
<th>Formula design</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$v = xy$</td>
<td>$\Delta v = x_1y_1 - x_0y_0 = A_x + A_y$</td>
<td>$A_x = \Delta v (y_0 + 0.5 \cdot y_1) = 0.5 \Delta v (y_1 + y_0) = \Delta v \cdot \frac{x_0y_0 + 0.5x_1y_0}{2x_0y_1}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Analogous to $A_x$</td>
</tr>
<tr>
<td>2</td>
<td>$v = xyz$</td>
<td>$\Delta v = x_1y_1z_1 - x_0y_0z_0 = A_x + A_y + A_z$</td>
<td>$A_x = 0.5 \Delta v (y_0z_0 + y_1z_0 + x_0z_0) + \frac{1}{3} \Delta \Delta y \Delta z$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Analogous to $A_x$ and $A_y$</td>
</tr>
<tr>
<td>2a</td>
<td>$v = xw$, where $w = yz$</td>
<td>$\Delta v = x_1w_1 - x_0w_0 = A_x + A_w$</td>
<td>Analogous to point 1</td>
</tr>
<tr>
<td>3</td>
<td>$y = \frac{x}{y}$</td>
<td>$\Delta v = \frac{x_1}{y_1} - \frac{x_0}{y_0} = A_x + A_y$</td>
<td>$A_x = \frac{\Delta x}{\Delta y} \frac{y_0}{y_0}$, $A_y = \frac{\Delta y}{\Delta y} \frac{x_0}{y_0}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Variations for $y$:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>a) $A_x = -\Delta \left(\frac{y_0 + y_1}{y_0 + y_1} - \frac{y_0}{y_0 + y_1}\right)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>b) $A_x = \frac{\Delta x}{\Delta y} \left(1 - \frac{y_0 + \ln y_0}{y_0}\right) + \frac{\Delta y}{\Delta y} \frac{x_0}{y_0}$</td>
</tr>
<tr>
<td>3a</td>
<td>$y = \frac{x}{z}$</td>
<td>$\Delta v = \frac{x_1}{z_1} - \frac{x_0}{z_0} = A_x + A_y$</td>
<td>Analogous to point 3</td>
</tr>
<tr>
<td>4</td>
<td>$v = x\sqrt{y}$</td>
<td>$\Delta v = x_1\sqrt{y_1} - x_0\sqrt{y_0} = A_x + A_y$</td>
<td>Variations:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1) $z = \sqrt{y}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$A_x = 0.5 \Delta v (x_0 + z_0)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$A_y = 0.5 \Delta v (x_0 + z_1)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2) $A_x = \frac{2x_1}{2\Delta y} \left(\sqrt{y_1} - \sqrt{y_0}\right)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$A_y = \frac{x_0}{\Delta y} \left(\sqrt{y_0} - \sqrt{y_1}\right) + \frac{\Delta x}{\Delta y} \left[\frac{y_0}{2\Delta y} + \frac{2\sqrt{y_0}}{2}\right]$</td>
</tr>
<tr>
<td>4a</td>
<td>$v = x\sqrt{z} = w\sqrt{z}$, where $w = xy$</td>
<td>$\Delta v = w_1\sqrt{z_1} - w_0\sqrt{z_0} = A_w + A_z$</td>
<td>Analogous to point 4</td>
</tr>
</tbody>
</table>
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Table 4  
Factors influence (of transport and logistics operations) on total logistics costs

<table>
<thead>
<tr>
<th>No.</th>
<th>Factor (indicator)</th>
<th>Formula design</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$A$</td>
<td>$f_a = 0.5 \Delta \left( a_0 + a_i \right) + \left( \frac{C_c \cdot j \cdot \tau}{D} \right) + \left( \frac{C_r \cdot j \cdot \tau}{D} \right)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$a = \frac{C_0 + C_r + C_{so} \cdot S_{so} + C_{pld} \cdot F_{pld}}{S} + \frac{\varphi \cdot \lambda \cdot C_i}{S_i}$</td>
</tr>
<tr>
<td>2</td>
<td>$B$</td>
<td>$f_{c_{B}} = 0.5 \Delta C_i \left( \frac{A}{S_0} + \frac{A}{S_i} \right)$</td>
</tr>
<tr>
<td>3</td>
<td>$C$</td>
<td>$f_{c_{C}} = 0.5 \Delta C_i \left( \frac{A}{S_0} + \frac{A}{S_i} \right)$</td>
</tr>
<tr>
<td>4</td>
<td>$D$</td>
<td>$f_{c_{D}} = 0.5 \Delta \left( \frac{C_p \cdot j \cdot A}{D} \right) \cdot [r_a + r_i]$</td>
</tr>
<tr>
<td>5</td>
<td>$E$</td>
<td>$f_e = \frac{\Delta d}{\Delta S} \left( 1 - \frac{S_0}{S_i} \ln \left( \frac{S_i}{S_0} \right) + \frac{d_s}{S_i} - \frac{d_0}{S_0} + 0.5 \cdot \Delta S (q_0 + q_i) \right)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>where $d = A \left( C_0 + C_r + C_{so} \cdot S_{so} + C_{pld} \cdot F_{pld} \right)$; $q = 0.5C_i$</td>
</tr>
<tr>
<td>6</td>
<td>$F$</td>
<td>$f_{c_{F}} = 0.5 \Delta C_i \left( (0.5 \cdot S + S_C)_0 + (0.5 \cdot S + S_C)_i \right)$</td>
</tr>
<tr>
<td>7</td>
<td>$G$</td>
<td>$f_{c_{G}} = 0.5 \Delta \left( C_{so}<em>0 + (C</em>{so})_i \right)$</td>
</tr>
<tr>
<td>8</td>
<td>$H$</td>
<td>$f_{c_{H}} = 0.5 \Delta S \left( (C_{so}<em>0 + (C</em>{so})_i \right)$</td>
</tr>
<tr>
<td>9</td>
<td>$I$</td>
<td>$f_{c_{I}} = 0.5 \Delta C_{so} \left( (S_{so})<em>0 + (S</em>{so})_i \right)$</td>
</tr>
<tr>
<td>10</td>
<td>$J$</td>
<td>$f_j = 0.5 \Delta \left( \frac{C_p \cdot j \cdot A}{D} \right) + \left( \frac{C_r \cdot j \cdot A}{D} \right)$</td>
</tr>
<tr>
<td>11</td>
<td>$K$</td>
<td>$f_{c_{pld}} = 0.5 \Delta C_{pld} \left( \frac{A}{S} \cdot F_{pld} \right)<em>0 + \left( \frac{A}{S} \cdot F</em>{pld} \right)_i$</td>
</tr>
<tr>
<td>12</td>
<td>$L$</td>
<td>$f_{c_{pld}} = 0.5 \Delta F_{pld} \left( \frac{A}{S} \cdot C_{pld} \right)<em>0 + \left( \frac{A}{S} \cdot C</em>{pld} \right)_i$</td>
</tr>
<tr>
<td>13</td>
<td>$M$</td>
<td>$f_{c_{M}} = 0.5 \Delta \left( \frac{\varphi \cdot A \cdot C_i^s}{S_i} \right)_0 + \left( \frac{\varphi \cdot A \cdot C_i^s}{S_i} \right)_i$</td>
</tr>
<tr>
<td>14</td>
<td>$N$</td>
<td>$f_{c_{N}} = \frac{\Delta k}{\Delta k} \left[ \frac{1}{S_i} \ln \left( \frac{S_i}{S_0} \right) + k_0 \left( 1 - \frac{1}{S_i} \right) \right]$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$k = \lambda \varphi AC_i^*$</td>
</tr>
</tbody>
</table>
Table 4 shows the dependences obtained by IMA applied for TLC equation (6). In the formulas represented in Table 4, we did not consider transportation costs and ordering costs for returnable products.

Comments to Table 4 are enlisted below:

A consumption per year, $A$, units
B ordering costs, $C_0$, USD
C transportation costs, $C_t$, USD
D storage costs (during transportation), $C_s$, USD
E order stock, $S$, units
F storage costs per unit output (current and safety stock), $C_s$, USD
G insurance stock, $S_{ss}$, units
H average of the stock-out (of returnable products), $S_{so}$, units
I the costs associated with stock-out (with returnable products) $C_{so}$, USD
J delivery time (or transportation period), days
K penalties related to late delivery
L the probability of ‘just in time’ order
M share of return flow
N return products, units.

Ultimately, these formulas have proved that our approach allows a comparison of factors influencing the assessment on the TLC elements not only for existing ones, but also for planned SCs.

4 The case of logistics operations evaluation on TLC

To test our approach we carried out some calculations for different variants of model (6).

Let us look at one example. The source data was gathered from companies which actually fitted the profile. The current activities are defined by the following. Real data from a logistics company is represented by ‘Fact 0’ and the optimal values (best practice) by ‘Plan 1’ as illustrated in Table 5.

TLC [by formula (6)] is defined for the actual (fact) and planned indicators of the company on the 1st stage. We substitute the actual values and get ($C_p = 150, f = 0.2, f' = 0.2, K_p = 1.3, \sigma_2 = 1.32, j = 0.1, D = 250, E(K_s) = 0.047$) in USD: $C_\Sigma = 8,012.8$ USD.

So, for the planned values: $C_\Sigma = 7,402.24$ USD.

Clearly, with the planned indicators we get a reduction of TLC:

$$\Delta C_\Sigma = -610.56 \text{ USD.}$$

The deviation of planned (1) and fact (0) indicators were identified at the 2nd stage. Table 5 shows that the deviation has different dimensions: the amount (units of production); costs, fines (USD); time (days); relative values (shares). Therefore, the
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deviation is not allowed to show the impact of each indicator of transportation and logistics operations on total costs.

Table 5  Factors influence on total logistics costs

<table>
<thead>
<tr>
<th>No.</th>
<th>Factors in the supply chain</th>
<th>Plan (1)</th>
<th>Fact (0)</th>
<th>Deviation (1–(0))</th>
<th>The impact on the TLC (IMA), USD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The consumption per year, A</td>
<td>945</td>
<td>1,000</td>
<td>–55</td>
<td>–258</td>
</tr>
<tr>
<td>2</td>
<td>Reduction in ordering costs, $C_0$</td>
<td>90</td>
<td>100</td>
<td>–10</td>
<td>–57</td>
</tr>
<tr>
<td>3</td>
<td>Transportation costs growth, $C_t$</td>
<td>595</td>
<td>500</td>
<td>95</td>
<td>542</td>
</tr>
<tr>
<td>4</td>
<td>Size of an order changes, S</td>
<td>200</td>
<td>150</td>
<td>50</td>
<td>–222</td>
</tr>
<tr>
<td>5</td>
<td>Storage costs growth (in stock) $C_s$</td>
<td>32.5</td>
<td>30</td>
<td>2.5</td>
<td>234.56</td>
</tr>
<tr>
<td>6</td>
<td>Reduction of storage costs (during transportation), $C_r$</td>
<td>49</td>
<td>60</td>
<td>–11</td>
<td>–136</td>
</tr>
<tr>
<td>7</td>
<td>Reduction in insurance stock $S_i$</td>
<td>5.99</td>
<td>6.86</td>
<td>–0.87</td>
<td>–27.39</td>
</tr>
<tr>
<td>8</td>
<td>Reduction in the average stock-out $S_{so}$</td>
<td>0.42</td>
<td>1.65</td>
<td>–1.23</td>
<td>–309.06</td>
</tr>
<tr>
<td>9</td>
<td>Stock-out costs growth $C_{so}$</td>
<td>300</td>
<td>200</td>
<td>100</td>
<td>103.63</td>
</tr>
<tr>
<td>10</td>
<td>Reduction of delivery time $\tau$</td>
<td>9</td>
<td>16</td>
<td>–7</td>
<td>–382</td>
</tr>
<tr>
<td>11</td>
<td>Penalties related to late delivery</td>
<td>100</td>
<td>180</td>
<td>–80</td>
<td>–35</td>
</tr>
<tr>
<td>12</td>
<td>Decrease in default probability of no ‘just in time’ order</td>
<td>0.05</td>
<td>0.1</td>
<td>–0.05</td>
<td>–39.33</td>
</tr>
</tbody>
</table>

Calculations based on IMA were carried out at the 3rd stage. The total deviation is $\Delta = -586.3$ USD; the relative deviation of planned (1) and fact (0) indicators is:

$$\varepsilon = \frac{\Delta C_1 - \Delta C_0}{\Delta C_1} \times 100 = \frac{-586.3 + 610.56}{-586.3} \times 100 = -3.97\%$$

The results of estimating the various types of SSC accurately using computation ranges from 1 to 10%.

The estimation of factors influencing TLC is specified on the fourth stage.

These are the main factors that lead to a TLC reduction:

1. the effect on stock-out ($-309$ dollars) as well as an increase in the possibility (probability) of a deficit reduction, up to $F_{so} = 0.95$ and a reduction delivery time
2. transportation time ($-382$ dollars) a decrease of seven days in comparison to the fact.

The main factors that increase logistics costs:

1. storage costs rose by 2.5 dollars leading to an increase of TLC on $235$
2. an increase in transportation costs (up to $95 per the supply) increases TLC by $542$.

A comparison of the factors influencing TLC with potential investments for standard (planned) parameters will allow implementation of advanced solution to improve the SCs efficiency.
5 Conclusions and recommendations

Our research shows that despite the large number of studies related to the assessment of logistics costs, the existing approaches require development and adjustment.

The developed TLC model in this paper is fundamentally different from existing ones. This is the first attempt, which considered eight cost elements that are directly or indirectly linked to transportation. Also, it considers the ordering costs and the storage of the current and insurance stocks.

This technical approach developed, based on IMA, makes provision for multi-criteria selection to be able to calculate and ascertain the impact of each parameter in transport and logistics operations of TLC. It finds the main important factors and chooses sustainable solutions to improve the SC's efficiency.

Further studies on the development of this designed model should be focused on the following areas:

- to identify internal and external information (management accounts company) to the for the formation of a database of basic delivery options
- pay more attention to automated calculations and look at the possibility of introducing them on known software products
- to analyse the model changes for multi-level SCs (coordination between the parameters)
- to consider the model development, and include vital indicators (financial, information, service, etc.)
- expand the number of analysed indicators currently in use, such as transportation costs, storage costs and others
- the next stage of TLC model development must consider investments on logistics infrastructure.

Considering the underlisted statements, the next stage of TLC-model development, in our opinion, has two hypothetical forms:

- the evolution (the development of IT automation and automation decision-making based on artificial intelligence, etc.)
- a leapfrog in a better synthesis of analytical methods as well as simulative stochastic models with information technologies.

References


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