APPLICATION OF TECHNOLOGICAL MEANS AND MODELLING OF PROCESS ACTIVITY IN TRANSPORT TERMINALS

Aldona Jarasuniene

Transport Research Institute, Vilnius Gediminas Technical University
Plytinės Str. 27, LT-10105, Vilnius-16, Lithuania
E-mail: ajarasuniene@yahoo.com

This article deals with the analysis of technological means application and modelling of processes activities in transport terminals.
The author describes the analysis of management by complex technical systems and estimates models' using in transport terminals.
An analysis procedure for the location of transport terminals that integrates facility costs, transportation costs and service responsiveness is developed in the paper. The procedure integrates ideas in queuing theory, discrete choice location analysis and multi-objective decision-making.

Keywords: *transport terminals, technological process; using of mathematical models for transport terminals*

1. INTRODUCTION

A crucial question in the design of efficient logistics systems is the identification of location for transport terminals. The optimisation of these location decisions requires careful attention to the inherent trade-offs among facility costs, inventory costs, transportation costs and customer responsiveness. This article presents a modelling approach that provides such an integrated view and shows how it works in the context of a specific example involving the distribution of finished vehicles by an automotive manufacturer.

2. ANALYSIS OF MANAGEMENT BY COMPLEX TECHNICAL SYSTEMS

Management problems are very important and urgent.

Management of the quality of transport technologies application in transport terminals covers an integral multi-plan process and consists of the following operations: analysis of management system, planning of transportation quality (security of transportation, safety of transported goods, processing of transportation documents), reception of the information on haulers participating in the process of transportation, analysis of this information, reception of feed back information and its analysis).

Management of quality of technological means application in transport terminals, which meets the general theory of management of transport terminal, embodies an integral multi-plan process consisting of the following operations:

- Creation of management programmes;
- Planning of transportation quality (transportation safety, security of goods, documentation procedures, etc.);
- Reception of data and analysis about all haulers participating in freight transportation;
- Indications arising from received information analysis.

Thus the management of technological means application quality or technology of transport terminals covers implementation of means, handling and consolidation. The main principles of management technologies are the following: systematism, definition of tasks, adaptation, dynamics, quality normative, and standardisation.

The optimum achievements of technological quality standards are defined on the basis of cost of organisational-technical and economic measures interrelated with commercial principles and impacting certain factors and conditions.

Creation of model of transport terminals starts from the analysis of the modelled object, by the application of mathematical formulae, accumulation of information with the aim of qualitative coordination on the basis of experimental mode and with the view of accomplishing the task, to make its analysis, correction on model by supplementary solutions and finally, to carry out the last testing of the experimental model.

The object analysis has to pertain to a full view of the modelled system and its management capacities.

From the mathematical formulation of the system will depend how efficient will be the system. The mathematical formulation of the systems makes the modelling of the whole process, i.e. description of economic processes and economic-mathematical actions of the model. The aim of modelling is a possibility to manage and control a concrete process.

Several mathematical models are used for the optimisation of the process in transport terminals:

- Optimal programming: linear, non-linear, discrete, block, etc.;
- Network methods of management and planning;
- Theory of mass servicing/handling, etc.

In general the mathematical model may be expressed as follows:

$$z = f(x_1, x_2, ..., x_n) \to \max(\min); \tag{1}$$

$$\varphi_i = (x_1, x_2, ..., x_n) \le b_i \ (i = 1, 2, ..., m_1); \tag{2}$$

$$\varphi_i = (x_1, x_2, ..., x_n) = b_i \ (i = m + 1, m_1 + 2, ..., m_2); \tag{3}$$

$$\varphi_i = (x_1, x_2, ..., x_n) \ge b_i \ (i = m_2 + 1, m_2 + 2, ..., m); \tag{4}$$

$$x_j \ge 0 \ (j = 1, 2, ..., n_1); \tag{5}$$

$$x_j \ (j = n_1 + 1, n_2 + 2, ...); \tag{6}$$

$$x_j \le 0 \ (j = n_2 + 1, n_2 + 2, ..., n); \tag{7}$$

here (1) – the function of aim; (2)–(7) – restriction system; $b_i \ge$ free members of restrictions $(l = 1, 2, ..., m)$.

The aim of the system is to show the system's condition to be achieved in the process of management. The use of methodological basis in the creation of technological management would enable a possibility to meet all the demands and requirements of the market.

The efficiency of the technological process may be evaluated by the only criterion – the growth of national income in regard with the production costs or increased transportation resources under the optimal proportion between consumption and accumulation funds.

By their content all economical criteria of the national economy may be attributed to one of the three groups:

- Maximum economical effect under fixed expenses/costs;
- Minimum expenditure under fixed effect;
- Maximum economic effect by using available resources.

Given the concrete task the economic criteria have to meet these requirements:

- To reflect objective demands of the national economy for handling/servicing system;
- To reflect the demand of this service for the national economy system;
- To reflect costs/expenditures and obtained results;
- To foresee the scientific progress of this type of services.

Optimal selection of the criterion sometimes causes certain difficulties and problems that cannot be solved unambiguously. The criterion of application of technological means has to be analysed comprehensively, so that afterwards to avoid errors in the solution of problems. The criteria usually depend on management parameters (x_j). Shifting dimension changes depending on the number of variation possibilities. Most peculiar are those that are using in tasks various technologies. Not only relevant technologies often are included into the model, but the indices defining the economical parameters of the system as well [1–2].

3. USING OF MODELS IN TRANSPORT TERMINALS

Lithuanian transport system development strategy foresees the investigation of the interface between all transport modes, namely: road, railway, maritime, inland waterways, pipeline and in part, air transport [3]. For this reason the whole number of models was adapted and principally changed.

For transport modelling, for the assessment of costs for its efficient operability maintenance, a dynamic model serving the development of general transport capacities was elaborated. In the model the following denoted values are accepted: $G(t)$ – general costs for the period t; $V(t)$ – transportation capacity of transport system for the period t; m – comparative costs of the transportation capacity unit, the costs being necessary for uninterrupted functioning of transport system; f – comparable costs of a transportation capacity unit, necessary for renewal (replacement of present ones) of transport means; r – transportation capacity unit comparative costs necessary for the increase of transportation capacities; k – coefficient of proportionality; K_1, K_2 – constants of integration.

The general costs of transport functioning related to transportation capacity:

$$G(t) = kV(t),$$

where $kV(t) = cV(t) + rV'(t)$

$$c = m + f\ .$$

Having solved the differential equation in the $V(t)$ attitude we will obtain:

$$V(t) = K_1 \frac{k-c}{r} t + K_2\ .$$

The latter model may be generalised by the three cases of the assessment of costs necessary for the maintenance of transport system's working ability in transport terminals.

Case I. First generalisation – by presenting the general costs in the form of the linear equation:

$$K_1(t) = a_i + b_i t,\ i = 1, ..., (l)N,$$

where a – initial costs; c_i – coefficient of cost increase for a time unit.

Coefficients $K_i(t)$ may be interpreted as linear functions for maintenance of system's work ability in transport terminals.

The function of general costs is put down as follows:

$$G(t) = \sum_{i=l}^{N} K_i(t),\ i = 1, ..., (l)N\ .$$

When $G(t) = a = \text{const}$, we shall obtain:

$$V'(t) = \frac{a}{r} - \frac{c}{r} V(t).$$

From this

$$V(t) = \frac{a}{c}\left(l - c^{-\frac{c}{r}t} \right) + e^{-\frac{c}{r}-t},\ c_1 = \frac{a}{c} - K\ .$$

In this expression the first member assesses the influence of external factors on the operation of transport activities in transport terminals.

The second member characterises the influence of factors (the ageing of the main transport means, the structure of the main transport means fleet, etc.).

If $i=3$, we shall obtain:

$$V(t)=i^{-\frac{c}{r}t}\left[c+A(t)\right],$$

where $A(t)=\dfrac{K_1(t)+K_2(t)+K_3(t)}{r}\cdot e^{\frac{c}{r}t}\,dt$.

Case II. The second generalisation is the coefficients of comparative costs, which are divided into separate components for the sake of assessing the separate factors.

In this case the model of general costs is put down as follows:

$$G(t)=\sum_{i}^{N}c_iV(t)+\sum_{i}^{M}r_jV'(t),\ i=1(i)N\ ,\ j=1(l)N\ .$$

Computer technology enables us to analyse the real levels of specification during the processing of the different forecasted data.

Case III. The third generalisation is the assessment of the reversible impact of transportation capacities on the general costs.

Transportation capacities' expansion enhances the realisation of transport services, and preconditions the growth of transport functioning costs, its work ability maintenance, and modernisation.

Therefore the function of general costs will be this:

$$G(t)=\sum_{i=1}^{S}g_iV(t),\ i=1(l)S\ .$$

Coefficients g_i may be analysed as coefficients of proportionality between the costs of the transportation capacity and the separate elements of the transport terminals. In turn, these coefficients may act as transportation capacity functions:

$$g_i=u_i+z_iV(t),\ i=1(l)S\ ,$$

where u_i – initial costs for maintenance of system's work ability; z_i – coefficient of cost increase for a time unit.

For assessing the efficiency of separate transport modes and for their mutual comparison, it is necessary to have a system of indices characterising the operation of transport, the coefficients of the value of these indices and the rules of their aggregation into a uniform quantity.

From the whole set of indices there are selected the principal ones characterising the efficiency of transport system's operation:

- cost of transportation;
- time consumption for transportation (in monetary expression);
- time consumption for waiting (in monetary expression);
- cost of transportation unit.

The operational efficiency of a transport mode is assessed as follows:

$$I_{EM}=(\alpha d_1)+(\beta d_2)+(\gamma d_3)+(\delta d_4),\tag{8}$$

or, if detailed more specifically according to the transport modes, the route, and freight types:

$$I_{EM_{i,r,c}} = \left(\alpha_{i,r_i c_i} d_{1,i,r,c}\right) + \left(\beta_{i,r,c} d_{2,i,r,c}\right) + \left(y_{i,r,c} d_{3,i,r,c}\right) + \left(\delta_{i,r,c} d_{4,i,r,c}\right), \quad (9)$$

where i – index of transport mode; r – index of route; c – freight type index; α – freight category; d_1 – transportation cost; β – time consumption, h; d_2 – recalculation of freight unit transportation time consumption (into the cost in monetary expression); y – waiting time, h; d_3 – recalculation of freight unit waiting time into the cost (in monetary expression); δ – probability of freight non-delivery, its loss or damage; d_4 – cost of freight unit.

For the assessment of the transport system's operational efficiency in general it is necessary to sum up the meanings of separate transport modes obtained.

$$I_{EM} = M_1 I_{EM_1} + M_2 I_{EM_2} + \ldots + M_i I_{EM_i} \rightarrow \min, \quad (10)$$

where $M_i = \sum_{g=1}^{G} m_i, c$; $m_{i,c}$ – c $(c = 1,\ldots,C)$ type of freight volume transported by the i-th transport mode; M_i – general amount of freight transported by the i-th transport mode.

After having solved the (8)–(10), it is possible to identify an efficient combination of transport modes. Whereas the assessment of transport modes is exercised as that of the whole transport network in general, the applied data is very aggregated. In transportation planning such an aggregation level is not always necessary. Usually it suffices to select the most efficient transport modes in one corridor existing in transport system. In such a case the problem is being solved:

$$I_{EM} = M_{12} + M_2 I_{EM_{22}} + \ldots + M_1 I_{EM_1} \rightarrow \min, \quad (11)$$

when

$$M_{i,r} = \sum_{g=1}^{G} m_{i,r,c}, \quad (12)$$

where $M_{i,r}$ – general amount of transportation performed by the i-th transport mode in the corridor r; $M_{i,r,c}$ – c mode freight transportation performed by the i-th transport mode, in the corridor r.

Whereas all the indices are expressed by the cost, the application of models does not cause difficulties. Models may be used also for the solution of complex problems, for instance, for the assessment of efficiency influence of separate transport means' functioning [3–5].

4. ANALYSIS OF MODELLING INVENTORY COSTS

Manufacturers and retailers are increasing their focus on logistics systems, looking for ways to reduce costs and improve customer responsiveness (providing a desired product where and when the customer wants it). The goal of cost reduction provides motivation for centralization of inventories [6]. On the other hand, the goal of customer responsiveness provides motivation for having goods as near to the final consumer as possible. Thus, there is a basic conflict between these objectives, and locating terminals is a critical decision in finding an effective balance between them. Location decisions for terminals also affect transportation costs. There are described a modelling approach that provides an integrated view of inventory costs, transportation costs, and service levels when making terminals location decisions.

In Fig. 1 is provided a simple illustration of product flow from plants to retail outlets through terminals. Retailers demand products from terminals to which they are assigned in response to customer demand.

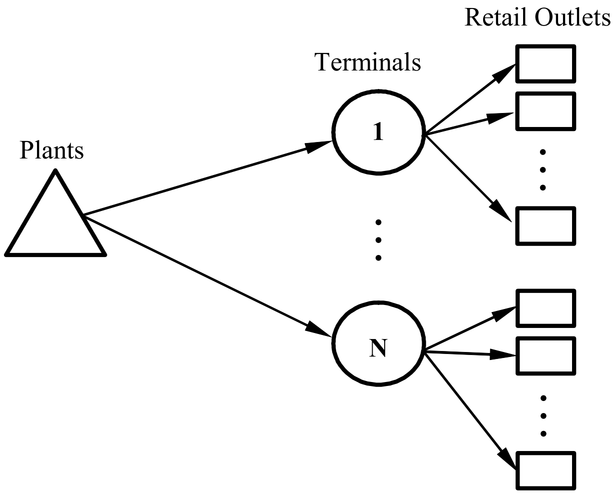

Figure 1. *A basic terminal system*

Terminals backorder excess demand. In parallel to these actions, orders are placed for the same products at the plants. That is, the inventory policy adopted at the terminals is continuous review with one-for-one replacement.

For a given number of retail outlets, inventory levels can be determined to provide a given level off-service. Consider a single product configuration or group of configurations that for inventory planning purposes can be analyzed together and for which demand levels are assumed to be independent.

That is, a temporary shortage of one product does not increase the demand for related products.

Assume that there are n retail locations assigned to the terminal, each with a Poisson demand process whose mean rate is λ_i, where $1 < i \le n$.

Therefore, the demand at the terminal follows a Poisson distribution with a mean rate:

$$\Lambda = \sum_{i=1}^{n} \lambda i . \tag{13}$$

Assume the terminal has s units of a product in inventory, and orders one unit from the plant each time one unit is sent to a retail outlet. Let μ and σ^2 represent the mean delivery time and its variance for a product shipment from plant to terminal.

Stock out rate the percentage of demand that cannot be satisfied from on and inventory, is an important level-of-service measure in inventory systems. In the presence of uncertain demand, an amount of safety stock will be carried to reduce stock out rates. If the demand rate at the terminal is λ, and the average replenishment time is μ, then the number of units on order, m, is Poisson distributed with parameter $k!$ If the established stock level is s, then the probability of a stock out is simply $Pr(m > s)$:

$$Pr(m > s) = \sum_{k=s+1}^{\infty} \frac{e^{-\Lambda\mu}(\Lambda\mu)^k}{k!} . \tag{14}$$

Eq. (14) can be used to find the minimum inventory necessary for a maximum stock out rate. If r is the desired stock out rate, then find s_r, the smallest value of s such that Eq. (14) is less than or equal to r. Inventory savings from consolidation result from reductions in safety stock, as discussed below. Nozick and Turnquist [7] show that for a given stock out rate the safety stock held at each terminal varies with the square root of the number of terminals. This is consistent with results provided by other authors like Eppen [8]. Nozick and Turnquist [7] also show that for a given stock out rate and total demand, safety stock can be accurately approximated with a linear function as long as the number of terminals is relatively large.

This provides an effective way to incorporate inventory costs into location models. They also show that if safety stock is calculated based on an equal allocation of demand to each terminal, the result is an upper bound on actual safety stock required for any other demand assignments to terminals. This means that a conservative estimate of safety stock requirements can be determined from the number of terminals, without specifying exact locations and demand volumes.

In order to illustrate these concepts, suppose an auto manufacturer sells 700 products or new vehicle "configurations" in the continental US of which 200 have yearly demand of 8 000 units, 225 have yearly demand of 6 000 units, and 275 have yearly demand of 4 000 units. Total annual demand for all products is therefore 4 050 000 new vehicles.

Fig. 2 shows the expected safety stock for different numbers of terminals early volumes and a 5 % stock out rate. Notice, that safety stock is relatively linear in the range of 15–50 terminals [6].

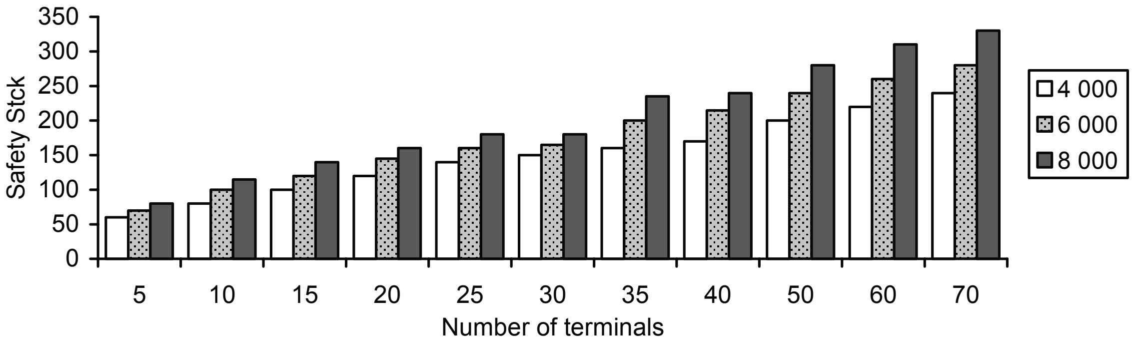

Figure 2. *Safety stock for different number of and annual demand level*

A linear regression equation is estimated to predict safety stock requirements for each of the three demand volumes shown in Fig. 2 using data for the 15–50 terminals range. The equations are then aggregated using the number of configurations with each demand volume, yielding the following regression relationship between safety stock and number of terminals:

$$s = 58\ 836 + 2\ 140 \times N\,. \tag{15}$$

If average vehicle price is assumed to be \$15 000, and yearly holding cost is 22 %, the inventory cost equation is as follows:

$$\$194\ 158\ 800 + \$7\ 063\ 523 \times \mathrm{N}\,. \tag{16}$$

Implying that a safety stock annual inventory cost is slightly over \$7 million for each additional terminal.

Clearly, parameter values in (16) reflect assumptions concerning product prices, number of products, annual demand, etc. However, the idea is that if total inventory costs can be represented by a linear function of the number of terminals to be located, inventory costs can be embedded directly into a location model.

5. ESTIMATE OF LOCATION MODEL

The fixed-charge facility location model can be specified as follows [9]:

Minimize

$$\sum_j f_j X_j + \alpha \sum_{i,j} h_i d_{ij} Y_{ij} \tag{17}$$

subject to $\sum_j Y_{ij} = 1 \quad \forall i$, (18)

$$Y_{ij} \le X_j \quad \forall i, j , \tag{19}$$

$$X_j \in (0,1) \quad \forall j , \tag{20}$$

$$Y_{ij} \in (0,1) \quad \forall i, j , \tag{21}$$

where f_j is the fixed cost of creating a facility at candidate site j, h_i the demand at location i, d_{ij} the distance from demand location *i* to candidate site *j,* α the cost per unit distance per unit demand,

$$x_j = \begin{cases} 1 & \text{if a facility is located at candidate site } j, \\ 0 & \text{otherwise,} \end{cases}$$

$$Y_{ij} = \begin{cases} 1 & \text{if demands at } i \text{ are served by a facitility at candidate site } j, \\ 0 & \text{otherwise.} \end{cases}$$

The linear approximation to safety stock requirements is incorporated into the fixed-charge coefficient, f_j, for the candidate sites. The "slope" parameter from the inventory cost equation (4) becomes part of f_j, because it reflects a constant increment in inventory safety stock needed for an additional terminal. The intercept term in (4) is independent of the number or location of facilities, so it plays no role in the optimisation.

The model specified by (17)–(21) minimizes both inventory costs and transportation costs. Solution procedures for the fixed-charge model include a variety of greedy heuristics including add, drop, and exchange heuristics, Lagrangian relaxation, and branch and bound [6–9]. A hybrid heuristic using a combination of a greedy adds and an improvement algorithm is used in this paper, as discussed by Daskin [9].

Integration of inventory costs into the location model is an important step for overall cost minimization, but it still does not deal with the competing objective of providing a high level of customer responsiveness in the distribution system.

Stock out rate indirectly reflects customer demands, but the distance between terminal and retail outlet may be too large to meet time-based service standards.

The objective of providing fast, reliable, delivery of products to retail outlets may be met by operating a large number of terminals conveniently located, implying large facility development and operating costs, and higher inventory costs. Thus, there is a fundamental trade-off between customer responsiveness and costs when designing a terminal system.

A mathematical model to maximize coverage ensures that a proportion of demand that is within a specified "coverage"' distance of a terminal will be met. Delivery is then guaranteed for the set of retail outlets within a certain radius (e.g., 200 miles) of the terminal. Church and Re-Velle [10] first described a set of N facilities that covers the objective of maximizing the proportion of total demand. Hillsman [11] formulated an equivalent model that minimizes uncovered demand. This formulation facilitates the integration of coverage maximization and cost minimization.

Defining the following variable:

$$q_{ij} = \begin{cases} 1 & \text{if a facitility located at candidate site } j \text{ cannot cover demand at } i, \\ 0 & \text{otherwise,} \end{cases}$$

the minimization of uncovered demand can be expressed as follows:

$$\text{Minimize } \sum_{i,j} h_i q_{ij} Y_{ij} \tag{22}$$

$$\text{subject to } \sum_j Y_{ij} = 1 \quad \forall i , \tag{23}$$

$$\sum_j x_j = N, \tag{24}$$

$$Y_{ij} \le X_j \quad \forall i, j, \tag{25}$$

$$Y_{ij} \in (0,1) \quad \forall i, j, \tag{26}$$

$$X_j \in (0,1) \quad \forall j. \tag{27}$$

Constraints (23) and (25)–(27) in this model are identical to constraints (18)–(21) in the fixed-charge model, allowing integration of the total cost objective and the coverage objective. More specifically

$$\text{Minimize } \sum_j f_j X_j + \sum_{ij} \{W h_i q_{ij} + \alpha h_i d_{ij}\} Y_{ij} \tag{28}$$

subject to $Y_{ij} = 1 \ \ \forall i,$ (29)

$$Y_{ij} \le X_j \quad \forall i, j, \tag{30}$$

$$X_j \in (0,1) \quad \forall j, \tag{31}$$

$$Y_{ij} \in (0,1) \quad \forall i, j, \tag{32}$$

where W is the weight given to the objective of minimizing uncovered demand. Notice that the number of terminals is endogenous to the model, in the fixed-charge facility location model. All demand will be served but the uncovered demand will be served at a lower level-of-service.

If W is very large then the model, that gives the Eqs. (28)–(32), is equivalent to minimizing uncovered demand. This will result in the location of a large number of terminals because the constraint that limits the number of facilities to locate has been removed. If W is small, then the model is equivalent to minimizing total cost. By varying the value of the weight, W, a variety of trade-off solutions can be identified. As the model that gives the Eqs. (28)–(32) has the same structure as the fixed-charge facility location model, standard algorithms for solving that problem can be used.

In any given application of the model, the percentage coverage is determined by the trade-off with total cost. If a pre-specified percentage of coverage is to be guaranteed, then an alternative formulation (and solution method) may be used, as described by Nozick [7].

6. CONCLUSIONS

1. Creation of model of transport terminals starts from the analysis of the modelled object, by the application of mathematical formulae, accumulation of information with the aim of qualitative coordination on the basis of experimental mode and with the view of accomplishing the task, to make its analysis, correction on model by supplementary solutions and finally, to carry out the last testing of the experimental model.
2. If all the indices are expressed by the cost, the application of models does not cause difficulties. Models may be used also for the solution of complex problems, for instance, for the assessment of efficiency influence of separate transport means' functioning.
3. This paper has developed an analysis procedure for the location of terminals that integrates facility costs, inventory costs, transportation costs and service responsiveness. That procedure integrates ideas in queuing theory, discrete choice location analysis and multi-objective decision-making. Using this procedure, decision-makers can easily understand the service-cost trade-off that is available, so that optimal location decisions can be reached.

References

[1] Jarašūnienė A. The Optimisation of Transport Flows Crossing Lithuanian Customs Houses. (A. Jarašūnienė. Transporto srauto optimizavimas vežant krovinius per Lietuvos muitines). In: *Transport.* Vilnius: Technika, 2002, Vol. XVII, No 1, pp. 15-18.

[2] Jarašūnienė A. Formulation of Optimal International Freight Transport Objective. (A. Jarašūnienė. Tarptautinio krovininio transporto srautų teorinis tyrimas). In: *Transport.* Vilnius: Technika, 2002, Vol. XVII, No 5, p. 201.

[3] Baublys A. *Transport System: Models of Development and Forecast: Monograph*. Vilnius: Technika.

[4] Baublys A. *Introduction to the Theory of Transport System.* (Transporto sistemos teorijos įvadas). Vilnius: Technika, 1997. 298 P. (in Lithuanian)

[5] Baublys A. Assessment of Statistical Probability of the Technological Transportation Process, *TRANSPORT-2002*, Vol. XVII, No 4, pp. 127-136; 2003. 204 p.

[6] Nozik L.K., Turnquist M.A. Inventory, Transportation, Service Quality and the Location of Distribution Centre, *European Journal of Operational Research*, 129, 2001, pp. 362–371.

[7] Nozick L.K. The Fixed Charge Facility Location Model with Coverage Restrictions, *Transportation Research*, Part E, 2000. (In press)

[8] Eppen G. Effects of Centralization on Expected Costs in a Multi-Location Newsboy Problem, *Management Science,* 25 (5), 1979, pp. 498-501.

[9] Daskin M.S. *Network and Discrete Location: Models, Algorithms, and Applications*. New York: Wiley, 1995.

[10] Church R., ReVelle C. S. The Maximal Covering Location Problem. In: *Papers of the Regional Science Association*. 1974, Vol 32, pp. 101-118.

[11] Hillsman E.L. The P-Median Structure as a Unified Linear Model for Location-Allocation Analysis, *Environment and Planning*, A 16, 1984, pp. 305-318.