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OPTIMISATION OF TECHNOLOGICAL PROCESSES IN TERMINALS

Aldona Jarašūnienė

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

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Abstract. In this article technological processes in transport terminals are analysed. A technological scheme of the transport terminal is analysed graphically reflecting the sequence of working operations with regard to aerial location, necessary equipment, outfit and workers. A technological graph chart reflecting the technological acceptability and time normatives of technological operations of a transport process is present. The estimation and adaption of models in transport terminals are presented. A dynamic model serving the development of general transport capacities was elaboated for process modeling of transport terminals.

Keywords: technological process; technological center of terminal; transport terminals; using of mathematical models for transport terminals.

1. Introduction

The analysis of technological processes and their optimisation in transport terminals enables successful functioning of freight transport, thus guaranteeing for consignee reliability, independency and quality [1–4].

At present in terminals various operations are performed that influence vehicle and freight inspection. The inspection quality partially makes a positive influence on security, freight preserve, and efficient delivery to the client. Therefore it is important to analyse technological processes in transport terminals, their optimisation opportunities, as well as the application and assessment of models.

2. Analysis of the technological process in transport terminals

For structuring technological operations of a transportation process it is necessary to start the analysis of the amount of necessary equipment, its location, outfit of terminals and working places of the main working staff, the analysis of the present technology conditions and methods of organisation of operations in proper places. Also it is necessary to have the data about vehicles, their supply, loading capacity, length, norms of time required for typical working operations, information systems used, data exchange methods, determined norms for management of vehicles work (inner instructions, work management, decisions, statements, etc.).

It is important to analyse the technological scheme of the transport terminal graphically reflecting the sequence of working operations with regard to aerial location, necessary equipment, outfit and workers.

It is necessary to present a technological graph chart reflecting the technological acceptability and succession of relevant operations in line with the orders of executive personnel, work range, norms and time normatives of technological operations of a transportation process.

It is important to evaluate the accounting of time functions in handling vehicles regarding the dependent and independent positions of critical work.

It can be seen from the technological graph chart that the general succession of handling is the sum of critical operations (dependent and independent). Thanks to the technological simplicity and reliability, the given equal number of vehicles and equal initial conditions, it is convenient to define data in the uniform measurement unit, by which all operations will be related and to which all time normatives will be attributed. Usually the number of vehicles is selected as such a measurement unit [5–7].

Reliability of technological system mostly depends on the technical equipment of handling and on the reliability of staff. Efficient and uninterrupted traffic of vehicles to the place of destination and handling depends on the reliable arrangement of activities of transfer posts.

In the location of document procedures actually the same repetitive operations are carried out: documents are received, filled in, accumulated, structured and then forwarded.

If by personnel fault the normal flow of one of the elements is inhibited, the total cycle of a vehicle handling process will be disconcerted and the process of document preparation for forwarding will be interrupted, which will cause downtime. For this reason the departure organisation is carried out in three directions: in the reception location of freight consignment, in the technological centre where documents are prepared and in the distribution post where freight is formed.

It is obvious that the organisation of the technological centre of terminal (TCT) and transfer activities are of utmost importance.

Organisation of TCT activities in the process of preparation of documents has to meet the possibilities of all links of the chain, all units related to freight handling.

Document procedures are carried out in two directions: procedures of handling the main documentation and performing of subsidiary operations for document handling. The process of handling of the main documents covers the reception of documents from drivers, checking of waybills or denotation, forwarding of documents to TCT, sorting station, marshalling of documents according to references on boxes and keeping straight to the sorting plan, stamping, accumulation/archiving, selection of documents for freight consignment, transfer to forwarding centre and, finally, submission of documents to the departing vehicle driver.

The following belong to the subsidiary processes: customs and border-crossing transfer documents and vehicle inspection, all other operations related to the management method according to the location of freight, technical and commercial inspection, elimination of commercial and technical discrepancies.

The main process of document handling has to be carried out gradually in the process of freight movement.

Subsidiary processes have to comply with the general movement range.

Freight consignment after arriving in the fleet (t_n) is disintegrated ($t_p = t_H + t_{poc}$) and together with the end of the disintegration occurs a possibility to start a new formation (t_ϕ). After a new freight consignment is formed it may be forwarded/transferred to the forwarding centre/fleet. Until this moment documents have to be handled/processed by TCT within certain time (t_1), sorted within certain time (t_2) and inspected within certain time (t_3). Afterwards they are transferred from one point to another point within certain time (t_{per}), i.e.

$$t_n + t_p + t_\phi = t_1 + t_{nep} + t_2 + t_3 ,$$

from here

$$t_{nep} = t_n + t_p + t_\phi - (t_1 + t_2 + t_3) .$$

In the course of the optimisation of a technological process one of the possibilities may be this: it is necessary to establish in the terminal an independent transfer centre of TCT base. This centre has to be located near the inspection premises. In the places of arrival and departures special customs and border-crossing posts have to be located. Intake and release operations should be going on in these posts.

Customs and border-crossing staff busy with arrival, sorting (forming) and in departure fleets have to be related to TCT and to have bilateral communications. Operational transfer system of documents has to be installed between TCT and special posts. It should be coordinated with the director of the terminal.

Complex approximation of the technologies used by the organisation and those rationally functioning within it enable the optimisation of a technological document handling process. It may be defined as follows:

TCT base independent forwarding centre receives a document. It is fixed there and its one copy is forwarded to the inspector together with sorting sheet, another copy is forwarded to customs office. Customs officers meet or inspect vehicles with this document using technical means (inspection devices, industrial television, etc.). In the case of occurrence of discrepancies between the present condition of the train and the present document the data are coordinated by the radio communication with the customs officer situated in the transfer post.

It has been calculated that the organisation of such inspection of freight consignment enables to decrease the time of these operations by 8–10 minutes.

The issue of coordination of both systems jointly (each of them is handling a relevant direction) has a number of advantages: it facilitates inspection of vehicles, improves communication between posts and TCT. Further problems concerning the organisation methods of the inspector work occur.

Therefore, these issues have to be necessarily handled separately by each case considering typical technological processes and present local conditions [8–11].

3. Application of technological means and modelling of processes in transport terminals

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 multiplan 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 the implementation of means, handling and consolidation. The main principles of management technologies are the following: sistemacy, definition of tasks, adaptation, dynamics, quality normatives, and standardisation.

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

The creation of a model of transport terminals starts from the analysis of the modelled object, by the application of mathematical formulae, the 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 of model by supplementary solutions and finally, to carry out the last testing of the experimental model. Only after the accomplishment of such operations, the model may be disposed to information system for the use and accomplishment of the tasks [8–11].

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

The mathematical formulation of the system will determine how efficient the system will be. The mathematical formulation of the systems makes the modelling of the whole process, i.e. the 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:

$$z = f(x_1, x_2, ..., x_n) \rightarrow \max(\min); \quad (1)$$

$$\varphi_i = (x_1, x_2, ..., x_n) \leq b_i \; (i = 1, 2, ..., m_1); \quad (2)$$

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

$$\varphi_i = (x_1, x_2, ..., x_n) \geq b_i \; (i = m_2 + 1, m_2 + 2, ..., m); \quad (4)$$

$$x_j \geq 0 \; (j = 1, 2, ..., n_1); \quad (5)$$

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

$$x_j \leq 0 \; (j = n_2 + 1, n_2 + 2, ..., n); \quad (7)$$

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

The aim of the system is to show the condition of the system to be achieved in the process of management. The use of a 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 to the production costs or increased transportation resources under the optimal proportion between consumption and accumulation funds.

According to their contents 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 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 various technologies in tasks. Not only relevant technologies often are included into the model, but the indices defining the economical parameters of the system as well [10–11].

4. 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 [12]. 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 $V(t)$ attitude we will obtain:

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

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

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

$$K_1(t)=a_i+b_it,\ i=1,\dots,(l)N,$$

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 work ability in transport terminals.

The function of general costs is put down as follows:

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

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

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:

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

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:

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

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 the principal ones are selected characterising the efficiency of transport system 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:

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

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

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

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 operational efficiency in general it is necessary to sum up the meanings of separate transport modes obtained:

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

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.

Having solved (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:

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

when

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

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 [12–14].

Static model with discrete-continuous variables. If we dissociate ourselves from the structure of transportation volumes and changes of direction in time, then the model of the problem may be presented as follows:

$$\min_{X,\eta} F(X,\eta) = \min_{X,\eta} \sum_u \sum_k f_{uk}(X, X_\Pi)\eta_{uk}. \qquad (13)$$

When there are restrictions:

$$S_p X = b; \qquad (14)$$

$$X \ge 0; \qquad (15)$$

$$\eta_{uk} = \begin{cases} 0 \\ 1 \end{cases} \forall u,k; \qquad (16)$$

$$\sum_k \eta_{uk} \le 1 \ \ \forall u; \qquad (17)$$

$$X_u \left(1 - \sum_k \eta_{uk}\right) = 0 \ \ \forall u; \qquad (18)$$

$$\sum_u \sum_k r_{juk} \eta_{uk} \le R_j \ \ \forall j, \qquad (19)$$

where f_{uk} – function of brought out costs exposed in the network element u, being k level of its development (taking into account the development costs); X – initial vector of network loading by flows of all freight types; X_{Π} – defined vector of network loading with passenger transport; b – vector of shipment–delivery amounts in the network peaks; X_u – loading vector of the network element loading u; η_{uk} – identificator showing the network element u status k (if $\eta_{uk} = 1$, then it exists, if $\eta_{uk} = 0$ – it does not exist); $\eta = \{\eta_{uk}\}$ – the sought vector of the status of technical furnishing of network elements; r_{juk} – use of the resource j in the network element u, seeking to lead it from the initial status into the k status; R_j – general permissible consumption quantity of the resource j; S_p – generalised incidents matrix corresponding to the flows of transportation of non-uniform freights:

$$S_p = \left\| S_{ijl} \right\|, \text{ whereas } l = 1, 2, ..., p;$$

$$S_{ijl} = \begin{cases} +1, & \text{if the radius of the network goes out from the node } i \text{ and it is possible to perform by it the transportation of } l \text{ type freight (total number of freight types - } p); \\ -1, & \text{if the radius } j \text{ goes enters into the node } i \text{ and it is possible to bring by it the freight } l; \\ 0 & \text{- other cases.} \end{cases}$$

Thus, according to the purpose function (13) general brought out costs are minimised when there are restrictions:

a) restrictions of a technological type (13) and (14) – the condition that all transportations should be performed;

b) for reconstruction: restrictions (16)–(17) – every element may be only in one status, and if the element is not created, then the work performed by it equals to zero – restriction (14)–(19);

c) resource restriction (19) – every resource type may be used within the limits of the defined amounts.

In solving the problem (13)–(19) the list of means of the optimal development of the network is obtained however, their implementation terms are not identified, as well as their stages, i.e. successive change over the time of the level of the elements of technical status.

Dynamic model with discreet-continuous variables. While formulating the dynamic problem we shall consider that the identified freight shipping and delivery time changes (vector b_t), the intensity of network loading in passenger flows X_n^t, the influence of scientific and technical advance, as well as impact of other brought out costs for the function $f_{uk}^t\left(X^t, X_n^t\right)$.

We shall also consider that:

a) possible technical supply states of each element of network are partially ordered (for instance, in capacity growth) and this order is realised over the time, i.e. passing to lower levels is not foreseen;

b) the cost of "situation rescue" in changing the state of elements is small, i.e. investment necessary for passing of element from one state to another directly or through other intermediate hierarchic links of state does not change much;

c) the quantity of operational costs of transportation performed by any element of the network is identified for each entire year according to the technical supply and loading of each separate element of the network.

Then the dynamic model is natural generalisation of the model (13)–(19) and will be:

$$\min_{X^t, \eta^t} F\left(T, X^t, \eta^t\right) =$$

$$\min_{X^t, \eta^t} \sum_{t=1}^{t=T} \sum_{u,k} f_{uk}^t\left(X^t, X_n^t, \eta^t\right)\eta_{uk}^t (1+E)^{-t} . \quad (20)$$

When there are restrictions:

$$S_p^t X^t = b^t; \quad (21)$$

$$X^t \geq 0; \quad (22)$$

$$\eta_{uk}^t = \begin{cases} 1 \\ 0 \end{cases} \forall u, k, t; \quad (23)$$

$$\sum \eta_{uk}^t \leq 1 \ \forall u, t; \quad (24)$$

$$X_u^t \left(1 - \sum_k \eta_{uk}^t\right) = 0 \ \forall u, t; \quad (25)$$

$$\sum_{t=\theta_1}^{t=\theta_2} \sum_{u,k} r_{juk}^t \eta_{uk}^t \leq R_j^{\theta_1, \theta_2} \ \forall j; \quad (26)$$

$$\left(\sum_k k\eta_{uk}^t - \sum_k k\eta_{uk}^\tau\right)(t - \tau) \geq 0 \ \forall k, u, t, \tau, \quad (27)$$

where t, τ – index of the current year; T – length of the accounted period; $R_j^{\theta_1, \theta_2}$ – restrictions to the resources j for the general period of use from the year θ_1 until the year θ_2 inclusively (usually θ_1 – the year of the beginning of planning, and θ_2 – the year of the finishing of planning), if the restriction (31) is defined for a certain year separately, then $\theta_1 = \theta_2 = t$.

While defining in the inequality (26) the existing meanings r^t_{juk} (resource amount is necessary to lead the element u in the year t from initial state into the state k) then as an initial state there is taken the state $(t-1)$ in the end of the year.

The essence of the purpose function (20) and the restrictions (21)–(26) are analogous (only analysed in dynamics) to the corresponding relations (13) and (14)–(19) in a static model. The condition (27) defines the order of possible change in the technical state of the system elements [12–14].

Solving the problem (20)–(27) it is possible to define in which year, which elements, and of which state should be reconstructed (or built). In this case the time is assumed as the discrete one, i.e. the pace of change of the quantities t, τ, θ_1, θ_2 equals to one year.

5. Conclusions

1. It was explained that technological service of transport means consists of technological operations of transport means, of the transport terminals graphically reflecting the sequence of working operations in regard to aerial location, necessary equipment, outfit and workers.

2. The analysis showed that the complex approximation of the technologies used by the organisation and those rationally functioning within it enable the optimisation of a technological document handling process.

3. For transport terminals process modelling, for the assessment of cost for its efficient operability maintenance, a dynamic model serving the development of general transport capacities was elaborated.

4. The described models may be used also for the solution of complex problems, for instance, for the assessment of efficiency of the influence of separate transport means functioning.

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