MODELLING OF MULTIMODAL FREIGHT TRANSPORTATION SYSTEM USING PROCESS APPROACH

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ABSTRACT
In the present paper the following main tasks are considered: choice of a set of indices characterizing efficiency of multimodal transportations, formation of optimization criteria of the system of multimodal transportation, construction of models of the multimodal transportation system, the usage of methodology IDEF0 in BPWin package to describe business processes of freight transportation.

Keywords: multimodal transportation, logistic system, criteria of optimization, business-process, modelling

1. INTRODUCTION

Current trends of development of the international system of freight transportation are characterized by essential increase of multimodal transportation in total amount of cargo transportation. Usage of several types of transport in multimodal transportation makes the management of transportation, loading and warehousing processes, in which various executors and various facilities are involved, significantly more complicated. Thus, considering great transportation volumes, miscalculations in the organization and management of these processes lead to considerable material and financial losses.

Search for optimal solutions in realization of multimodal freight transportation should be based on a set of the initial data, considering logistic rinciples, and be done using modern mathematical methods and computer engineering (Ghiani, Laporte and Musmanno 2004; Lukinsky 2008). Taking into consideration a complicated structure of multimodal transportation, high dynamics and rapidity of transport processes, the random factors influencing these processes and geographical dispersion of participants of the transportation, the task of the present research is development of the mathematical description of the multimodal transportation system. First of all, such formalization is required for managing multimodal transportation processes and searching for optimal decisions in freight transportation.

In the presented research, the following main tasks, which require solutions, are highlighted:

- choice of a set of indices, characterizing efficiency of multimodal transportation, and formation of an optimization criteria of the system of multimodal transportation on their basis;
- construction of mathematical model of the multimodal transportation system;
- usage of methodology IDEF0 in BPWin to describe business processes of freight transportation.

2. FORMATION OF OPTIMIZATION CRITERIA OF THE TRANSPORTATION SYSTEM

In the presented paper multimodal transportation is considered as a set of *logistic systems* $\mathbf{LS} = \{LS_1, LS_2, ..., LS_n\}$. Each logistics system is considered to be a route of transportation, which is characterized by a set of indices. To estimate the efficiency of multimodal transportation, the system of indices including cost, duration, reliability of transportation of cargo and its safety is used. It is easy to notice that the offered indices have the various physical natures and are measured by different physical magnitudes. The part of indices is deterministic, the part is stochastic. Additional difficulties for estimating the system's indices are related to the fact that part of indices has quantitative nature and part has qualitative nature. For example, cost and durations of transportation are quantities, but reliability and safety, estimated by experts, are qualitative parameters. For conversion of quality indices into quantitative it is offered to use Harrington's desirability function (Lukinsky 2008).

In general case set of chosen indices is used for search of optimal decision in the freight transportation task, and two approaches of optimization criteria formation can be used: monocriterion and multicriterion approaches.

The *first (monocriterion) approach* assumes usage of one generalized optimization criterion and recognizes that various indices (delivery time, reliability of delivery, safety of cargo, etc.) can be estimated in expression in terms of value. It allows constructing a generalized criterion of total costs E_Σ for realization of multimodal transportation, which unites a set of local criteria, among them:

- direct cost for freight transportation, i.e. expenses for cargo transportation, reloading and warehousing, customs operations, documentation, etc.;
- losses appearing as a result of delay in delivery schedule (including penalties for non-fulfillment of the delivery terms and the lost and-or half-received profit);

- losses from cargo loss, and deterioration of its consumer properties (partial or full damage of cargo which reduces its cost);

- expenses for capital freezing (they are defined taking into account cost of transported cargoes and time of delivery);

- losses related to currencies' exchange rates fluctuations;

- expenses for additional insurance of cargo;

- expenses for stock holding in case of irregular deliveries.

At the same time, the given criterion can be supplemented with new components, considering concrete transportation system.

In general case total costs $E_{\Sigma}(LS_j)$ for realization of multimodal transportation of logistic system LS_j will be calculated by the following formula

$$E_{\Sigma}(LS_j) = \sum_{i=1}^{n} E_i \ , \quad (1)$$

where n is quantity of components (items), which form total costs for realization of multimodal transportation; E_i is a value of i-th component of expenses for realization of multimodal transportation (for example, direct cost for freight transportation; losses appearing as a result of delay in delivery schedule etc).

In this case the problem of search of optimal multimodal freight transportation system LS_{opt} on the basis of set of possible logistic systems $\mathbf{LS}$ has the following view:

$$E_{\Sigma}(LS_{opt}) = \min_{LS_j \in \mathbf{LS}} [E_{\Sigma}(LS_j)] \ . \quad (2)$$

In number of cases constrains on used resources (time, technique, means etc.) are additionally introduced:

$$p_k(LS_j) \le p_k^{\max}, \quad k = 1, 2, ..., m; \ \forall LS_j \in \mathbf{LS}, \quad (3)$$

where $p_k(LS_j)$ is the value of k-th index of the logistic system LS_j; $p_k^{\max}$ is the maximum possible value for k-th index for the given multimodal transportations; m is quantity of indices on whose constrains are imposed.

For the fixed number of variants of the systems, determined by set $\mathbf{LS}$, the choice of an optimum variant LS_{opt} by criterion (2) consists of checking conditions (3) and calculations of total costs for realization of multimodal transportation for $\forall LS_j \in \mathbf{LS}$.

The *second approach* considers a *multicriterion* problem of multimodal transportation, when the system of q various criteria $C_1(LS_j), C_2(LS_j), ..., C_q(LS_j)$ is used. This criteria have the various physical natures and are measured by different physical magnitudes.

The part of criteria is minimised (for example, cost and time), and part is maximised (for example, safety of transportation, safety of cargo). In this case we have a *vector optimisation* problem of a kind:

$$C_l(LS_{opt}) \to extremum, \ l = 1, 2, ..., q; \ LS_{opt} \in \mathbf{LS} \ ,$$

where *extemum* for separate criteria corresponds to a minimum, for others – to a maximum.

In the present research the system of four criteria (cost, duration, reliability of transportation of cargo and its safety) is considered by authors. Respectively, we have the following problem formulation:

$$\begin{aligned} &E_{TR}(LS_{opt}) \to \min; \\ &T_{TR}(LS_{opt}) \to \min; \\ &P_{SC}(LS_{opt}) \to \max; \\ &P_{CTR}(LS_{opt}) \to \max, \end{aligned} \quad (4)$$

where $LS_{opt} \in \mathbf{LS}$;

$E_{TR}(LS_{opt})$ is direct cost (expenses) for freight transportation;

$T_{TR}(LS_{opt})$ is time of cargo delivery;

$P_{SC}(LS_{opt})$ and $P_{CTR}(LS_{opt})$ are safety of cargo and reliability of transportation, respectively.

The multicriterion problem can be solved using method of "*consecutive concessions*» (Lukinsky 2008). This method considers a priority of criteria $C_l(LS_j), l = \overline{1, q}$. It is based on estimation and comparison of an increase and decrease in local criteria $C_l(LS_j)$, which are unavoidable in the field of compromises. In the judgment of the authors, *Analytic Hierarchy Process (AHP) method* (Saaty 2001) is the most efficient for choice of optimal logistic system. The AHP method allows arranging the systems of trasportation in the order of efficiency and showing their difference in the given set of criteria.

3. MODELLING OF MULTIMODAL TRANSPORTATION SYSTEM

The model of logistic system (LS) is constructed for the purpose of the description of cargo transportation and calculation of LS indices. Thus for the description of multimodal transportation system it is possible to use two approaches: functional and process.

1. *Functional approach* was the first for describing business-systems. It considers usage decomposition of the system, which includes 3 basic steps. On the first step, logistic system is divided into set of subsystems. On the next step subsystems are presented as a set of logistic functions (LF). On the final step, each logistic function is presented as a set of logistic operations (LO), which is characterized by its own set of indices.

The main disadvantage of the functional approach is dissociation of separate logistic functions and insufficient interaction among them. However, an ultimate goal of formalization of the description of transportation process is not only calculation of efficiency indices, but also development of the approach to efficient control system of multimodal transportation. The last is difficult for implementing using the functional approach.

2. The *process approach* has found wide application recently only. Thus the model of logistic system, realised at the functional approach, joins additional process level. This level in hierarchy of the system precedes level of functions. Logistic process is considered as a set of logistic functions, however in certain cases LP can consist of one LF. The main task of this approach is elimination of lack of the functional approach, which is noted above, and consists in absence of interaction between various LF within the limits of one system.

In the present paper the process approach is used for the description of multimodal freight transportation system. For presentation of the multimodal freight transportation system, decomposition of possible options of logistic system, including four basic steps is done (see example in Fig.1)

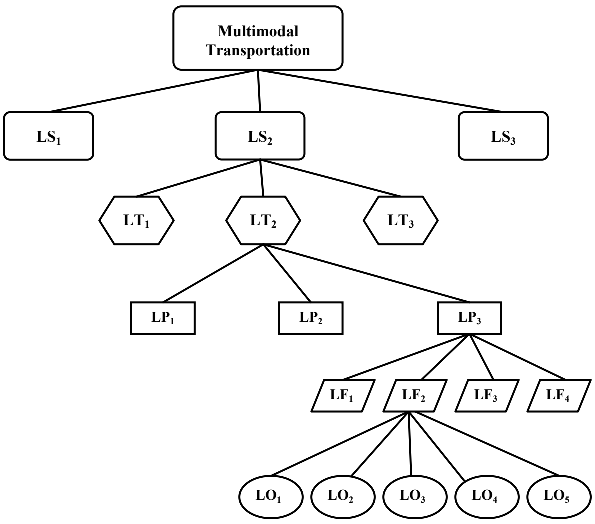

Figure 1: Decomposition of logistic system

On the first step, the logistic system LS_j is divided into a set of *subsystems* $\mathbf{LT} = \{LT_1, LT_2, ..., LT_g\}$. On the second step subsystems are presented as a set of *logistic processes* $\mathbf{LP} = \{LP_1, LP_2, ..., LP_z\}$, which are divided into a set of *logistic functions* $\mathbf{LF} = \{LF_1, LF_2, ..., LF_r\}$. On a final step each function is presented as a set of *logistic operations* $\mathbf{LO} = \{LO_1, LO_2, ..., LO_h\}$, which are characterized by own set of indices.

The constructed system of sets allows making calculations of LS efficiency, taking in account different indices. Besides, these calculations are made "bottom-up", starting from the bottom level (level of LO) and finishing by the top level (level of LS). So, the calculation process can be presented by the chain $\mathbf{LO} \to \mathbf{LF} \to \mathbf{LP} \to \mathbf{LT} \to \mathbf{LS}$.

It is necessary to underline that cost indices at the next level of hierarchical bottom-up system are calculated by simple summation of corresponding indices of the previous level. Then cost index E for logistic system LS_j is calculated under the formula:

$$E(LS_j) = \sum_{LT_i \in LS_j} E(LT_i) = \sum_{LT_i \in LS_j} \sum_{LP_m \in LT_i} E(LP_m) =$$
$$= \sum_{LT_i \in LS_j} \sum_{LP_m \in LT_i} \sum_{LF_h \in LP_m} E(LF_h) = \qquad (5)$$
$$= \sum_{LT_i \in LS_j} \sum_{LP_m \in LT_i} \sum_{LF_h \in LP_m} \sum_{LO_p \in LF_h} E(LO_p).$$

However, calculation of time indices in the transportation system involves severe difficulties. It is necessary to take into account factors like shifts of separate operations, functions and processes for fixed moments of time, parallel and consecutive performance of separate elements of logistic system and so forth. With this aim, methods of network planning are used (Novitsky 2004). In considered task **LO**, **LF**, **LP** and **LT** are presented by the weighed graphs in which edges are corresponding elements of appropriate hierarchy level (i.e. **LO**, **LF**, **LP** and **LT** accordingly), when time indices of functions, processes and subsystems are calculating.

4. EXAMPLE OF CALCULATION OF LOGISTIC SYSTEM'S INDICES

The created model is tested against real-world conditions. To illustrate the offered approaches, the example of multimodal freight transportation from Shanghai to Almaty by three alternative routes is considered. The suggested routes are the following:

- Shanghai – Hamburg – Riga – Almaty;
- Shanghai – Hamburg – Riga Port – Riga Terminal – Almaty;
- Shanghai – Alashankou – Dostyk – Almaty.

Let us consider features of each route.

1. Shanghai – Hamburg – Riga - Almaty. This route considers transportation of cargo in container during the whole transportation process without reloading (intermodal transportation). Container is delivered from Shanghai to Hamburg by mother vessel. Thereafter container is being reloaded onto feeder vessel for delivery to the port of Riga. In Riga container is reloaded onto truck and delivered to the terminal in Almaty.

2. Shanghai – *Hamburg – port of Riga – railway terminal in Riga – Almaty.* This route considers reloading of cargo from container into railway wagon. Cargo in container is delivered from Shanghai to Hamburg by mother vessel. Then container is reloaded and delivered by feeder vessel to the port of Riga. At terminal container is reloaded onto truck and further delivered to railway terminal. Here cargo is reloaded from container into railway wagon. Thereafter cargo is delivered to the terminal in Almaty by rail.

3. *Shanghai – Alashankou – Dosty – Almaty.* This route considers transportation of cargo in container

during the whole transportation process without reloading (intermodal transportation). Cargo in container is delivered from Shanghai to Alashankou by short see vessel. In Alashankou container is reloaded onto railway platform and further delivered to Dostyk, Chinese/Kazakhstan border point. In Dostyk the container is reloaded onto railway platform of Kazakhstan railways (changing the gauge) with further delivery to terminal in Almaty.

Actually we are considering three logistic systems presented by the graph in Fig.2. The edge of the graph corresponds to a logistic subsystem (or to a route stage).

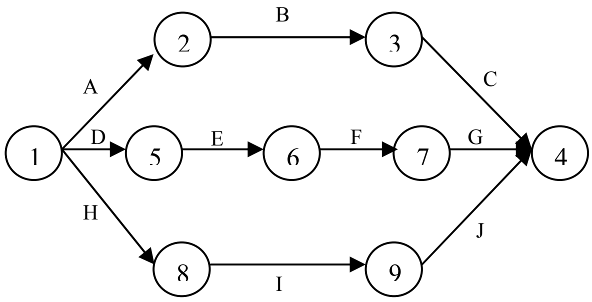

Figure 2: Logistic Systems

Description of routes LS_j is presented in Table 1.

Further the first route LS_1, (Shanghai – Hamburg – Riga – Almaty) will be considered in more details. It is presented by vertexes 1-2-3-4 (or by edges A-B-C) on the graph in Fig.2. As it can be seen, logistic system LS_1 includes three subsystems (stages of routes):

stage A - cargo transportation in container from Shanghai to Hamburg, unloading of container at port of Hamburg;

stage B - loading of container onto feeder vessel, delivery from Hamburg to Riga, unloading of container at port of Riga;

stage C - loading of container on truck at port of Riga, delivery from Riga to Almaty terminal.

Each subsystem (stage) consist of one or several logistic processes. Let us in details consider stage C which consists of three logistic processes: transshipment of container, customs clearance and transportation, shown in Fig.3.

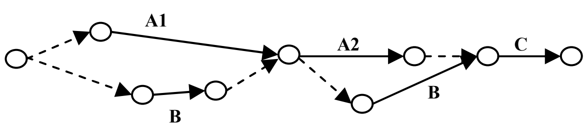

Figure 3: Logistic processes of the stage DB

Each edge in Fig.3 corresponds to one process of the stage: A1 – customs clearance of incoming container; B – transshipment of container, A2 – customs clearance of outgoing container, C – transportation. By dashed lines the edges, used for marking "fictitious processes» (shift in time, parallel performance of processes, etc.), are shown.

Table 1: Subsystems (stages) of routes

LS_j	LT_k Stage	Description of stage
LS_1	A	Cargo transportation in container from Shanghai to Hamburg. Unloading of container at port of Hamburg.
	B	Loading of container onto feeder vessel, delivery from Hamburg to Riga, unloading of container at port of Riga.
	C	Loading of container on truck at port of Riga, delivery from Riga to Almaty terminal.
LS_2	D	Cargo transportation in container from Shanghai to Hamburg. Unloading of container at port of Hamburg.
	E	Loading of container onto feeder vessel, delivery from Hamburg to Riga, unloading of container at port of Riga
	F	Loading of container onto truck, delivery from port to railway terminal in Riga.
	G	Reloading of cargo from container to wagon. Rail delivery from Riga to Almaty terminal
LS_3	H	Cargo transportation in container from Shanghai to Alashankou. Unloading of container at port of Alashankou.
	I	Loading of container onto rail platform in Alashankou. Rail transportation Alashankou – Dostyk, unloading of container at Dostyk border terminal.
	J	Loading of container onto Kazakhstan rail platform to Dostyk terminal, rail delivery to Almaty terminal.

Further we will make decomposition of processes onto logistic functions. We will show it on an example of process of container transshipment at port of Riga. In the offered statement of a problem, at the level of detailed elaboration accepted by us, we will allocate following logistic functions for transshipment process:

- handling of incoming container;
- storage;
- handling outgoing container;
- processing of documents.

Schematically this process is presented on Fig.4.

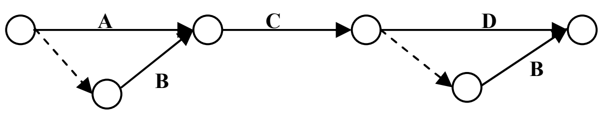

Figure 4: Process of container transshipment at port of Riga

Each stage in Fig.4 corresponds to a concrete function: B1 – processing of documents for incoming container, B2 – processing of documents for outgoing container, C – storage, D – handling of outgoing container.

Decomposition of functions is shown on example of LF „Handling of outgoing container". This function consists of set of following logistic operations:

- receiving truck number and sending the truck for loading
- registration of loading in IT system of terminal
- generating PIN code for loading;
- loading of container.

Schematically function "Handling of outgoing container" is presented on Fig.5.

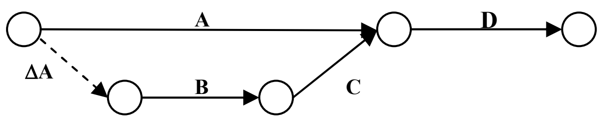

Figure 5: Logistic Function "Handling of outgoing container"

Each edge in Fig.5 corresponds to the concrete logistic operation: A – receiving truck number and sending the truck for loading, B – registration of loading in IT system of terminal, C – generating PIN code for loading, D – loading of container.

Decomposition of all elements of logistic system (route) has been similarly executed, which has allowed to define cost of transportation of cargo, using the formula (6), and to calculate time of cargo transportation from 1 in 4 (see Fig.2), having defined a critical way of the obtained graph of logistic operations.

As an example, results of calculation of duration of performance of separate logistic function «Handling of outgoing container», considered above are given. Durations of performance of separate operations of function are presented in Tab. 2.

Table 2: Operation inside the function "Handling of outgoing container"

Logistic Operations	Duration, minutes
A – receiving truck number and sending the truck for loading	60
ΔA – waiting time	10
B – registration of loading in IT system of terminal	15
C – generating PIN code for loading	10
D – loading of container	80

As can be seen in Fig.5, critical way AD for the presented graph is equal 140 minutes. In a similar way, a critical ways for all functions, processes, subsystems and logistic system as a whole are calculated. Results of calculations of two basic indices of efficiency of the chosen routes of freight transportation: transportation costs and transportation time – are presented in Tab. 3.

Table 3: Efficiency indices of logistic systems

Route, LS_j	Transportation cost, USD	Delivery time, days
1	8400	40
2	5800	25
3	7300	57

It is easy to notice that 2nd route has the best efficiency indices, both on delivery time, and delivery cost. Rather frequently it is not possible to receive such unanimity of criteria (see for example, indicators of efficiency of 1st and 3rd routes). In this case higher priority between price and delivery time should be chosen.

5. MODELLING OF BUSSINESS PROCESSES IN MULTIMODAL TRANSPORTATION SYSTEMS USING BPWIN PACKAGE

For carrying out a business analysis of multimodal freight transportation system, a modelling methodology IDEF0 is proposed by authors. It considers elements of the system (processes, functions and operations), required resources and gained results (Repin 2004). IDEF0 notation is one of the most popular for today and has a number of advantages: simplicity of documenting of processes; completeness of description of business process (management, information and material streams, feedback); integrated approach to decomposition (migration and tunneling of arrows); possibility of aggregation and detailed elaboration of data flows and the information (division and merge of arrows); presence of firm requirements of the methodology, providing reception of process models of a standard kind.

Realization of suggested approach is performed using BPWin software package, where modelling tools of three basic business aspects: processes/functions (IDEF0 notation), data flows (DFD notation) and workflows (IDEF3 notation) are realized (Hunt 1996.).

The usage of modelling methodology IDEF0 in BPWin is illustrated on an *example of transshipment process at Riga Port*. The diagrams, characterizing interrelation of separate elements of business processes at various levels of detailed elaboration, are constructed using BPWing tool.

In Fig.6 the contextual diagram of process of transshipment, where the basic inputs and outputs are shown, is presented. The container on a vessel arrives to the terminal where instructions and requirements from clients come. On an output of the process – the container loaded onto truck. Container handling at the terminal is performed using special equipment basing on internal instructions.

In Fig.7 container transshipment process is presented by a set of functions. In the offered statement of a problem, with accepted level of detailed elaboration, the following logistic functions for transshipment problem are stand out: handling of incoming container, storage, handling of outgoing container and processing of documents.

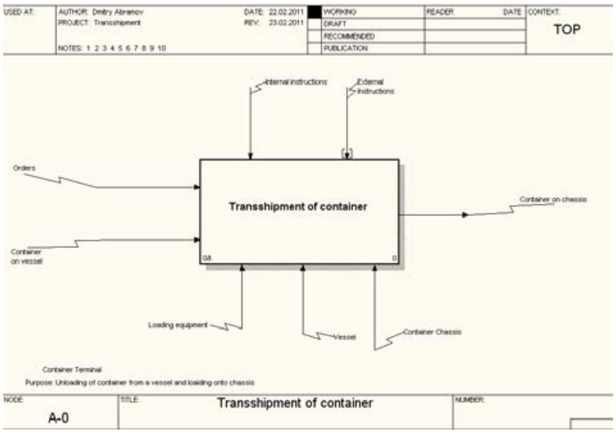

Figure 6. Context diagram of transshipment process

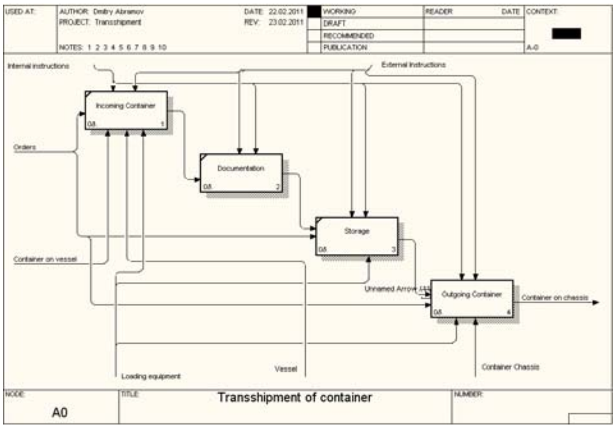

Figure 7: Functions of transshipment process

Further decomposition of function onto separate operations is performed too. In Fig.8 LF "Handling of outgoing container" is presented as a set of operations.

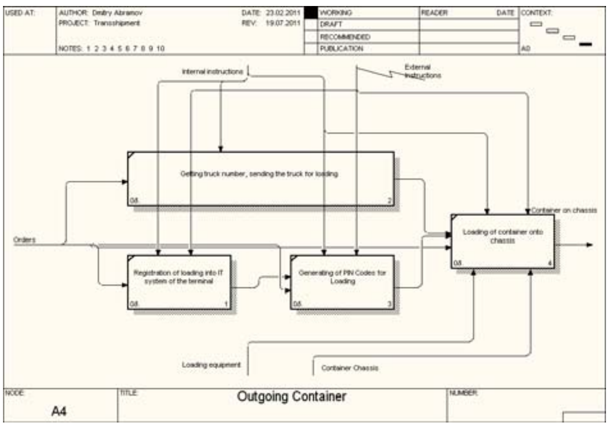

Figure 8: Function "Handling of outgoing container"

CONCLUSIONS

The constructed model of multimodal transportation system allows calculating total costs for freight transportation and total delivery time over considered routs. The received results allow choosing the most favorable route for which the indicator of system's efficiency has the optimal value.

The usage of the methodology IDEF0 in BPWin allows to describe business processes of the transportation chain as whole and to work out corrective actions to improve the transportation system.

Further guidelines of the current research are the following: to find an optimal solution of the transportation problem using the simulation approach; to consider the cases with different optimization criteria.

REFERENCES

Hunt V. D., 1996. *Process mapping. How to reengineer your business processes*. John Wiley & Sons, Inc.

Ghiani, G., Laporte, G., and Musmanno, R., 2004. *Introduction of Logistic Systems Planning and Control*. John Wiley and Sons. England.

Lukinsky V., 2008. *Models and methods of the theory of logistic: the Manual*. St.Petersburg: Piter (In Russian).

Novitsky N., 2004. *Network planning and production management.* Moscow: Mir (In Russian).

Repin V.V., 2004. *Process Approach to Business Process Modelling Management*. Standarti i Kachestvo. Moscow (In Russian).

Saaty T.L., 2001. *Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World*, New Edition (Analytic Hierarchy Process Series, Vol. 2), RWS Publications.

Weske M., 2007. *Business Process Management. Concepts, Languages, Architectures*. Springer-Verlag-Berlin Heidelberg.

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