

MATHEMATICAL MODELLING AND PARAMETERS CALCULATIONS IN MULTIMODAL FREIGHT TERMINAL NETWORKS

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Abstract: *There are presented the mathematical models, routing algorithms and calculation algorithms for cargo flows in transport-terminal road-air-railways networks of multimodal transport operators.*

Key words: *Multimodal cargo operators, transport-terminal networks, optimal delivery routing, terminal, interterminal and withinterterminal cargo flows, planning, algorithms, software*

1. Introduction

Increasing consumer demand for transport services for door-to-door service (door-to-door cargo delivery) makes the relevant requirements to the members of the transportation process like a freight-forwarder companies which serve and extend the services what provided by an air company for the benefit of commercial customers. Freight-forwarding companies are freight transportation agents, perform services for customs clearance, handling of goods, mutual settlements, etc. A huge number of freight-forwarder companies which serve air-freight operations, offer organization services of road transportation and railway transportation. Large freight-forwarder companies have own terminal networks what consist of cargo distributional and sorting centers, organize distributional centers at the airports and railway stations, build their own network of road, air and railway transportation. Logistics and transportation companies operate as a multimodal transport operator (MTO) by giving the client their own (not from an agency) waybill.

Among the variety of services offered today by multimodal operators, there are two main types of service: express delivery and economy delivery. In the first case, the basic requirement of customers is the minimum time and reliability of delivery with reasonable rates. In the second case - a minimum transportation cost at reasonable requirements to transit time. Express delivery uses air transport mostly. Road transport is used for initial and final stage of express door-to-door transportation. Road and rail transport is used less often at initial and intermediate stages (between two air

transportation) express delivery, only in certain areas and coordinated schedule. Conversely, economy shipping uses mainly road and railway transport for transportation between terminals. Air transport is used only in certain areas.

Competitiveness of multimodal operators is determined by their capacity to present the widest range of services for today and to comply with the diverse requirements of customers. Economy shipping is relatively cheap but long and express delivery is fast, but expensive. They can be considered as two extreme options offered by MTO services. There are many intermediate cost and time of delivery options between them. These options are described by the concept of the family of L-shortest routes on the network MTO for different values of parameters $L = 1, 2 \dots$ and a variety of criteria as a the minimum cost, minimum distance or the time of delivery. Optimal routes match value $L = 1$. If $L = 2$, route is calculated by the second most important (by rank) the objective function and etc.

In this article we develop a mathematical model of the three-modal transport terminals network (TTN), i.e. it consists of three types of transport (road, air and rail). This model and the algorithms help to calculate the optimal L-shortest routes, what are optimal according to various criteria including customer preferences. Also they help to simulate the processes of delivery and distribution of freight flows to the optimal routes with a specified schedule. The modeling function TTN with different modes can be obtained data describing the effectiveness of a decision management solutions (such as flight schedules), related to the

organization of transportation by a carrier company, revealed the most "narrow" places of the organization of freight forwarding services in transport terminals network.

The issues of modeling and optimization what are close to the purposes of this article are considered in [1-6] articles.

2. Mathematical model of the three-modal transport terminals network - basic version

The structure of the network.

Transport terminals network is a set of nodes and arcs. Network nodes are its terminals. Network arcs are transport routes which connecting the two terminals. Nodes are the distribution centers (DC), which made for handling and sorting of cargo for transportation. There are two types of DC- head distribution center and gateway DC (GDC). Head DC works with customers directly (shipper and consignee). Also it performs auto-service by regular road routes between each other and collects the goods from the shipper (the initial stage of carriage) and the final recipients delivery [2]. The gateway distribution centers are designed to transmit (and receive) cargo from main line carrier of aviation and rail transport. They are located at airports and train station. Air and rail routes link only respective type of gateway DC between each other. Transportation between head DC and GDC are carried out by road.

Basic transport terminals network, what is considered in the examples of this article and implemented in the software package, consists of three interrelated parts - the central (fig.1 – fig. 2), eastern and western.

The central part of the transport terminals network covers the European part of Russia and consists of 17 head DC what are linking their regular networks of road routes (fig. 1), 8 GDC to air network and air routes which linking the gateway terminals of air network (fig. 2). Terminal designations indicated in the fig. 1-2, comply with the Civil Aviation (IATA) designation of the city where they are located - St. Petersburg, Moscow (North and South terminals), Voronezh, Rostov-on-Don, Krasnodar, Nizhny Novgorod, Kazan, Yaroslavl, Samara and Yekaterinburg. Air network nodes connected network (arcs) flight routes.

The eastern part of transport terminals network consists of 7 head DC in major cities of Siberia and

the Far East of Russia, 7 gateway DC to aviation network (at local airports), 7 gateway terminals to the rail network (at the local railway station) and connecting them network of routes. Network of automobiles connects to the central part of the transport terminals network through the head DC in Yekaterinburg and Omsk, and then in the direction of the Trans-Siberian Railway to the head DC in Omsk to head DC in Novosibirsk, Krasnoyarsk, etc. up to Vladivostok. Road transportation between head DC is made only by transshipment through intermediate head terminals. The rail network route connects the railway gateway DC in St. Petersburg, Moscow, Yekaterinburg, which related to the central part of the transport terminals network, with the DC of approach in Siberia and the Far East of Russia. The rail routes connect head DC in Moscow and St. Petersburg with all the regional gateway terminals towards the East. Each GDC in the eastern part connects with other GDC directly by rail route. Exit to the western part of transport terminals network through the rail network via gateway DC "Moscow" train route what is connecting it with GDC "Berlin." Eastern network routes of aviation are connected with the central part of the transport terminals network through aviation GDC in St. Petersburg and Moscow (two terminals North and South), Krasnodar and Yekaterinburg (shown in fig.2). Air links within the eastern part are made through GDC in Novosibirsk and Krasnoyarsk.

The western part of the transport terminals network consists of 7 head DC in Western Europe (Helsinki, Berlin, Frankfurt am Main, Hamburg, Rotterdam, Paris, London), 6 gateway DC to aviation network (at local airports, with the exception of head DC in Hamburg and Rotterdam, which have joint DC of approach to aviation network in the Amsterdam airport) , 1 gateway terminal to the rail network (at the Berlin train station) and connecting them the network of routes. Network of automobiles connects to the central part of the transport terminals network through head DC in St. Petersburg and two terminals in Moscow (road routes to Helsinki and Berlin). Western aviation network routes related to the central part of transport terminals network through aviation head DC in St. Petersburg and Moscow (North terminal and south terminal), (fig. 2).

Air routes connect these terminals to each of the six GDC of western transport terminals network. Air links within the western part of TTN are made through transport terminals network of Helsinki Airport and Amsterdam Airport.

In total, transport terminals network basic version contains $n = 31$ head DC, $nav = 21$ terminals of approach to aviation network and $nRS = 11$ terminals of approach to the rail network.



Fig. 1. The central part of TTN. Head DC and car route network



Fig. 2. Central part of TTN. Gateway Distribution centers to airline network and aircraft fleet

Transport terminals network schedule and rates.

Road, air and rail transport routes are described equally bellow. We can add array *ScheDat* [*i*, *j*] in the logistics information system «*MultiTransNet*», what contains information about the routes interterminal transportation schedule (*ScheduleData*). Here “*i*” is routing code in the schedule and “*j*” is parameter routing. Variables like *ScheDat* [*i*, 1] are denote the code of departure DC, *ScheDat* [*i*, 2] - destination DC code, *ScheDat* [*i*, 3] – code of the type of scheduling, *ScheDat* [*i*, 4] - the time of departure, *ScheDat* [*i*, 5] – transit time of route. All timing parameters are set in minutes. Schedule is attached to the weekly cycle. Schedule type allows interterminal routes with different departure days of the week:

- Code 0 means the daily schedules of departure
- Code 1 - 6 days of departure (except Sunday)
- Code 2 - departure on even days,
- Code 3 - departure on odd days,
- Code 4 - departure for the third and second days of the week.

Fares (USD / kg) are given by the matrix of cost

$$C = C [i, j]$$

diagonal elements of $C [i, i]$, which means the rates for terminal handling in the *i*-th terminal, and the off-diagonal elements when $i \neq j$ - interterminal rates for transportation.

A matrix of distances on roads (km) between nodes (head DC and DC of approach) of the network is also refers to the network. If the terminals are not connected by direct routes, the distance and the corresponding elements of cost matrix are equal to infinity.

3. L-optimal tariff and distance routing

We introduce the quantities $U_r^k [i]$ as a length of *r*-th shortest route, $r = 1, 2, \dots, L$ from the *i*-th node to the fixed end node i_k of the network with numbers of intermediate nodes up to *k*. Generic term "node", "length", "shortest route" are used in the general definitions here and throughout the article. But the route length means its value (price, \$ / kg) or distance (rally, km) in this section, and length means the time of delivery in the next section. When the route calculation parameter $k = 0, 1, \dots, (n-2)$, it also has the meaning of the iteration number, where *n* is the total number of nodes.

Values $U_r^k [i]$ are defined by the following recursive equations:

$$U_r^k [i] = \min_r \left\{ C[i, i] + C[i, j] + U_{\mu}^{(k-1)} [j] \right\} \quad (1)$$

$$i = 1, 2, \dots, n$$

Here and below, the symbol \min_r is the *r*-th smallest (*r*-th minimum, grade) set of numbers in curly brackets. The set of numbers is formed by sorting of all nodes $j \neq i$, connected by arcs (interterminal routes) with the *i*-th node and the length of μ -s shortest routes $U_{\mu}^{(k-1)} [j]$ from node *j* to node i_k , what is calculated on the previous (*k*-1)-th iteration. The initial conditions for these equations are determined with $k = 0$ by the expression

$$U_r^0 [i] = C[i, i_k] + C[i, i] + C[i_k, i_k], \quad r = 1 \quad (2)$$

When $r \neq 1$, or if the nodes *i* and i_k are not directly related arcs, the $U_r^0 [i]$ meanings are set equal to the infinity.

Computation of the L-optimal routes leading from a given initial node i_0 to a fixed end node i_k is performed after the calculation of the target functions $U_r^k [i]$ with $k = (n-2)$. The calculations are similar to the procedure described in [2]. Bust rank values $r = 1, 2, \dots, L$ defines a family of L-optimal tariff routes.

L-optimal by a minimum distance routes are calculated by the algorithms, putting the cost of the matrix equal to the matrix of distances by road between terminals. L-optimal routes by tariffs and distance (as opposed to the optimal time) do not depend on the timing of the transport terminals network, the time and day of cargo arrival at the departure terminal.

4. Calculation of L-optimal time of delivery routes

This type of routes tied to a schedule of regular interterminal transportations what depend on parameters of the schedule and the arrival of the cargo to the original departure terminal. Algorithm of the search is complicated by the emergence of new variables. Enter the quantities $U_r^k [l, t, i]$ that is the length of *r*-th shortest route, $r = 1, 2, \dots, L$ (a minimum time of delivery) from the *i*-th terminal to the end terminal i_k , providing that the route contains no more *k* intermediate terminals, and

cargo arrived to the i -th departure terminal at the time t days l -th day of the week, $l = 1, 2, \dots, 7$.

T is discrete variable, what appeared as a result of the discretization of continuous time of the day with a step dt . There is $dt = 10$ min, discrete time is set to 0, 1, ..., 144 in the program. Further, all the temporal characteristics of the transport terminals network (time of arrival at the terminal, departure, duration of the interterminal routes, and the meaning of function $U_r^k[l, t, i]$) is measured in minutes. Variables $U_r^k[l, t, i]$ are related by the equations

$$U_r^k[l, t, i] = \min_r \{ T[l, t, i, j] + U_{\mu}^{k-1}[l_j, t_j, j] \}, \quad (3)$$

$$r = 1$$

Here $T[l, t, i, j]$ is the time of cargo delivery from the i -th to the j -th terminal, by a schedule what is determined by the regular service, provided that the cargo have arrived to the i -th terminal with arrival parameters (l, t) . If there is no direct flight between the i -th and j -th nodes in the, this value is equal to infinity; l_j and t_j are day and the daily arrival time to the j -th terminal. The parameter $k = 1, \dots, (n-2)$ has the same meaning as in the equation (1).

The initial conditions with $k = 0$ for equations (3) have the form

$$U_r^0[l, t, i] = T[l, t, i, i_k], \quad \text{if } r = 1 \quad (4)$$

If $r > 1$, or there is no direct interterminal flights between the i -th and j -th points, the values of the functions $U_r^0[l, t, i]$ are set equal to infinity.

Gasket L-optimal route by delivery time is the reverse motion procedure [2]. Time optimal routes depend on the day of the week and the time of cargo arrival to the departure terminal in contrast to the optimal tariff routes. In addition, the existence and uniqueness of the routes can be violated.

5. Calculation of freight flows in the three-modal transport terminals network

Input freight flows are modeled in the matrix form

$$X_{inp} = (X_{inp} [i, j]), \quad i, j = 1, 2, \dots, n = 31,$$

$$\text{if } r = 1$$

elements $X_{inp} [i, j]$, which determine the amount of weight (kg / day) sent from the region maintained by the i -th distribution center (DC) to the j -th terminal region. The input traffic is calculated by the equation

$$X_{inp} [i, j] = \alpha \text{Population}[i] \lambda_{i,j} \quad (5)$$

where the parameter α is the mean amount of weight (kg / (1000 people a day)) sent by a company a day from every 1,000 people in the region, the array $\text{Population}[i]$ contains population data of the region i -th DC in thousands of units, coefficient $\lambda_{i,j} \in (0, 1)$ means proportion of the total freight flow what is coming from the i -th region and being routed to the j -th region. The example assumed $\alpha = 3$ kg / (1000 people a day). Coefficients $\lambda_{i,j}$ satisfies the normalization condition

$$\sum_{j=1}^n \lambda_{ij} = 1, \quad \lambda_{ij} = 0 \text{ for } i = j$$

The numerical values of weights $\lambda_{i,j}$ are selected in proportion to the population of the region

$$\lambda_{i,j} = \text{Population}[j] / (U - \text{Population}[i])$$

which sent freight to. Here U is a total population of all regions covered by the transport network. The condition $\lambda_{i,i} = 0$ means that the freight flow in the direction $i \rightarrow i$, maintained out of the terminal network is excluded from consideration, $X_{inp}[i, i] = 0$.

Interterminal network freight flow (kg / day) is given by the matrix

$$\text{NetFl} = (\text{NetFl}[i, j])$$

its elements are calculated as the total flow path in the direction of the i -th terminal to the j -th (the arc (i, j)) along the optimal route $M_{opt} [l, m]$, which connects the initial l -th and m -th end nodes

$$\text{NetFl}[i, j] = \sum_{l=1}^n \sum_{m=1}^n X_{inp} [l, m], \quad l \neq m \quad (6)$$

The summation of input flow $X_{inp}[l, m]$ is performed by all optimal routes $M_{opt} [l, m]$, that includes the arc (i, j) . Computing algorithm of the value of network flows performed by calculation the (first) best route $M_{opt} [l, m]$ from node l to node m , assigning to all the flow values $\text{NetFl} [i, j]$ of all the arcs along the route $M_{opt} [l, m]$ of the input flow $X_{inp}[l, m]$ and sum over all the values of the input l and output m . The flow $\text{NetFl} [i, j]$ is the volume of traffic (traffic in kg / day), operated by the company in the direction of (i, j) . Its value is

required for selecting the vehicle and flights planning, which ship in the direction from the i -th terminal to the j -th terminal.

Terminal (node) flows determine the operation of terminal network as transshipment points. Flows (total in both outgoing and incoming flights) of local shippers (index "mgo") and consignees (index "mgp") in the i -th node are determined by

$$X_{mgo}[i] = \sum_{j=1}^n X_{inp}[i, j] \quad (7)$$

$$X_{mgp}[i] = \sum_{j=1}^n X_{inp}[i, j] \quad (8)$$

Total input (index "input") and output (subscript "output") flows through the i -th terminal are determined by

$$F_{ex}[i] = \sum_{j=1}^n NetFl[j, i], \quad (9)$$

$$F_{bbx}[i] = \sum_{j=1}^n NetFl[i, j]$$

These flows define the scope of work fronts unloading and loading. Transit traffic of the transport terminals network equal

$$F_{mp}[i] = F_{ex}[i] - X_{MTI}[i]$$

or

$$F_{mp}[i] = F_{bbx}[i] - X_{MTO}[i]$$

6. Calculation of in terminal freight flow of transport terminals network

The structure of the technological areas of department sorting terminals includes K receptions areas to serve the arriving flights, and the same number of shipping platforms maintaining departing flights (because of the symmetry of transport interterminal bonds) [2]. Receiving and shipping areas form unloading and loading fronts. A detailed description of the freight flow inside the terminals (head DC and gateway DC) is determined by the matrix

$$CrFl[i] = (q_{rs}), r, s = 0, 1, \dots, K,$$

where i is the number (code) of the terminal, which is not considered in the notation of elements of the

matrix, zero index is assigned to the local freight flows; q_{os} is a flow of local shippers which sent for loading to the flight of s -th shipping area; q_{r0} is a flow for local consignees arriving on the r -th arrival reception area; q_{rs} - transit freight flow for $r, s = 1, \dots, K$, passing through the terminal from the flight what arrived to the r -th reception area to the flights what is departing from s -th shipment site. All flows have the dimension kg / day.

Flights from certain "adjacent" terminal (or a particular terminal) are assigned for each of the receiving and shipping areas. Denote $j_{pr}[r]$ as a code of adjacent terminal. The flight from this terminal is discharged at r -th receiving area. $j_{opr}[s]$ is a code of adjacent terminal. The flight to this terminal is sent from s -th shipping area. These flights form interterminal transport routes in directions $j_{pr}[r] \rightarrow i, i \rightarrow j_{opr}[s]$. With their help we can calculate the flow.

Equals (6) - (8) are used in the calculation, but the terms of summing are different every time. Flows q_{os} of local shippers are calculated by formula (7); values of the outgoing from the i -th terminal stream which is sent to the j -th end terminal for the best route $M_{opt}[i, j]$, containing an initial route $i \rightarrow j_{opr}[s]$ are accounted. Flows of the local consignees q_{r0} are distributed to the receiving area in accordance with the formula (8) similar, where the summation is only over the terminal j , coming from the best route which $M_{opt}[j, i]$ ends by route $j_{pr}[r] \rightarrow i$.

Transit (cross) q_{rs} flows are calculated by formula (6), where the sum of input streams sent from l -th terminal to the m -th is performed only if the optimal route what is connecting them $M_{opt}[l, m]$ contains two adjacent interterminal route $j_{pr}[r] \rightarrow i, i \rightarrow j_{opr}[s]$.

7. Logistics information system «MultiTransNet»

Previous algorithms are a basis for information and logistics system (ILS) «MultiTransNet», developed at the department of intermodal transport and logistics in Saint-Petersburg State University of Civil Aviation. Software package allows calculating and displaying the entire set of L-optimal routes and their characteristics with a given direction (from the i -th to the j -th terminal); through rate of the route, delivery time and full-time schedule of the customer order transportation with the arrival-departure schedule at intermediate

terminals. The client chooses the route that suits for him from a variety of L-optimal routes (fig. 3 - 5). The routes that are selected by the customer are the source for solving the problem of simulation transport terminals network. Network parameters are entered in the Main Menu mode "Basic version of the transport terminals network", "The schedule", "Online database."

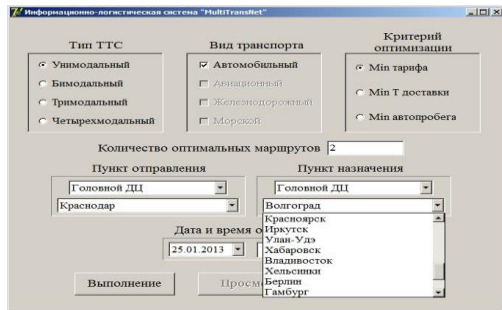


Fig. 3. Input your search entry form L-optimal client shipment routes

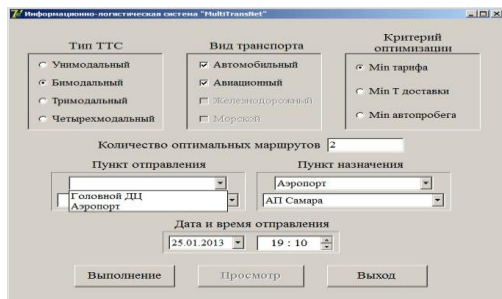


Fig. 4. Entering search parameters of L-optimal routes client items for bimodal transport

Тип маршрута: Автомобильный; Критерий оптимизации: Min тарифа, Min автопоезда (пункт отправления - Санкт-Петербург, пункт назначения - Воронеж)

	Пункт - 1	Пункт - 2	Пункт - 3	Пункт - 4	Пункт - 5
1 маршрут Тариф маршрута = 43,125 руб/кг Дата и время отправления 13.02.12 15:00 (поиск/выполнение) Дата и время прибытия 15.02.12 15:00 (оргал)	Санкт-Петербург	Москва	Воронеж		
2 маршрут Тариф маршрута = 92,2 руб/кг Дата и время отправления 13.02.12 15:00 (поиск/выполнение) Дата и время прибытия 16.02.12 15:00 (сезон)	Санкт-Петербург	Москва	Москва	Воронеж	
3 маршрут Тариф маршрута = 71,375 руб/кг Дата и время отправления 13.02.12 15:00 (поиск/выполнение) Дата и время прибытия 16.02.12 14:00 (сезон)	Санкт-Петербург	Москва	Брянск	Воронеж	
4 маршрут Тариф маршрута = 75,075 руб/кг Дата и время отправления 13.02.12 15:00 (поиск/выполнение) Дата и время прибытия 16.02.12 14:00 (сезон)	Санкт-Петербург	Москва	Саратов	Воронеж	
5 маршрут Тариф маршрута = 80,45 руб/кг Дата и время отправления 13.02.12 15:00 (поиск/выполнение) Дата и время прибытия 19.02.12 14:00 (поиск/выполнение)	Санкт-Петербург	Москва	Москва	Брянск	Воронеж

Fig. 5. Search results L-optimal routes of client items

Route calculation is carried out in the procedures and *MatrShortRoute* and *OptTimeRouteNew*.

Imitation modeling block reproduces the minute change in the current data of the freight flow in the transport terminals network with time *dt*, the change of day and days of the week, the emergence of transportation orders on all terminal centers (16 orders per day at each of the n terminals are simulated in this example). Procedures which are forming unit perform the following functions:

- Modeling and storing of basic order parameters (DC of departure, destination, departure weight - procedure *ShipmentSimulator*), modeling of flight departure for the entire network in accordance with the schedule (procedure *DepartureOrder*);
- The distribution of orders for flights according to the selected transportation routes and forming cargo manifest for each flight, arrival flight schedule to the appropriate destination terminal (procedure *ArrivalOrder*);
- The order tracking on the terminal network with the issuance of notice of arrival to the intermediate terminal and a notice of delivery to the final destination terminal (procedure *ArrivalProcessing*);
- Calculation of input (procedure *InputFI*), network (procedure *NetworkFI*) and node (procedure *NodeFlow*) freight flows.

There are a matrix (*Xinp*) of daily freight flows from the first terminal (Saint-Petersburg) to the second terminal (Moscow, southern terminal), third terminal (Moscow, northern terminal), fourth terminal (Voronezh), fifth terminal (Rostov-on-Don), etc., as well as total outbound daily flow *SumInpFlow* from the first terminal (Saint-Petersburg) and the rest of the terminal on the fig. 6. Here and below, all the traffic flow data have the dimension kg / day.

Cargo traffic of network of transport terminals inside the terminal is shown on fig. 7.

Fragment of matrix *NetFI* [*i*, *j*] of network (interterminal) freight flow on directions from Saint-Petersburg terminal to the same terminal points has the form

	2	3	4	5	SumIshFlow
	9885.00	13595.00	0.00	0.00	27568.00

Оперативная база Отчеты Выход

Информационно-логистическая Система «МилТ Експресс»

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Входные грузопотоки

Терминал	Самар. Петербург	Москва (Южная)	Москва (Северная)	Воронеж	Ростов-на-Дону	Краснодар	Саратов	Волгоград	Астрахань	Воронеж	Иркутск	Новый Новгород	Казань	Самара	Екатеринбург	Муромск	Арзамас
Самар. Петербург	0	3 034	3 034	285	1 079	1 079	427	371	350	371	407	285	1 079	1 079	1 035	489	427
Москва (Южная)	3 034	0	4 289	470	910	910	363	485	300	485	316	470	910	910	1 931	424	363
Москва (Северная)	3 034	4 289	0	470	910	910	363	485	300	485	316	470	910	910	1 931	424	363
Воронеж	285	470	470	0	142	142	96	79	47	79	90	142	142	142	241	66	66
Ростов-на-Дону	1 079	910	910	142	0	196	77	100	64	100	110	142	196	196	330	90	77
Краснодар	1 079	910	910	142	196	0	77	100	64	100	110	142	196	196	330	90	77
Саратов	427	363	363	96	77	77	0	41	25	41	43	96	77	77	131	36	36
Волгоград	371	485	485	79	100	100	41	0	34	34	34	79	100	100	175	48	41
Астрахань	350	300	300	47	64	64	25	34	0	34	34	47	64	64	100	30	25
Воронеж	371	485	485	79	100	100	41	34	0	34	34	79	100	100	175	48	41
Иркутск	407	316	316	90	110	110	43	36	36	0	0	110	110	110	196	51	43
Новый Новгород	285	470	470	194	142	142	96	79	47	79	90	9	142	142	241	66	66
Казань	1 079	910	910	142	196	196	77	100	64	100	110	142	0	196	330	90	77
Самара	1 079	910	910	142	196	196	77	100	64	100	110	142	196	0	330	90	77
Екатеринбург	1 035	1 931	1 931	241	330	330	131	100	175	100	110	241	330	330	0	192	131
Муромск	489	424	424	66	90	90	36	48	30	48	51	66	90	90	192	0	36
Арзамас	427	363	363	66	77	77	30	41	25	41	43	66	77	77	131	36	0
Суммарный грузопоток	21 244	18 026	18 026	3 496	4 730	4 730	1 928	2 034	1 902	2 034	2 714	3 496	4 730	4 730	7 796	2 040	1 928

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Fig. 6. Matrix Xinp of input of daily traffic

Матрица внутритерминальных потоков

Терминал

Площадки отправления / Площадки прибытия	Площадка № 0 Местные грузополучатели	Площадка № 1 Рейс на терминал: Москва (Северная)	Площадка № 2 Рейс на терминал: Казань	Площадка № 3 Рейс на терминал: Екатеринбург	Суммарные потоки	Транзитные потоки
Площадка № 0 Местные грузоотправители		3234,00	272,00	265,00	3771,00	3771,00
Площадка № 1 Рейс из терминала: Москва (Северная)	3296,00		0,00	5555,00	8851,00	5555,00
Площадка № 2 Рейс из терминала: Казань	272,00	0,00		0,00	272,00	0,00
Площадка № 3 Рейс из терминала: Екатеринбург	265,00	5301,00	0,00		5566,00	5301,00
Суммарные потоки	3833,00	8535,00	272,00	5820,00	18460,00	14627,00

Fig. 7. Matrix CrFl[i] intra-terminal TTN

indicating the total upstream *SumIshFlow* (kg/day) from Saint-Petersburg.

Maximum daily flow in the transport terminals network is 16 170 kg and has the direction 2 → 3 (Moscow-South→ Moscow-North). The minimum flow is 36 kg / day and falls on the route 16 (Murmansk) → 17 (Arkhangelsk).

Nodal flow (input - INPUT, transit - TRANSIT, output - OUTPUT, local recipients - LocalRecip, local shippers - LocalShipper) through Saint-Petersburg DC are

INPUT		TRANSIT	OUTPUT	
<i>SumInp</i>	<i>LocalRecip</i>		<i>SumOut</i>	<i>LocalShipper</i>
27568.00	21244.00	6324.00	27568.00	21244.00

8. Simulation of multimodal TTN in information and logistics system

Block simulation reproduces the change for minutes the current traffic flow data in the TTN in increments of time *dt* change of day and days of the week, their average of orders for transportation in all main distribution centers in ILS MultiTransNet are daily occurrence (n-1) new order (each n= 33 terminals per day) and transporting them to the best routes through TTN and etc. functions.

Block's work of ILS is carried out in the following order.

- 1) Parameters of TTN, characterizing the used modes of transport - quantity of GDC *n*, the number of terminals approach aviation *nav*, rail *nRS*, marine *nSP* and their total number of *nsum*: = *n* + *nav* + *nRS* + *nSP*. The data is an array, the elements of which *ModTr[i]* describe terminal belonging to a particular mode of transport.
- 2) Calculate optimal routes, linking each of the GDC with other GDC according to the criteria of a minimum rate or time of delivery. These routes form a database of routes (DBR) - matrix (1). Routes are written to an array of *RoutTarif*. The total number of routes is $n * (n - 1) = 33 * 32 = 1056$.
- 3) Run *DepartureOrder* and *ArrivalOrder* procedures. These procedures shall govern the departure and arrival of the flights schedule within days. The results of those procedures are *DepOrd* and *ArrivOrd* arrays, containing codes

flights schedule in order of their departure and arrival respectively.

- 4) Are set to initial values timing simulation model: *T* - current time (mins.); *dt*=1min - time discretization step; *Tmod* - model time (mins.); *chimsut* - the current number of nights at the time of the Model *T*; *chimWDa*, *chimmin* - the current day of the week and the number of minutes within 24 hours at the time of the modeling *T*.

These values are consistently changed the program in process simulation.

- 5) Start procedure *ShipmentSimulator*, that modeling and memorization of basic parameters of shipments. The current values of these parameters are written to an array of *DataShipm*. Its elements are:

- *StrData* - the line number of the data record was sent;
- *DataShipm[StrData, 0]* := *CodShipm* -code send;
- *DataShipm[StrData, 1]* := *i* - code of the terminal, at which the cargo is in the moment *T*, the starting point here is the code of the original terminal of departure accepting the goods for carriage;
- *DataShipm[StrData, 2]* := 0 - status parameter, its value to zero means that the terminal is sending, in anticipation of, otherwise, this variable indicates the code flight carrying the shipment;
- *DataShipm[StrData, 3]* := *round(Xinp[i,j])* - the number of the shipment of the *i* -th terminal in the *j*-th;
- *DataShipm[StrData, 4]* := *T* - is the time (in minutes) the taking over of the goods;
- *DataShipm[StrData, 5]* := *int* - route code from database DBR, which this posting must be carried; string array *RoutTariff[int, i]* contains full record route, as the terminal sequence of codes through which should be sending.

Fill the array with new data on shipments occurs every day at the time of *Timsh* = 720 minutes (or at the moment of reception of the order, when the data entry form).

The input of new postings on the examples set 30 days. The total number of items generated in ILS during this time is the amount $(33 * 32 = 1056) * 30 = 31680$ u.

- 6) Will start flights on departure in accordance with the procedure established by the DepOrd array. Is used the logic that controls the day of days of departure to the declared type of the schedule of the voyage. When is the moment of departure (interterminal) flight schedule code $J := DepOrd[LDep]$, is the new record flight parameters in database “Flights on the way”. This database is in an array *DataRejVPuti*. Array elements (new line records) indicate the following:
- *ChRejVPuti* - the line number of the record is generated at the time of departure;
 - *DataRejVPuti[ChRejVPuti, 0] := CodRejs* - code (the voyage in the general list of simulated flights) new to be sent at the moment of the flight;
 - *DataRejVPuti[ChRejVPuti, 1] := j* - the code of the flight schedule database;
 - *DataRejVPuti[ChRejVPuti, 2] := T* - is the time of departure.

Parameter *ChRejVPuti* also means the current array dimensions *DataRejVPuti* the total number of flights in transit at the current moment.

After the recording of the flight options are search shipments loaded in this flight and the formation of the cargo manifest of the flight. This is the database of current shipments of *DataShipm*. On variable *DataShipm[StrData, 1]* matches your terminal of departure, and on condition *DataShipm[StrData, 2] = 0*, meaning that sending a shipment, select the desired send. Its status code should be written to cruise *DataShipm[1, 2] := CodRejs*.

- 7) View the arrival flight takes place in accordance with the procedure established by an array of *ArrivOrd*. That uses the logic that controls the correct fixation of the arrival of the flight code *CodRejs*. At the moment of the arrival interterminal flight with code schedule $J := ArrivOrd[LDep]$ is the definition of the code *CodRejs* in the database of flight route. For this are string array *DataRejVPuti*. Number *l* of the string is determined by the conditions of $(DataRejVPuti[l, 1] = j)$ and $((T - DataRejVPuti[l, 2]) = ScheDat[j, 5])$.

Code *CodRejs* define equity

$CodRejs = DataRejVPuti[l, 0]$.

Start procedure *ArrivalProcessing* handling the arriving flight. This procedure creates two arrays:

- array *ArrivaList* that contains the list of shipments arriving at the terminal of arrival specified flight;
- array *DestinationList* that contains the list of codes of consignments delivered to the terminal specified flight, as the final delivery terminal (according to the chosen route).

Both lists are drawn up by notices, which are notifications about the arrival of the voyage and cargo and its delivery to the destination terminal on the route of the shipment. At the same time keeps records of the tonnage and total number of delivered shipments.

Line of flight data records at the end of all operations is obliterated in an array *DataRejVPutiFlight* data can be saved for later analysis in the special array-archive.

In the procedure *ArrivalProcessing* is a separate message about the delivery of the latest shipment, adopted by the first day. These data characterize the time transition process *ttrans*, during which a complete filling of the TTN goods. In addition, a message is displayed on the last delivery of the shipment at the end of the work (in the examples on the 30 day) generation procedure of cargo *ShipmentSimulator*. In the example, the generation of dispatches is carried out daily, starting from the first day on the 30-th day.

- 8) Modelling is terminated under clause $T = Tmod = 70 * 1440min$, i.e. after 70 days.

Example 1. Was simulated 4 modal network, beginning Monday, 12:00 pm. Modelling was used previously for the base, optimal routes on tariffs. The program runs 20 seconds.

The notice ARRIVAL NOTICE that controls the transport of send the specified number No. 1201 has the form:

Posting No.1201 arrived at terminal No.4 interterminal flight No.46 (code schedule) on the second day (since the beginning of the simulation), Friday 7:30 pm. Posting follows the route code *CodRoute DataBase = 549*:

Rostov-na-Donu → Volgograd → Saratov → Moscow (Northern) → Kazan → Ekaterinburg → Omsk.

A similar view has notice of the delivery of the shipment to the final destination on the 10th day. Notice of delivery last send generated on the first day, notify its delivery on day 33. This shipment is transported to the longest threemodal route, with 6

points of transshipment. Traffic on this route are carried out using road, rail and marine modes of transport. The transition process t_{trans} , during which a complete filling of the TTN goods is 33 days.

If the routes are used to transport, the best on-time delivery, the transition process (i.e., the more lengthy route) had been reduced from 33 days to 8 days. At the end of the simulation $T_{mod} = 70.00$ days was modeling 25340 flights.

Modeling enables you to identify traffic flows in the TTN with daily departure and arrival and the uneven frequency of shipments on your routes.

9. Conclusion

The problem what is considered in this article covers the important modeling tasks, transport route and freight flow calculation in freight terminal networks of multimodal transport operators. Connecting to interterminal networks what is usually carried out road, aviation and rail routes is not only expands its traffic significantly, but also provides significant opportunities for further diversity of services and routes used. The use of L-optimal routes with different ranks and different criteria (minimum rates and delivery time) provides effective formal selecting routes mechanism, allowing to realize the full transport potential of intermodal transport terminal network. Manager who is working with the customer with the L-optimal routes can offer the customer a range of a routes to suit the maximum extent hardly compatible requirements for cost and delivery time. To access the full database of routes, their timetables and fares on all terminals allows Manager running on a designated Terminal, sell and organize transport throughout the territory and on behalf of the entire network, between the senders and recipients of all other regions. Freight flow calculations for estimated values of the input flows, which express the expected traffic demand, can properly allocate handled cargo resources of MTO - vehicles on interterminal routes, drivers and loaders inside the terminals. All the proposed algorithms are implemented in the form of appropriate software and have been effective.

References

- [1] R.E. Bellman, I. GLICKSBERG, O.A. Gross.: Some aspects of the mathematical theory of control processes. RAND CORPORATION. SANTA MONICA – CALIFORNIA. 1958.
- [2] Palagin U.I.: Logistics-Planning and materials management – SPB: OAO «Izdatel'stvo «Polytechnic», 2009.
- [3] Kryzhanovsky G.A., Palagin U.I.: A simulation model for determining the characteristics of passenger flow in the intermodal transport network//transport: Science, technology, management.-1998.- No. 6, p. 23 – 27.
- [4] Palagin U.I.: Optimal planning of tasks of bringing cargo in and out of several distribution centers//VINITI. Transportation: Science, technology, management.-2010.-No 2.
- [5] Palagin U.I., Mochalov A.I.: Interaction of transport modes in multimodal transport. Part II. Definition of the optimal route for the international carriage of IP "Microsoft AutoRoute"/ SPBGU GA. St.-Petersburg, 2006. 113 p.
- [6] Palagin U.I., Mochalov A.I.: Modeling and optimal planning of delivery of cargoes in transport and terminal operators networks in multimodal transport. Bulletin GUGA, 2011. - No 3.