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INTEGRATED MANAGEMENT OF AUTOMOBILE TRANSPORT-ORIENTED SYSTEMS USING INTERVAL GRAPHS

Paper is devoted to solution of the problems of transport processes planning on the example of the construction industry. New approach to the planning of transport - storage processes is considered, classification of tasks, models and optimization techniques with numerical example are proposed. New approach is based on the model of interval schedules of transportation that contain maximum reserves of time in order to provide organizational flexibility and insensitivity to external disturbances.

Key words: *Autotransport accumulation process, interval graph, reserve of time, route, sequence, traffic diagram.*

1. Analysis of problems of transport and storage processes planning

Actuality and purpose of the research

Nowadays the problem of cargo transportation planning in different spheres of national economy (trade, light industry, construction, etc.) plays an important role. Current approaches, offered by different authors [1, 2], have some drawbacks, complicating their practical application. Accordingly, we can identify the following problems proving the actuality of the given subject:

- Determination of existing approaches to the planning of transport processes, which makes them sensitive, under conditions of frequent disturbances, and as a consequence, lack of practical use, or management only in terms of logistics, that is, planning for one route;
- lack of integrated approach , that is, neglecting productive capacities of the supplier and storage capacity of the consumer, which leads to the impossibility of overall transportation planning processes.

The main purpose of the study is the development of new approach regarding the management of transport and cumulative processes in production on the basis of interval schedules of the traffic.

The purpose of this article is the consideration of new approach in general terms, classification of problems and solution techniques, detailed review of some models with numerical examples.

For transportation processes planning the approach [3] on the basis of interval schedules of transportation (IST) will be used.

IST is called a schedule for each unit of transport in which order of delivery is set (number, route, and the maximum possible or desirable interval of delivery), and intervals (reserves of time) of departure from warehouses and the arrival intervals at the point of destination are calculated. Intervals contain reserves of time to ensure the reliability of transportation, as well as organizational breaks (lunch, shift change, days-off, etc.).

This approach provides the organizational flexibility, that is, providing the opportunity to the driver to solve such problems as traffic jams, minor damage without disruption of the schedule of transportation. The driver is guided by the calculated intervals of departure and arrival. If the driver does not keep in the reserves of time, he reduces the organizational break, focuses on the interval of the order, informs by mobile phone the controller about his next trip with possible recalculation of interval schedule. This approach allows in management tasks to pass from models of logistics, which, in practice information technologies are not used, to the problems of operational calendar planning with the period of 3-10 days.

First, imagine the result, which is to be achieved using this approach. The example of the calculated interval schedule of transportation by vehicles is presented below (Table 1). Interval graphs in the Table contain the following data:

- Delivery intervals - intervals in which the vehicle (TV) must be loaded and leave the supplier;
- Arrival intervals - intervals in which the TV must as soon as possible arrive to the consumer and unload, organizational breaks being taken into account;
- № order and object - input information such as "what and where" to be delivered;
- Maximum intervals of arrival (order) - input information from the dispatcher, which must be used in the case of violations of the calculated intervals of arrival.

Table .1 «Automobile traffic schedule»

Intervals of departure (date / time)		Intervals of arrival (date / time)		№ order	number of the object	maximum intervals (order) of arrival (date / time)	
З	До	З	До			З	До
1	2	3	4	5	6	7	8
Vehicle 1							
10.02/6.32	10.02/8.02	10.02/8.12	10.02/9.32	548	14	10.02/8.00	10.02/11.00
10.02/9.02	10.02/10.32	10.02/10.42	10.02/12.02	525	6	10.02/9.00	10.02/12.00
10.02/11.30	10.02/13.30	10.02/13.00	10.02/15.00	154	1	10.02/10.00	10.02/15.00
Vehicle 2							
10.02/7.00	10.02/8.00	10.02/9.00	10.02/10.00	843	20	10.02/9.00	10.02/12.00
10.02/10.00	10.02/11.00	10.02/12.00	10.02/13.00	245	14	10.02/10.00	10.02/14.00
10.02/13.00	10.02/14.00	10.02/15.00	10.02/16.00	265	15	10.02/12.00	10.02/16.00

For better understanding further graphic representation of calculated schedule of automobile traffic is suggested (Fig. 1).

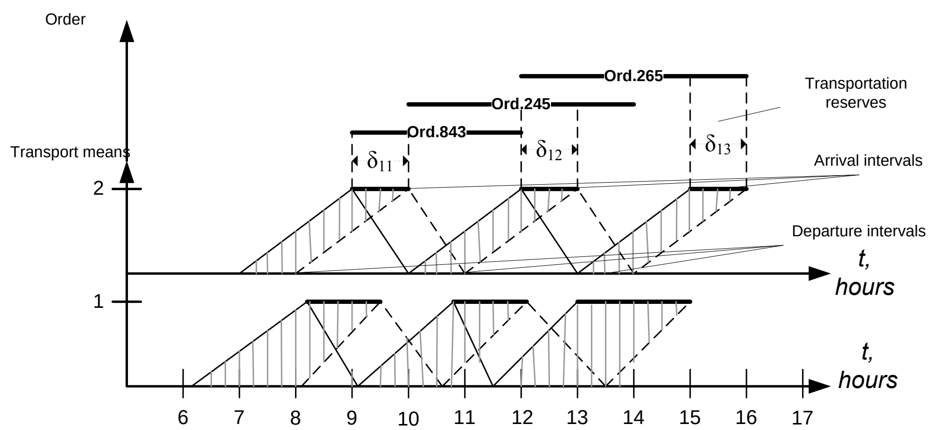


Fig. 1. Automobile traffic schedule

In this graph the intervals of the arrival and departure of vehicles and transportation time reserves in the form of the shaded area, which must be maximized are presented.

Calculated time of arrival of vehicles is specified not in predetermined manner, but by the intervals. This provides a number of the following advantages:

removal of disturbances by the driver alone or together with other vehicles or the manager (without recalculations in the control system), thereby extending the period of administration;

system has high organizational flexibility [4], which can be calculated by the formula $K_{org} = \left(1 + \frac{\sum t_{dawn\ t.} - \sum t_{resev}}{\sum t_{trans}}\right)^{-1} \to 1$, where the idea to replace all technological downtimes , $t_{dawn\ t.}$ by the calculated time reserves t_{resev} relatively total time of transportation t_{trans}

is suggested; the coefficient of organizational flexibility K_{org} can be as close to 1 as possible.

However, other flexibilities are considered along with providing organizational flexibility, such as: technological (the number of TV types must be minimal), structural (maximum ability of TV to be used interchangeably), interactive (rate of IST recalculation is high enough), evolutionary (independence of IST models on the development of transportation technologies) and machine (implementation of the new approach using low-cost pocket PC).

2. Schemes of traffic. Basic definitions. Classification of tasks

Before considering methods of graphs construction , we suggest to consider possible schemes of transport traffic (Fig. 2), basic definitions and tasks to be solved.

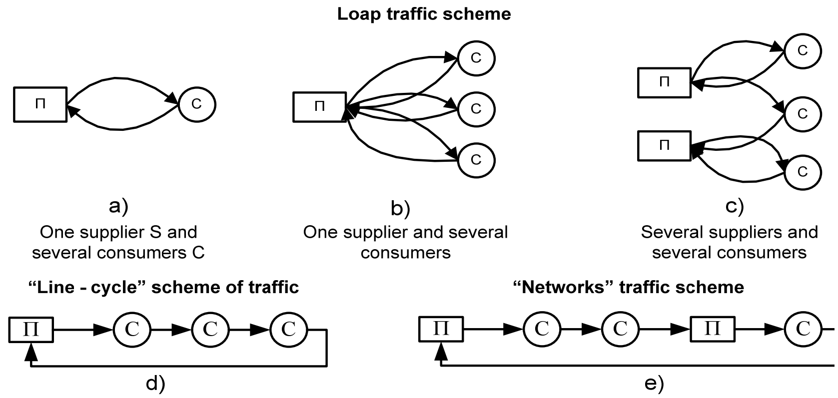
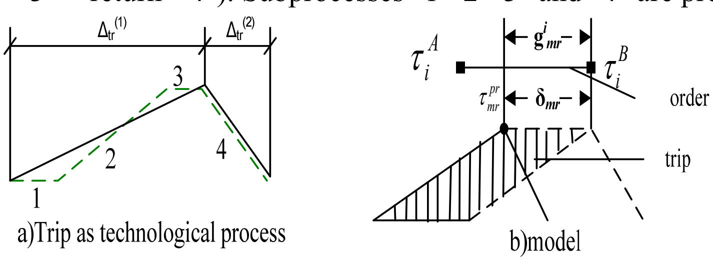


Fig. 2. Examples of transportation schemes

In most cases (80%) loop scheme is used, which was chosen as a basis.

Basic definitions

Trip (***t***) – is the process of transportation of resources (load "1" - transportation "2" - unloading "3" - return "4"). Subprocesses "1 +2 +3" and "4" are presented by simplified cycle .



$\tau_{mr}^{pr} \in \lfloor \tau_i^A, \tau_i^B \rfloor$ order interval

$g_{mr}^i = \tau_i^B - \tau_{mr}^{pr}$ projection on the interval

$\delta_{mr} = g_{mr}^i \,|\, for$ – the the last trip – reserve

Fig. 3. General presentation of the trip

in the form of a part of sequence diagram

The sequence (***l***) – is a continuous set of trips between "S" and "C" in the form of sequence diagram , according to technological and ergonomic requirements.

$$\delta_{mr} = \min_{n=r,R_l}\left\{ g^i_{mn} \right\} \quad or$$

$$\delta_{mr} = \min_{n=r,R_l}\left\{ \max_{i=1,I}\left\{ g^i_{mn} x^i_{mn} \right\} \right\}$$

$$x^i_{mr} \in \{0,1\}, \quad r = \overline{1,R_l}$$

$$\tau^{pr}_{mr+1} = \tau^{pr}_{mr} + \Delta^{(2)}_{mr} + \Delta^{(1)}_{mr}$$

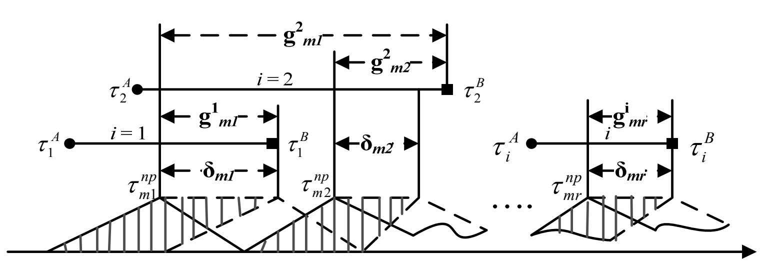


Fig. 4. Total image of the sequence displaying the time reserve

If time reserve of the last trip equals the projection on the intervals $\delta_{mR} = g^i_{mR}$, then the reserves of time δ_{mr} of following trips are defined as the minimum value of projections combinations for each possible order. This follows from the logic of the calculation, taking into account the time of transportation $\Delta_{tr}^{(1)}$ of cargo and time of return $\Delta_{tr}^{(2)}$ to supplier "S".

Initial information for calculation of IST is order interval $\left[\tau_i^A, \tau_i^B\right]$, where τ_i^A where determines the starting point for calculation of time reserve for order; τ_i^B indicates the beginning of work related to the set i. The start of work can be specified both subjectively and on the base of calculation of projects network [5] for project-oriented production (POP).

Based on the options of initial information formation, possible schemes of transportation, method of transport sequences organization and type of efficiency function of time reserve optimization, hierarchical classification scheme of IGT problems calculation is suggested (Fig. 5).

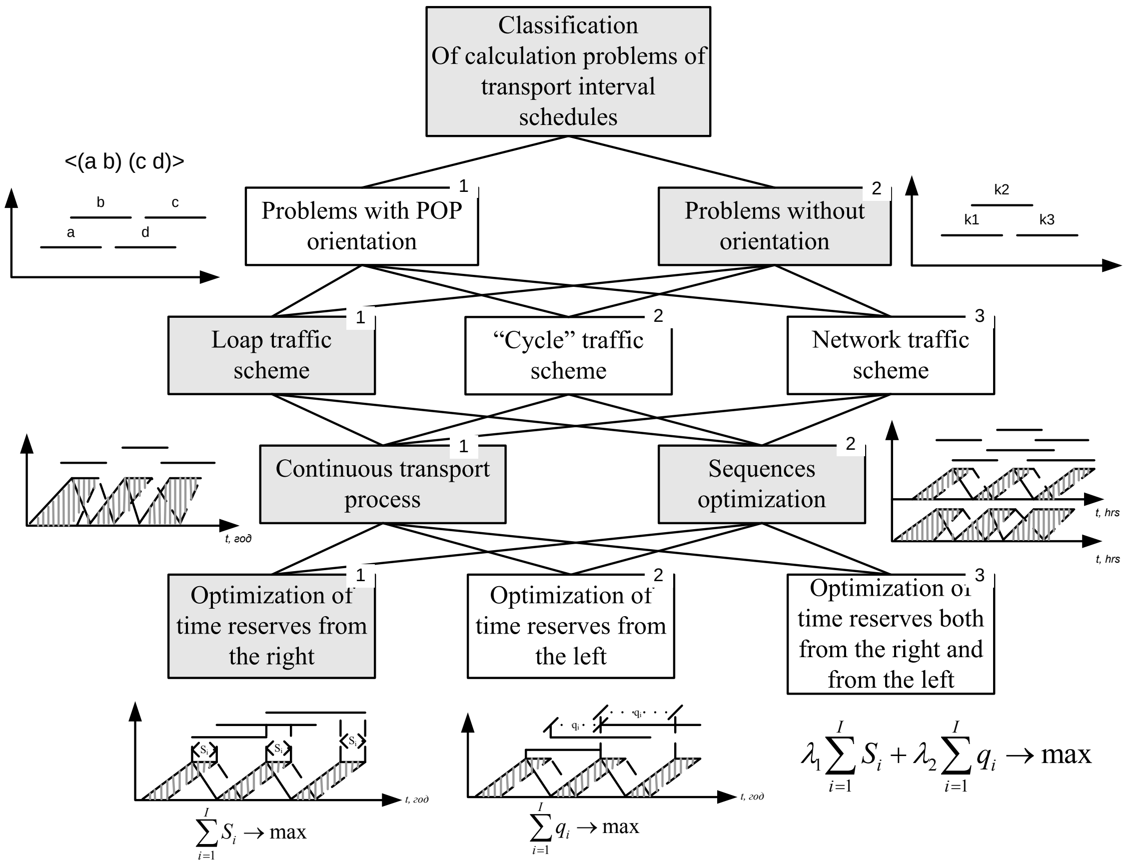


Fig. 5. Complex of modeling transportation graphs tasks

The total number of tasks can be calculated as the product of variants relatively each level:

$K_{set} = 2 \cdot 3 \cdot 2 \cdot 3 = 36$.

For all the problems there are several efficiency functions. One of them - is the number of vehicles must be minimal.

$Z_1 = M \to \min$;

where M - serched number of transport means.

And general constraints for all the problems:

$M \in \left[\underline{M}, \overline{M}\right]$; – limitation of available quantity of TM;

$\delta_{mr} \geq \delta^{opt}$ – time reserve must be not less then normative (set).

Other efficiency functions have the form depending on the task. Further we will consider the formulation of the following problem:

Problem 2.1.2.1. "Optimization of sequences and reserves of time from the right.

$Z_2 = \sum_{m=1}^{M} L_m \to min;-$ minimization ofsequences number for $M - th\ TM;$

where L_m – number of noninerrupted sequences for vehile m

$Z_3 = \sum_{m=1}^{M}\sum_{l=1}^{L_m}\sum_{r=1}^{R_l}\delta_{lr}^{m} \to \max;$ where δ_{lr}^{m} – time reserve taking into account sequences $"l";$

$Z_1 \succ Z_2 \succ Z_3;$

$$\delta_{lr}^{m} = \min_{j=r,R}\left\{ \max_{i=1,I}\left\{\left(\tau_i^B - \tau_{mlj}^{np}\right) y_{mlj}^i x_{mlj}^i \right\}\right\} \mid y_{mlr}^i \in \begin{cases} 1, if\ \tau_{mlr}^i \in \left[\tau_i^A, \tau_i^B\right]; \\ 0, otherwise; \end{cases};$$

$\sum_{i=1}^{I} x_{mlr}^i = 1; \quad m = \overline{1,M}; \quad l = \overline{1,L_m}; \quad r = \overline{1,R_l};$

$$x_{mlr}^i \in \begin{cases} 1, if\ trip\ "r"\ for\ order\ "i"; \\ 0, otherwise; \end{cases};$$

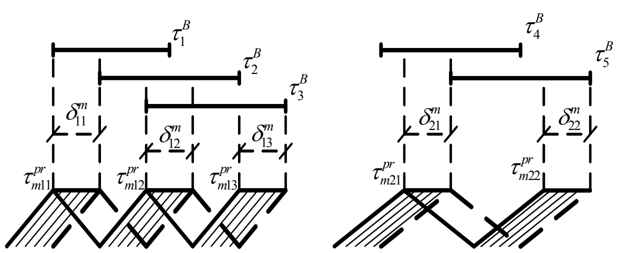


Fig. 6. Graphic representation of the problem 2.1.2.1 2.1.2.1.

Graph analytical representation of two sequences l=1,2 for a single vehicle to minimize the number of sequences and to maximize the reserves of time. This problem is actual for industries with prior delivery and the need for uninterrupted supply to the object (e.g. operation of concrete-delivery truck).

The problem is solved by splitting into two models [3]: Model of sequences optimization and model sequences setting to transport vehicles.

Searched variable for problems are:

Traffic schedule $\tau_{mr}^{ar} \in \left[\tau_i^A, \tau_i^B\right]$ and set orders $x_{mr}^i \in \{0,1\}$;
$i = \overline{1,I}, \quad r = \overline{1,R_m}, \quad m = \overline{1,M}$.

Schedule of traffic has the following form.

$S = \{S_1, S_2, ..., S_m ...\}$ – set of graphs for each $m = \overline{1,M}$ transport means

$S_m = \{\Omega_{m1}, \Omega_{m2}, ..., \Omega_{ml} ...\}$ – set of sequences Ω_{ml} of graph $S_m; l = \overline{1,L_m};$

$\Omega_{ml} = \left\{e_{m1}^{(1)}, e_{m2}^{(1)}, ..., e_{mr}^{(1)}\right\}$ – set of trips $r = \overline{1,R_l}$ of the sequences l of the vehile $m;$

$e_{mr}^{(1)} = \left(\Pi_i, t_{mlr}^{dep}, t_{mlr}^{ar}, i, v_i, C_i\right)$ – description of the trip (m,r) from the suplier S_i to consumer C_i while transporting of the order and in the period of the order $v_i = \left[\tau_i^A, \tau_i^B\right]$;

$t_{mlr}^{dep} = \left[\tau_{mlr}^{dep}, \tau_{mlr}^{dep} + \delta_{lr}^{m}\right]; \quad t_{mlr}^{ar} = \left[\tau_{mlr}^{ar}, \tau_{mlr}^{ar} + \delta_{lr}^{m}\right];$ – interval of departure and interval of arrival for the trip $e_{mr}^{(l)}$;

$t_{mlr}^{ar} \in v_i \ if \ x_{mlr}^i = 1 \,|\, x_{mlr}^i \in \{0,1,\}; \ i = \overline{1, I}, \quad r = \overline{1, R_{ml}}, \quad m = \overline{1, M}$

In case of organizational breaks (shift change, lunch, etc.), the set of orders $\{v_i\}$ may be compressed in time, then complete schedule S can be adjusted by stretching t_{mlr}^{dep} and t_{mlr}^{ar} by the value of organizational breaks.

The reserves of time δ_{lr}^{m}, later must be checked for sufficiency, using the simulation model.

3. Numerical example of problem 2.1.2.1 solution

For example, we will study the situation where there is one supplier and two consumer of resources. Also time of motion from each supplier to consumer (1 hour) and time of return (1 hour) is known.

At the input we have orders (without organizational breaks), which are presented in the table

Table2

S – C	Order	Int.
1 – 1	1	8.00 – 10.00
1 – 1	2	9.00 – 11.30
1 – 1	3	10.00 – 13.00
1 – 1	4	11.00 – 13.30
1 – 1	5	13.00 – 16.00
1 – 1	6	14.00 – 17.30
1 – 1	7	15.30 – 17.30
1 – 2	8	8.00 – 10.30
1 – 2	9	8.30 – 11.30
1 – 2	10	10.30 – 13.00
1 – 2	11	11.30 – 14.00
1 – 2	12	12.00 – 16.00
1 – 2	13	14.30 – 19.00
1 – 2	14	14.00 – 18.30

The algorithm is built on the principles of ramifications and limitations, and the problem is solved in three stages. Grouping on the basis of "one supplier - one consumer, optimization of sequences and setting of sequences. Stages of compression and extension are missing.

Orders are submitted in two groups (1-1 and 1-2) and for each of them the problem of sequences optimization is solved [3].

While calculating by matrix method the table in which rows are orders and columns are trips of TV in sequences is generated. At the intersections possible values of projections $g_{lr}^{i} = \tau_i^B - \tau_{lr}^{ar}$ for each order in the trip are put. After that the destination is solved, maximum value of the projections by each trip is selected and sequences are built.

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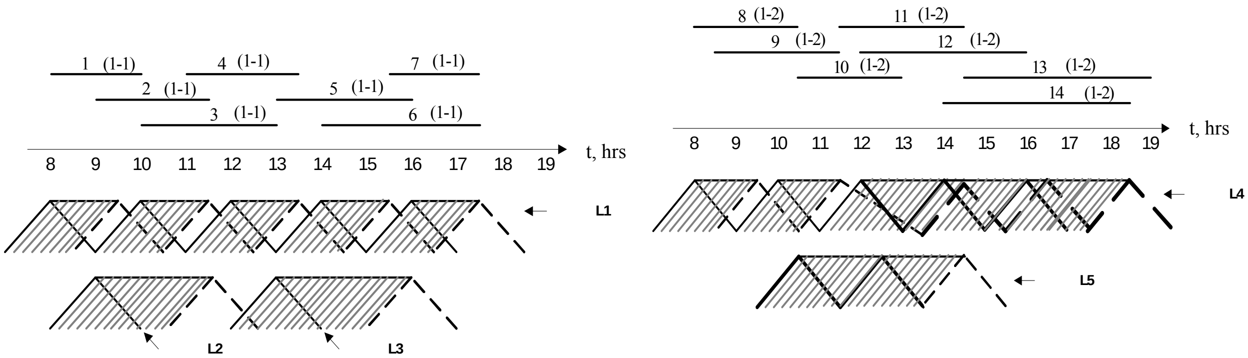
	Ω_{11}	Ω_{12}	Ω_{13}	Ω_{14}	Ω_{15}	Ω_{16}	Ω_{21}	Ω_{31}
1	2.00	0	-	-	-	-	-	-
2	-	1.30	-	-	-	-	2.30	-
3	-	3.00	1.00	-	-	-	-	-
4	-	-	1.30	0	-	-	-	-
5	-	-	-	2.00	0	-	-	3.00
6	-	-	-	3.30	1.30	-	-	-
7	-	-	-	-	1.30	0.30	-	-

	Ω_{41}	Ω_{42}	Ω_{43}	Ω_{44}	Ω_{45}	Ω_{46}	Ω_{51}	Ω_{52}
8	2.30	0.30	-	-	-	-	-	-
9	-	1.30	-	-	-	-	-	-
10	-	-	1.00	-	-	-	2.00	0.30
11	-	-	2.30	0.30	-	-	-	2.00
12	-	-	4.00	2.00	-	-	-	-
13	-	-	-	-	3.00	1.00	-	-
14	-	-	-	4.30	2.30	0.30	-	-

As a result of calculations we have 5 sequences with calculated reserves of time. Graphically, they can be represented in the following manner (Fig. 7 a, b).



a. b.

Fig. 7. "Graphic image of sequences"

Table 3

Reserves of time in trips of sequences

	e_{l1}	e_{l2}	e_{l3}	e_{l4}	e_{l5}	σ	τ^{ar}_{l1}
1	1.30	1.30	1.30	1.30	1.30	7.30	8.00
2	2.30					2.30	9.30
3	3.00					3.00	13.00
4	1.30	1.30	3.00	3.00	3.00	12.00	8.00
5	2.00	2.00				4.00	10.30

The problem of sequences distribution $\{\Omega\}$ by TV with their minimization the overall efficiency function $\sum_{m=1}^{M}\sum_{l=1}^{L_m}\sigma_{lm}x_{lm} \to \max;$ provision of maximum reserves. In the process of optimization the intersection of the first trip of sequences is possible (in this case the loss of reserve time is possible).

As a result, of the solution of destination sequences problem it was revealed that for transportation, you must use four vehicles and the following schedule of transportation by vehicles was obtained (4).

Table 4

IST by transport means

TV(m)	Order. (i)	Time of dep. t^{dep}_{mlr}	Time of arr. t^{ar}_{mlr}	Time of order. v^{ar}	Route	Reserve of time δ^{m}_{lr}
1	1	7.00 – 8.30	8.00 – 9.30	8.00 – 10.00	1 – 1	1.30
	3	9.00 – 10.30	10.00 – 11.30	10.00 – 13.00	1 – 1	1.30
	4	11.00 – 12.30	12.00 – 13.30	11.00 – 13.30	1 – 1	1.30
	6	13.00 – 14.30	14.00 – 15.30	14.00 – 17.30	1– 1	1.30
	7	15.00 – 16.30	16.00 – 17.30	15.30 – 17.30	1– 1	1.30
2	2	8.00 – 10.00	9.00 – 11.00	9.00 – 11.30	1– 1	2.30
	5	12.00 – 15.00	13.00 – 16.00	13.00 – 16.00	1 – 1	3.00
3	8	7.00 – 8.30	8.00 – 9.30	8.00 – 10.30	1 – 2	1.30
	9	9.00 – 10.30	10.00 – 11.30	8.30 – 11.30	1 – 2	1.30
	12	11.00 – 14.00	12.00 – 15.00	12.00 – 16.00	1 – 2	3.00
	14	13.00 – 16.30	14.00 – 17.30	14.00 – 18.30	1 – 2	3.00
	13	15.00 – 18.00	16.00 – 19.00	14.30 – 19.00	1 – 2	3.00
4	10	9.30 – 11.30	10.30 – 12.30	10.30 – 13.00	1 – 2	2.00
	11	11.00 – 13.00	12.00 – 14.00	11.30 – 14.00	1 – 2	2.00

4. Integrated approach to planning. Possible ways of input data formation

The peculiarity of these models is that at the input we have determined and normative data, and at the output we have results in the form of intervals, duration of which depends on the time of order. Input data for the problem: *constant normative information* (description of warehouses structure , distance and time (in minutes) of transportation, average time of loading and unloading, calendar of dates connected with organizational breaks), *statistic information* (function of traffic speed in time for each route) and *on-line information* (list of orders with intervals of delivery).

For problems, not connected with POP, the list of orders is given by the dispatching service of ATE. For problems associated with POP, the list of orders is calculated on the basis of cross-cutting planning "from network schedules of construction works to the schedule of orders for transportation." Involvement of direct planning of POP is also our task and the following development of the results [5]. In this paper, for the formation of input data used CAD-system «AllPlan» and proper development KARTC were used.

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