Decision-making problems of designing database in the aspect of planning transport of cargoes by intermodal transport

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Abstract. The article presents issues related to database design for problems of planning transport of cargoes by intermodal transport using road and air transport. The main aim of this paper is to develop the structure of the database used in the problems of planning transport of cargoes by intermodal transport. The issue of intermodal transport is a complex decision problem which requires taking into account many technical, economic and qualitative aspects of various modes of transport. The multitude of these aspects contributes to the processing of a large amount of input data used by advanced calculation algorithms developed to determine the optimal routes of cargo transportation. Designing database architecture depends on the number of modules responsible for the final determination of transport plans. It is assumed that the database is responsible not only for collecting input data about air, road infrastructure, processing of information necessary for transport but also for saving results generated by calculation modules. In the article, to understand the problem of the issue, a mathematical model of transporting loads by intermodal transport was included, and for its solution an ant algorithm was proposed. The developed structure of the database with the presented modules is a newly approach in problems of planning transport of cargoes by intermodal transport.

1 Introduction

The problem of intermodal transport planning is one of the general problem of determining vehicle routes presented in the literature as *vehicle routing problem* [1], [2], [11], [8], [9], [13]. According to the definition, intermodal transport consists in the transport of loads with at least two types of transport means used [9], [10], [12]. Planning transport routes in intermodal transport is a complex optimization issue that requires taking into account many factors of a technical, qualitative and economic nature.

Technical factors characterize the logistics network and limit the flow of cargo streams between network facilities, e.g. the reloading capability of a given airport, the limitation of the road network resulting from permissible loads, distances between network facilities. Technical factors characterize the logistics network facilities and the relationships between them.

Economic factors include e.g. the unit costs of fuel consumption by vehicles performing transport, the costs of transport by air, the costs of cargo handling at the airport.

The quality factors include service time and transport time.

The transport task consists in transporting the load from the place of loading to the place of unloading. The logistics process within the carriages analyzed in this work can be defined as transporting cargo by road to the transshipment place, which is the airport, cargo transport between two airports and delivery by car to the final recipient. It is problematic to choose the first transshipment point, i.e. the airport. The determinants of choosing the right airports in the entire logistics network are not only the distance between the loading point (the place of loading) and the airport, the distance between two airports, the distance between the airport and the landing point, but also the cost and time of transshipment at a given point. The problem of intermodal transport is analyzed in a multi-criteria approach, which underlines the complexity of the analyzed issue. An exemplary route for moving a load from the loading point to the unloading point is shown in Fig. 1 (continuous lines define the selected route, dashed lines, potential routes selection options). The main aim of this paper is to develop the structure of the database used in the problems of planning transport of cargoes by intermodal transport. The developed structure of the database with the presented modules is a newly approach in problems of planning transport of cargoes by intermodal transport.

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Fig. 1. The problem of intermodal transport including road and air transport

2 The concept of the structure of the intermodal transport infrastructure database

Due to the complexity of the problem of planning intermodal transport, it is necessary to process a large amount of input data used by advanced calculation algorithms developed to determine the optimal routes of cargo transportation. It is assumed that the database is responsible for collecting input data about air, road

infrastructure, information processing and saving of results generated by calculation modules. The development of the database architecture for the issues of planning transport of goods by intermodal transport is determined by the number of modules responsible for determining the final transport plans. Data for the application defining the intermodal transport plan is entered from the database. The structure of the database is shown in Fig. 2.

Fig. 2. Database architecture in intermodal transport

- The database consists of the following modules:
- the module of fixed data – contains tables of the database on suppliers, recipients, airports, locations, types of aircraft and vehicles,
 - the dynamic data module – designed to support the data that can be added, modified and removed by

- users during system operation, e.g. loading, unloading, cargo handling, transport costs,
- the archive module – is part of the database for storing analysis reports, results of intermodal transport plans,

- the data entry module – designed to support the process of direct input by the user,
- the data presentation module – mediates in the process of sharing data collected in the database for authorized users,
- the optimization and calculation module – the results of the module are reports and data collation on intermodal transport plans, this module is based on the built-in optimization algorithm,
- the calibration module for the optimization algorithm – sets and saves the parameters of the optimization algorithm,
- the verification module – validates the results generated by the optimization algorithm,
- the data exchange module – it is an interface between applications based on different base systems.

The database is updated via a dynamic data entry module. The optimization module, the calibration module of the optimization algorithm parameters and the results verification module operate independently of the other database modules. The correctness of the developed database is measured by the speed of solution generation, data storage and modification.

3 The mathematical model of intermodal transport

As mentioned in point 2, the designed database is responsible, among others, for saving and processing data generated in a mathematical model. In order to implement the database in the problem of intermodal transport, a mathematical model for planning these transports, including road and air transport, was developed. The necessary data for testing is:

- $\mathbf{PZ}=\{1, \dots, pz, \dots, \mathbf{PZ}\}$ – the set of loading points;
- $\mathbf{A}=\{1, \dots, a, \dots, \mathbf{A}\}$ – the set of airports;
- $\mathbf{S}=\{1, \dots, s, \dots, \mathbf{S}\}$ – the set of types of aircraft used to carry loads,
- $\mathbf{P}=\{1, \dots, p, \dots, \mathbf{P}\}$ – the set of types of vehicles used to carry loads,
- $\mathbf{PW}=\{1, \dots, pwz, \dots, \mathbf{PW}\}$ – the set of unloading points,
- $\mathbf{ZAD}=\{1, \dots, zad, \dots, \mathbf{ZAD}\}$ – a set of tasks,
- $\mathbf{D1}=[d1(pz,a): d1(pz,a) \in \mathbb{R}^+, pz \in \mathbf{PZ}, a \in \mathbf{A}]$ – the matrix of distances between the loading points and the airports,
- $\mathbf{D2}=[d2(a,a'): d2(a,a') \in \mathbb{R}^+, a \in \mathbf{A}, a' \in \mathbf{A}]$ – the matrix of distances between airports,
- $\mathbf{D3}=[d3(a,pw): d3(a,pw) \in \mathbb{R}^+, a \in \mathbf{A}, pw \in \mathbf{PW}]$ – the matrix of distances between airports and the unloading points,
- $\mathbf{T1}=[t1(pz,a): t1(pz,a) \in \mathbb{R}^+, pz \in \mathbf{PZ}, a \in \mathbf{A}]$ – the matrix of transit times between the loading point and the airport,
- $\mathbf{T2}=[t2(a,a'): t2(a,a') \in \mathbb{R}^+, a \in \mathbf{A}, a' \in \mathbf{A}]$ – the matrix of transit times between airports,
- $\mathbf{T3}=[t3(a,pw): t3(a,pw) \in \mathbb{R}^+, a \in \mathbf{A}, pw \in \mathbf{PW}]$ – the matrix of transit times between the airports and the unloading points,
- $\mathbf{TO}=[to(a,s), to(a,s) \in \mathbb{R}^+, a \in \mathbf{A}, s \in \mathbf{S}]$ – cargo handling time at a given airport depends on the type of aircraft chosen,
- $\mathbf{CL}=[cl(s), cl(s) \in \mathbb{R}^+, s \in \mathbf{S}]$ – the cost of transport by air,

- $\mathbf{CD}=[cd(p), cd(p) \in \mathbb{R}^+, p \in \mathbf{P}]$ – the cost of transport by road,
- tz – time of intermodal transport,
- $\mathbf{LS}=[ls(s,a), ls(s,a) \in \mathbb{N}, s \in \mathbf{S}, a \in \mathbf{A}]$ – the number of aircraft of a given type available at a given airport,
- $\mathbf{LP1}=[lp1(p,pz), lp1(p,pz) \in \mathbb{N}, p \in \mathbf{P}, pz \in \mathbf{PZ}]$ – number of vehicles of a given type available at a given loading point,
- $\mathbf{LP2}=[lp2(p,pw), lp2(p,pw) \in \mathbb{N}, p \in \mathbf{P}, pw \in \mathbf{PW}]$ – number of vehicles of a given type available at a given unloading point.

To identify the complexity of the problem, decision variables and the criterion function were also developed. It is assumed that the decision variables take the form of binary variables and define the connection between identified transport network nodes:

- $\mathbf{X1}=[x1(pz,a,p,zad): x1(pz,a,p,zad) \in \{0,1\}, pz \in \mathbf{PZ}, a \in \mathbf{A}, p \in \mathbf{P}, zad \in \mathbf{ZAD}]$ – the matrix of connections between loading points and airports, if $x1(pz,a,p,zad)=1$ there is a connection between the given loading point and the airport carried out by a given type of the vehicle in the given task, otherwise 0.
- $\mathbf{X2}=[x2(a,a',s,zad): x2(a,a',s,zad) \in \{0,1\}, a \in \mathbf{A}, a' \in \mathbf{A}, s \in \mathbf{S}, zad \in \mathbf{ZAD}]$ – the matrix of connections between airports, if $x2(a,a',s,zad)=1$ there is a connection between the given airports carried out by the a given type of the aircraft in a given task, otherwise 0,
- $\mathbf{X3}=[x3(a,pw,p,zad): x3(a,pw,p,zad) \in \{0,1\}, a \in \mathbf{A}, pw \in \mathbf{PW}, p \in \mathbf{P}, zad \in \mathbf{ZAD}]$ – the matrix of connections between airports and unloading points, if $x3(a,pw,p,zad)=1$ there is a connection between the given airport and the unloading point carried out by a given type of the vehicle in a given task, otherwise 0.

The restrictions apply to, among others:

- time of completing tasks:

$$\forall pz \in \mathbf{PZ}, \forall a \in \mathbf{A}, \forall p \in \mathbf{P}, \forall a' \in \mathbf{A}, \forall s \in \mathbf{S}, \\ \forall pw \in \mathbf{PW} \quad \forall zad \in \mathbf{ZAD}$$

$$x1(pz,a,p,zad) \cdot [t1(pz,a) + to(a,s)] + \\ x2(a,a',s,zad) \cdot [t2(a,a') + to(a',s)] + \\ x3(a,pw,p,zad) \cdot t3(a,pw) \leq tz \quad (1)$$

- the number of possible allocations of vehicles and aircraft:

$$\forall p \in \mathbf{P} \quad \forall pz \in \mathbf{PZ}$$

$$\sum_{a \in \mathbf{A}} \sum_{zad \in \mathbf{ZAD}} x1(pz,a,p,zad) \leq lp1(p,pz) \quad (2)$$

$$\forall s \in \mathbf{S} \quad \forall a \in \mathbf{A}$$

$$\sum_{a' \in \mathbf{A}} \sum_{zad \in \mathbf{ZAD}} x2(a,a',s,zad) \leq ls(s,a) \quad (3)$$

$$\forall p \in \mathbf{P} \quad \forall pw \in \mathbf{PW}$$

$$\sum_{a \in \mathbf{A}} \sum_{zad \in \mathbf{ZAD}} x3(a,pw,p,zad) \leq lp2(p,pw) \quad (4)$$

and other restrictions important from the point of view of the problem being realized.

Defining the criterion function it is assumed that for service recipients the problem is to define a plan so that the execution time is as short as possible and the cost as low as possible. Therefore, the criterion functions take the form (5) of minimizing the implementation time of the intermodal transport plan and the cost of transport (6):

$$F(X1, X2, X3) = \sum_{pz \in PZ} \sum_{a \in A} \sum_{p \in P} \sum_{zad \in ZAD} x1(pz, a, p, zad) \cdot [t1(pz, a) + to(a, s)] + \sum_{a \in A} \sum_{a' \in A} \sum_{s \in S} \sum_{zad \in ZAD} x2(a, a', s, zad) \cdot [t2(a, a') + to(a', s)] + \sum_{a \in A} \sum_{pw \in PW} \sum_{p \in P} \sum_{zad \in ZAD} x3(a, pw, p, zad) \cdot t3(a, pw) \longrightarrow \min$$

$$F(X1, X2, X3) = \sum_{pz \in PZ} \sum_{a \in A} \sum_{p \in P} \sum_{zad \in ZAD} x1(pz, a, p, zad) \cdot cd(p) + \sum_{a \in A} \sum_{a' \in A} \sum_{s \in S} \sum_{zad \in ZAD} x2(a, a', s, zad) \cdot cl(s) + \sum_{a \in A} \sum_{pw \in PW} \sum_{p \in P} \sum_{zad \in ZAD} x3(a, pw, p, zad) \cdot cd(p) \longrightarrow \min$$

4 The ant algorithm for planning intermodal transport

The database structure optimization module works based on the ant algorithm. Ant algorithms are algorithms whose principle of operation consists in imitating the existence of ants in the natural environment [4], [5]. The form algorithm is an optimization algorithm with success used in various complex decision problems, e.g. the traveling salesman problem [3], [6], [7]. The deciding factor in choosing the route of each ant is the pheromone, chemical substance released by ants. Ants choose the path with the strongest concentration of pheromone. The selection of the appropriate type of formic algorithm is important in correctly generating results, i.e.:

- *ant-density* – leaving a constant amount of pheromone on each section of the ant route,
- *ant-quantity* – leaving the amount of pheromone inversely proportional to the length of the selected edge on each section of the ant route,
- *ant-cycle* – leaving the pheromone only when all the ants build the whole road, the trail is updated between successive iterations.

In the developed algorithm for intermodal transport, an *ant-cycle* update was applied. The advantage of the ant algorithm is speed of action and a simple implementation method. In databases that take into account the execution of complex calculations, the decisive factor is the speed of results generation. Taking

into account the complexity of the problem of determining routes in intermodal transport and the time of generating the result, the ant algorithm was chosen as an algorithm solving the problem of transport in intermodal transport.

The developed algorithm determines the routes of cargo transport and selects the type of the vehicle and the aircraft to perform the task ordered. The ant algorithm has been developed to solve multi-criteria problems related to the determination of cargo transportation routes from suppliers to customers, including road and air transport. In order to solve optimization problems in the theory of ant algorithms, the concept of an artificial ant was introduced [4], [5]. Each ant in its route chooses the type of the vehicle and the type of the aircraft. The ant determines the minimum route of cargo transport in accordance with the adopted criteria. The route of a single ant consists of four layers that appear consecutively. The route of each ant consists of all completed tasks. During the construction of the route in the first layer, the type of the vehicle performing transport by road is selected, in the second layer the airport from which the cargo is sent is selected, the third layer shows the type of the aircraft performing air transport, while the fourth layer is the layer defining air route and road route transport between the airport and the unloading point. The starting and finishing point of the ant route is the loading and unloading point. These layers are repeated cyclically until all the tasks are completed by the ant. Ant route with highlighted layers is shown in Fig. 3. For the purpose of describing the components of the algorithm, a set of points of all layers of the route realized by a single ant was defined **WTP**. The set of ants in the anthill **MR** was defined as:

$$\mathbf{WTP} = \{1, \dots, y, \dots, z, \dots, \overline{\mathbf{WTP}}\} \quad (7)$$

where $\overline{\mathbf{WTP}}$ - the size of the set **WTP**, $y \neq z$.

The starting point for the route of each ant is the loading point. The further route of the ant, and thus the selection of subsequent points, takes place with a certain probability:

$$PR_{yz}^{mr}(t) = \begin{cases} \frac{[\tau_{yz}(t)]^\alpha \cdot [\eta_{yz}(t)]^\beta}{\sum_{l \in \Omega^{mr}} [\tau_{yl}(t)]^\alpha \cdot [\eta_{yl}(t)]^\beta}, & z \in \Omega^{mr} \\ 0, & z \notin \Omega^{mr} \end{cases} \quad (8)$$

where:

- $\tau_{yz}(t)$ – the intensity of the pheromone trail between y -th and z -th punktem in t iteration,
- $\eta_{yz}(t)$ – heuristic information, for each layer assumes a different value, e.g.
- for imaginary connections between the vehicle/the aircraft types and route points in each iteration of the algorithm is $\eta_{yz}(t) = 0$.
- for real connections between route points:

$$n_{yz}(t) = \frac{1}{d(y,z) \cdot c + t(y,z) + to(z)} \quad (9)$$

where:

$d(y,z)$ – the route between the points of the route,

c – the transportation cost, $t(y,z)$ – driving time,

$to(z)$ – service time,

α, β – the impact of pheromones and heuristic data on ant behavior,

Ω^{mr} – the set of 1 points in a given layers.

Fig. 3. Layers of the ant route

Random selection of the transition route between the point y and points l -th begins with calculating the probability of crossing to the points not yet visited by the ant according to the pattern (8). The next step is to calculate the distribution for each passage path and to draw a number r from the range $[0,1]$. The passage path tr about the value of the cumulative distribution q_{tr} which fulfills the dependence $q_{tr-1} < r \leq q_{tr}$ is selected, where tr is the route number between y -th point and l -th points defined in each layer.

After completing the construction of the route by all ants, the pheromone is updated. At the beginning it is assumed that the trail on connections between points is equally strong. In subsequent iterations, the pheromone trail is calculated according to the formula:

$$\tau_{yz}(t+1) = (1 - \rho)\tau_{yz}(t) + \sum_{mr=1}^{MR} \Delta\tau_{yz}^{mr}(t) \quad (10)$$

where:

mr – the another ant in the anthill $mr \in \mathbf{MR}$,

ρ – volatilization coefficient ($0 < \rho \leq 1$),

$\tau_{yz}(t+1)$ – pheromone enhancement, for the first iteration, assumes a value at every link τ_0 .

The first component of the formula (10) determines the speed of volatilization of the pheromone, while the second defines the enhancement of the pheromone and takes the value:

$$\Delta\tau_{yz}^{mr}(t) = \begin{cases} \frac{1}{L^{mr}(t)} \\ 0 \end{cases} \quad (11)$$

when the route (y,z) has been realized by the ant mr otherwise

where:

$L^{mr}(t)$ – the value of the route generated by the ant including the minimum task execution time and the cost, the value calculated for the entire ant route according to the denominator of the pattern (9).

The ant algorithm designing cargo transport plans in intermodal transport can be presented in the following steps:

- The step 0. Selection of the task (loading point) to be carried out at random way.

- The step 1. Selection of the type of vehicle performing transport by road. At the same time, checking the condition on the number of vehicles of a given type used to perform transport, limiting (2) the mathematical model. When there is a lack of the vehicle of a given type, the algorithm again selects a different type of the vehicle and checks the number of available vehicles. In the first iteration of the algorithm, the ant goes to layer I in a random manner, in subsequent iterations in accordance with the passage probability determined with patterns (8).

- The step 2. The passage of ants from the loading point to the airport in accordance with the probability determined from the formulas (8).

- The step 3. Selection of the type of aircraft at a given airport. The passage of ants from layer II to III in the first iteration in a random manner, in successive iterations in accordance with the passage probability determined with formulas (8).

- The step 4. Selection of the final airport in accordance with the passage probability determined with formulas (8). The choice of the final airport depends not only on

the distance between the ports, but also on the distance from the port to the unloading point. Step 4 completes the implementation of the selected task.

- The step 5. Checking the condition for the duration of the task, limiting (1) the model. If the restriction is not met, return to step 1.

- The step 6. Selecting the next task in a random way.

- The step 7. The ant carries out further tasks in accordance with steps 1-5.

- The step 8. After completing all the tasks by a single ant, the next ant from the anthill determines the cargo route for each task from the beginning in accordance with steps 0-8. Steps 0-8 are repeated until all ants have created routes consisting of all tasks.

- The step 9. After determining the routes by all ants, the pheromone is updated according to the pattern (10).

The steps of the 0-9 algorithm are repeated with the specified number of iterations until the stop condition of the algorithm is reached. The condition for stopping the algorithm is a certain amount of iteration determined at the beginning of the operation of the algorithm.

5 Conclusions

The developed database architecture for intermodal transport is an original proprietary concept presenting the database as an integrated modular structure that takes into account the various types of activities taking place during the planning of cargo transport in intermodal systems. The use of the ant algorithm in the optimization module will minimize the calculation time and speed up the processes taking place in the database.

In order to obtain the correct results generated by the ant algorithm, it is first necessary to analyze the sensitivity of this algorithm to change their input parameters. This analysis is carried out by a calibration module built into the database. The sensitivity analysis can be performed based on a set of fixed input parameters that are entered into the algorithms. The quality of generated solutions depends on correctly selected parameters. The maximum value generated by the ant algorithm in the sensitivity analysis indicates the parameters of this algorithm that determined this value. In the second place, the algorithm verification process should be carried out.

The verification process is carried out in the results verification module. The algorithm verification process can be carried out based on a comparison of algorithm solutions with solutions obtained using a random algorithm. The number of comparisons is determined at the beginning of the verification. In case when the random algorithm determines a better solution, the sensitivity stage should be performed for a different set of parameters of the algorithm. In the case where the ant algorithm generated a better result, the verification process is completed.

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