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Intermodal Transport
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COMPUTER-SUPPORTED MODELLING OF MULTIMODAL TRANSPORTATION NETWORKS RATIONALIZATION

ABSTRACT

This paper deals with issues of shaping and functioning of computer programs in the modelling and solving of multimodal transportation network problems. A methodology of an integrated use of a programming language for mathematical modelling is defined, as well as spreadsheets for the solving of complex multimodal transportation network problems. The paper contains a comparison of the partial and integral methods of solving multimodal transportation networks. The basic hypothesis set forth in this paper is that the integral method results in better multimodal transportation network rationalization effects, whereas a multimodal transportation network model based on the integral method, once built, can be used as the basis for all kinds of transportation problems within multimodal transport. As opposed to linear transport problems, multimodal transport network can assume very complex shapes. This paper contains a comparison of the partial and integral approach to transportation network solving. In the partial approach, a straightforward model of a transportation network, which can be solved through the use of the Solver computer tool within the Excel spreadsheet interface, is quite sufficient. In the solving of a multimodal transportation problem through the integral method, it is necessary to apply sophisticated mathematical modelling programming languages which support the use of complex matrix functions and the processing of a vast amount of variables and limitations. The LINGO programming language is more abstract than the Excel spreadsheet, and it requires a certain programming knowledge. The definition and presentation of a problem logic within Excel, in a manner which is acceptable to computer software, is an ideal basis for modelling in the LINGO programming language, as well as a faster and more effective implementation of the mathematical model. This paper provides proof for the fact that it is more rational to solve the problem of multimodal transportation networks by using the integral, rather than the partial method.

KEY WORDS

intermodal transportation, transportation networks, spreadsheets, mathematical modelling programming languages, Lingo, Solver

1. INTRODUCTION

The problem of scientific research: although for almost 50 years all human activities have successfully used information technologies the mathematical models of simulation, theoretical knowledge quantum of transport network information modelling and applied knowledge of such models within processes of production of transport, i. e. traffic and logistics services owned by the experts and managers in transport, traffic and logistic praxis, are still below the necessary minimum level.

According to the problem of research, the *research subject* has been defined: to explore the actual problems of information designing of transport network models and to suggest the appropriate solution. When the optimization of transport is concerned, there are some transport problems at different levels of complexity - from simple ones, well structured routine problems for which usage of program tools intended to end users only is sufficient, up to highly complex transport problems that require teamwork of informatics and traffic specialists.

The outcome of the subject problem is the purpose and objective of the research - to explore which are the ways and intensities of the transport system using the results given by the usage of model database in transport optimization. In achieving such objective it is necessary to determine research sub-objectives by consistent application of scientific-research methods:

- defining of features and possibilities of the usage of computer tools and programs in the context of new paradigm of computer-supported designing of complex configurations of transport network models;
- determine the optimization methods of transport in the function of solving different transport problems with different levels of complexity;

- consider the time and manner of transformation of models of simple transport network square matrix to complex models of transport networks in conditions of multimodal transport;
- consider the areas of usage and functioning of computer-supported models in designing of multimodal transport networks;
- suggest mutual methodological scope of information technologies usage in designing the models of multimodal transport networks and solving the optimization problems.

Taking into consideration the problem and the research objective, there is the foundation *scientific hypothesis*: it is possible to determine the general model of multimodal transport network that could be adjusted and implemented to different computer programs by scientific perceptions on information technologies, models and transport networks for solving multimodal transport problems, and rationalize transport networks. Spreadsheets in relation to the computer tools and programs stand for the representative software package for complex problems of mathematical programming and as such enable designing and implementation of multimodal transport network models.

2. THEORETICAL CHARACTERISTICS REGARDING INFORMATION TECHNOLOGIES, MODELS AND TRANSPORT NETWORKS

The development of computing has crucial influence on the meaning, functioning and usage of information technology in the solving of transport problems. While performing a quantitative analysis during the organization of the transport process (the planning and booking of transport capacities, the choice of the transport route and the vehicle type, the determination of the type of transport, the transport deadlines, the creation of rate calculations) it is necessary to create a mathematical model. Data, information, magnitudes and connections which are deemed relevant in the solving of particular transport problems are entered into the model. During the creation of the model, it is necessary to estimate the accuracy of the data, or to determine it with quantitative methods, upon which the individual connections and regularities can be simplified.

The ultimate target of the deregulation and privatization of transport, i. e. traffic, should be the liberalization, i. e. the abolition of all economic and other restrictions and prohibitions.[1] Under the conditions of market deregulation and liberalization, transport problems are continually growing in complexity and size. If we add the huge number of computational operations which require optimization methods, it is understandable that optimum solutions can only be achieved with the aid of electronic computers, as a basic device for the transfer, processing and delivery of data. This way, the application of computer-aided operation research methods formalizes the handling and decision processes, and affects the diffusion of information technology into tactical and strategic processes of the manufacturer or the production organizer of traffic products.[2]

The rationalization of the transport network represents the establishing of optimum connections among and within the elements of the transport process. With the rationalization of transport networks, it is necessary to achieve the adjustment and optimization of relevant factors of the transport process: the transport route, the means of transport, the transport type and the transport time. In this context, the tasks of information technology are:

- collecting relevant data and information,
- creating the information basis in order to define the adequate transport optimization model,
- shaping optimization models,
- data and information processing,
- distributing processed data and information to relevant locations (organization units within the company, and the company environment: customers, contractors and other participants of the transportation service production process...).

The basic factor of a successful rationalization of transport networks is the transport optimization, which creates the data for the transport calculation. During the creation of a transport calculation, it is not just the economy and cost-effectiveness which is being insisted on; the solvency of the customer is also analyzed, as well as the profit of the total transport process. All relevant transactions with the customer in question are included and analyzed in the calculation, the required rates are calculated on the basis of collective processing, and the optimum bidding is made for the customer. The development and use of a multitude of very complex methods and algorithms for the optimization of various events and processes is significantly stimulated by the development of digital electronic computers and information sciences. The use of computers and computer applications has become a basic tool in the process of transport optimization.[3]

The execution of optimization methods with the aid of such software packages has its advantages in the possibility of a physical integration of the programmed routines into independently generated applications. Computer-aided optimization methods are drafted so they would be able to be used along with other relevant applications, to the point that they can be physically incorporated in them. Such methods are ranked in the category of computer integrated tools of applied math.[4] Upon the execution of the program, the data permanently remains within the computer in the shape of an expert database, which is the basis of the development of an expert system in the solving of transport problems.

The traditional spreadsheet can be defined as a computer software package for the manipulation of objects arranged into segmental tables. These objects include text, numbers and formulas. Formulas are used in the calculation of values for the addresses of default output variables based on data stored in the addresses of input variables. The classic formula reads and arranges the value of the input variable without the possibility of changing and calculating their values. The result and the calculation appear only in the address of the output variable. The definition of the spreadsheet in the conditions of the new technological paradigm is redirected towards the functional nature of spreadsheets from the viewpoint of applicative states of system transition. In that paradigm, the spreadsheet is viewed as a unit consisting of four basic components: the formulas, the stored constants, the text (comments and labels), and the connection labels of those three components which are stored in the address strings of rows, columns and matrices.

The interface of Excel spreadsheet, with its implemented sophisticated functions and macro commands, allows the modular connecting of several functions into complex formulas.[5] The use of the interlinkage of computing tools and advanced spreadsheet functions introduces a new spreadsheet paradigm, which is redirected towards the shaping of flexible math models and algorithms that support the use of various powerful specialized functions and computing tools, which in turn can be integrally used and flexibly combined in the spreadsheet interface.

The modelling is based on the conceptualization of the business problem, and its abstraction in a qualitative and quantitative form. In the shaping of quantitative business models, variables are identified, and relations between these variables are defined. A model signifies the presentation (i. e. description) and excogitation (i. e. abstraction) of a real object or a real phenomenon. A model can be defined as a showcase of a process or system, which connects only those elements of the process or system which affect the established goal.[6]

The quantitative model is aimed at the presentation (i. e. description) and excogitation (i. e. abstraction) of a real object or a real phenomenon. Since there are certain realities explored with the aid of the model, the model needs to be much less complex than the corresponding reality, so that it would be directed at those components of the phenomenon to be explored which are important for the analyst. The quantitative model is intended to be used in the determination of relevant characteristics of a business system that can be quantitatively expressed, as well as the mutual connection and collocation of these characteristics within a modelled business system which is adequate for experimenting (because this is cheaper and faster in comparison with a real system), with the goal to discover – among the impossible alternatives and taking into account all relevant and real circumstances – the 'best' solution according to the established goal or goals, all in the context of a specific formulated problem.

3. DEFINING MULTIMODAL TRANSPORT PROBLEM

International multimodal transport covers designing of multimodal transport network. Significant feature of such transport networks in connecting the dispatch and destination nodes is the participation of different types of transport branches, which are mostly: road, railway, maritime and river transport. Models of multimodal transport networks are formed on the basis of given nodes and arcs. Mostly, multimodal transport networks are very complex.

Arcs of the multimodal transport networks represent roads, railway gauges (i. e. lines), ship lines, water canals, oil pipelines, gas pipelines, product lines (...). Transport nodes represent sea ports, river wharfages, road-railway terminals, train stations, airports. Dispatch nodes could be connected to destination nodes by transport arcs across variety of transport nodes.[7]

The operator of international multimodal transport could be faced by a problem of continued distribution of containers with different cargo, which can be homogeneous cargo as well (i. e. coffee, cacao, wheat, rice and similar), from a large number of initial centres to certain number of destinations, with the usage of variety of different traffic branches (i. e. road, maritime, road, railway), in the way of exploring all the supply and satisfying the entire demand, where at the same time, total manipulative transport expenses reach their minimum. In such cases the entrepreneur of multimodal transport could form partial problems of transport for each traffic branch and then place a transport problem for the entire transport project (i. e. all initial centres, all traffic branches, all destinations). It is necessary to determine for the partial and for the whole transport problems those quantities of cargo containers that will be transported from such i-initial centre (i = 1, 2... m) to such *j-destination* j = 1, 2 ... n), where:

- offer of any initial centre will fail;
- demand of each destination will be settled;
- total manipulative transport expenses are minimal.

While formulating the transport problem it is necessary to follow these assumptions:

1) Manipulative transport expenses by each transported container (TEU) with cargo at line *i-initial centre - j-destination* (**Cij**) are proportional to the quantity of containers (TEU) with cargo that should be transported from i-initial centre to j-destination (**X_{ij}**).
2) There is a possibility that each container (TEU) with the cargo of any initial centre is substituted with cargo container (TEU) from some other initial centre (this is assumption of homogeneous manipulative transport unit with cargo, i. e. container with characteristics of TEU).
3) When partial problems are concerned transport cargo containers are not reloaded. Each shipment Xij is dispatched directly from and out of that i-initial centre to j-destination.
4) Parameters **ai** (quantity of containers with cargo - TEU that are at disposal of i-initial centre) and - **b_i** (quantity of containers with cargo - TEU demanded by j-destination) must always be positive.
5) Parameter **C_{ij}** (manipulative transport expenses by each container with cargo - TEU that is transported on the line i-initial centre - j-destination) could be positive and negative.

Mathematical forming of the transport problem could be expressed as objective function that expresses total expenses that should be minimised and which contain unit expenses multiplication product and transported quantities.[8]

$$\text{Min} = \sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij} X_{ij} \quad (1)$$

Limitations are:

$$\sum_{j=1}^{n} X_{ij} = a_i, \text{ for each } i = 1,2,\dots m \quad (2)$$

$$\sum_{i=1}^{m} X_{ij} = b_j, \text{ for each } j = 1,2,\dots n \quad (3)$$

$$X_{ij} \geq 0, \text{ for each pair } i, j \quad (4)$$

Further are the explained partial theoretical problems of cargo container transport in TEU in international multimodal transport. Basic, global assumption: one entrepreneur of international multimodal transport (in practice there could be several entrepreneurs), should organize fast, safe and rational transport (and distribution) of larger quantity of containers with cargo (all calculated to containers with TEU characteristics), from different land terminals in the USA area by road vehicles across different US ports (i. e. port container terminals) towards European ports (i. e. container port terminals), and further on distributing by railroad to several land terminals (i. e. rail-road terminals), and finally from those terminals distribution would continue by road vehicles to end users in East European countries.

Each partial transport problem and container distribution with cargo (there will be four - all in TEU) is to be formed on the basis of the general model of container transport problem (Table 1).

Table 1 - General multimodal transportation model

j / i	KT_1	KT_2	KT_3	KT_4	KT_5	a_i
KKT_1	C_{11} X_{11}	C_{12} X_{12}	C_{13} X_{13}	C_{14} X_{14}	C_{15} X_{15}	a_1
KKT_2	C_{21} X_{21}	C_{22} X_{22}	C_{23} X_{23}	C_{24} X_{24}	C_{25} X_{25}	a_2
KKT_3	C_{31} X_{22}	C_{32} X_{32}	C_{33} X_{33}	C_{34} X_{45}	C_{35} X_{35}	a_3
KKT_4	C_{41} X_{41}	C_{42} X_{42}	C_{43} X_{43}	C_{44} X_{44}	C_{45} X_{45}	a_4
b_j	b_1	b_2	b_3	b_4	b_5	$\sum a_i = \sum b_i$

Symbols in table represent:

1) a_i = quantity of cargo containers (TEU) at disposal of i-initial centre, such as:
   a_1 = quantity of containers at disposal of LCT_1 (land container terminal).
2) b_j = quantity of cargo containers (TEU) demanded by j-destination, such as:
   b_1 = quantity of containers demanded by the CT_1 (container terminal).
3) X_{ij} = quantity of cargo containers (TEU) that should be transported from i-initial centre to j-destination, i. e. X_{11} quantity of containers that should be transported from LCT_1 to CT_2.
4) C_{ij} = transport expenses per each transported container (TEU) at the line i-initial centre to j-destination, i. e.: C_{11} = freight (land or sea transport) for transportation of one cargo container (TEU) from LCT_1 to CT_1.
5) i = initial centre (centre with fixed supply), i. e. LCT_1
6) j = destination (centre with fixed demand or consumption), i. e.: LCT_1
7) P_{ij} = field inside the container transport problem model, i. e. p_{11} = field in the first line and first column.
8) TEU = equivalent of twenty-feet unit - containers calculated to 20 feet or twenty feet-equivalent unit (such as ISO 1C containers), that have the average mass of 13500 kg

The value of parameters a_i and b_j is expressed in manipulative transport unit **TEU** (Twenty Feet Equivalent Unit), therefore the containers are calculated to

20 feet (1 foot = 0.3048 m).[9] The value of parameter C_{ij} is expressed in thousands of kuna per each 20-feet container.

If in the general model of cargo container problem (TEU) the actual data on quantities of cargo containers that should be transported from i-initial centre to j-destination are entered, the complete forming of multimodal transport problem of cargo container is possible (Tables 2a, b, c and d). Tables 2a, 2b, 2c and 2d show formulated partial problems of container transport, whereas in Table 2a the initial centre nodes are defined, and in Table 2d partial problems of container transport. Further, Table 2a shows initial centre nodes, Table 2d destination nodes, and Tables 2b and 2c show reload nodes.

Table 2a defines the *first partial problem of container transport* ($TRANS_{-1}$) by road vehicles from four US continental container terminals, (i. e. $ACCT_{-1}$, $ACCT_2$, $ACCT_3$ and $ACCT_4$) up to five US container terminal ports (i.e. $APCT_1$, $APCT_2$, $APCT_3$, $APCT_4$ and $APCT_5$). Problem of transport and cargo container formed in such a way (TEU) will be used for exploring the optimal problem solution by application of methods of linear programming and simulation.

The second partial problem of transport and distribution of containers with cargo (TEU) - (TRANS-2) is formed in such a way that they are transported through container ships of fourth and fifth generation from five US port container terminals (i.e. $APCT_1$ l $APCT_2$, $APCT_3$, $APCT_4$ and $APCT_5$), through ships across the Atlantic towards four European port container terminals (i. e. $EPCT_1$, $EPCT_2$, $EPCT_3$ and $EPCT_4$) - (Table 2b).

The third partial problem of transport and distribution of cargo containers (TEU) - (TRANS-3) is formed in the following way: containers are transported by railroad from four European port container terminals (i. e. $EPCT_1$, EPCT2, $EPCT_3$ and $EPCT_4$) towards five European continental container terminals (i. e. $ECCT_1$ $ECCT_2$ $ECCT_3$ $ECCT_4$ and $ECCT_5$) - (Table 2c.).

The fourth partial problem of transport and distribution of cargo containers (TEU) - (TRANS-4) is formed in such a way that containers are transported by road vehicles from five European continental container terminals (i.e. $ECCT_1$, $ECCT_2$,

Table 2a - General multimodal transportation model TRANS 1

i \ j	$ALKT_1$	$ALKT_2$	$ALKT_3$	$ALKT_4$	$ALKT_5$	a_i
$AKKT_1$	2.2	3.1	3.4	2.7	2.5	12500
$AKKT_2$	1.9	2.3	2.7	3.2	3.3	14000
$AKKT_3$	2.9	3.4	2.5	3.3	4.2	13000
$AKKT_4$	3.2	2.7	2.9	3.4	3.8	15500
b_j	10800	11000	9000	10700	13500	55000

Table 2b - General multimodal transportation model TRANS 1

i \ j	$ELKT_1$	$ELKT_2$	$ELKT_3$	$ELKT_4$	a_i
$ALKT_1$	15	17	19	20	10800
$ALKT_2$	19	17	15	21	11000
$ALKT_3$	14	18	17	19	9000
$ALKT_4$	21	20	19	18	10700
$ALKT_5$	19	15	14	16	13500
b_j	12500	14000	13000	15500	55000

Table 2c - General multimodal transportation model TRANS 1

i \ j	$EKKT_1$	$EKKT_2$	$EKKT_3$	$EKKT_4$	$EKKT_5$	a_i
$ELKT_1$	1.0	1.2	1.4	1.5	1.7	12500
$ELKT_2$	1.2	1.5	1.6	1.7	1.9	14000
$ELKT_3$	1.4	1.6	1.9	2.1	2.2	13000
$ELKT_4$	2.0	2.1	2.3	1.9	2.2	15500
b_j	10800	11000	9000	10700	13500	55000

Table 2d - General multimodal transportation model TRANS 1

i \ j	$EKKT_1$	$EKKT_2$	$EKKT_3$	$EKKT_4$	$EKKT_5$	$EKKT_6$	$EKKT_7$	$EKKT_8$	$EKKT_9$	a_i
$EKKT_1$	0.8	0.7	0.6	0.7	0.8	0.9	0.8	0.7	0.6	10800
$EKKT_2$	1.0	1.1	1.2	1.3	1.2	1.0	1.1	1.3	1.4	11000
$EKKT_3$	0.9	1.0	1.2	1.3	1.4	1.5	1.6	1.3	1.2	9000
$EKKT_4$	1.0	0.9	0.8	1.2	1.1	1.3	1.5	1.4	1.3	10700
$EKKT_5$	1.2	1.3	1.4	1.5	1.6	1.7	1.3	1.1	1.4	13500
b_i	6500	6200	6100	5700	6200	5700	6200	6200	6200	55000

$ECCT_3$, $ECCT_4$ and $ECCT_5$) towards nine European continental container terminals (i.e. $ecct_1$, $ecct_2$, $ecct_3$, $ecct_4$, $ecct_5$, $ecct_6$, $ecct_7$, $ecct_8$ and $ecct_9$) - (Table 2d).

3. MODEL OF PARTIAL SOLVING OF MULTIMODAL TRANSPORT NETWORK

Multi-index problems of transport in general, as well as problems of container transport in international multimodal transport, as formulated above, are solved by different mathematical methods, such as, simplex model, method of jumping from rock to rock, Vogel method, MODI method or modified method of distribution, Hungarian method, and other linear or non-linear methods. Each of these methods has its rules, advantages and disadvantages, but based upon rules of such methods relevant software program can be executed, as well as through usage of computer calculated optimal transport and container distribution programs.

Complex multi-index problem of transport and container distribution for the entire transport project, i. e. for all four partial problems of transport where four branches of traffic participate in the entire relation of multimodal transport, "from manufacturer to consumer", can be solved in two different ways:

1. through method of partial solving of transport problems TRANS 1, 2, 3 and 4 and through simple multiplying of calculated minimal expenses for each problem separately, and
2. through the method of integral solving for the entire transport project by integrating all four partial transport problems.

The first method is limited to situations of partial transportation of goods where grouping of shipments of different types of goods is not considered. The second method could be applied in the partial and integrated model of multimodal transport. One of the significant objectives of grouping of shipments in integrated multimodal transport network is decreasing of total transport expenses, which shall be demonstrated by the calculated results.

Scheme 1 shows the model of partial solving of multimodal transport problem. It shows that the total solution of the transport problem is equal to the sum of partial transport problems. The advantage of this model is in its simple way of calculation for which it is sufficient to use simple user-oriented computer methods which are based on the usage of basic functions of spreadsheets and computer tool Solver. Much more significant fact is the disadvantage of this method where for solving the transport problem optimization of the entire transport problem is not considered, but calculated only sub-optimum of partial problems which are simply summed.

The example shows reload nodes that are treated as nodes of the required supply and demand of partial transport problems; therefore the integral model of solving transport problem as well, gives the same result. In the case the capacity of reloading nodes is higher than previously stated values of supply and demand and when transport problem considers only end initial and end destination centres, partial and integral models of solving the transport problem give different results.

5. MODEL OF INTEGRAL SOLVING OF MULTIMODAL TRANSPORT PROBLEM

Scheme 2 shows transformation of the classic model of partial transport problems from separate square matrix to integrated model of transport network. Scheme 1 presents the solved model of integrated transport network where values of required reloading nodes are equal in partial and in integral mode. In example on Scheme 1 the achieved value of minimal expenses of transport should be equal to the value of partial model considering that given entry values of unit expenses and nodes capacity are the same. Example in Scheme 1 represents successful testing of the model of integrated transport network considering the result of minimal expenses is 1,151,230, the same in partial and in integral model.

Comparing Scheme 1 and Scheme 2 one can notice that minimal expenses at partial model equal 1,151,230, where at integral equals 1,016,080, which means that the difference is 135150 currency units in favour of integrated transport, i. e. the saving in integrated transport is higher than 11% of total transport expenses. It should be mentioned that calculated optimal value in the amount of 1,016,080 has been calculated for the model of integrated multimodal transport in ideal conditions where the capacities of nodes and arcs are not limited. As discussed further, in one of the types of models the limitations of capacities of nodes and arcs will be joined, upon which less expenses of model of integrated transport will be presented, and the difference will be somewhat smaller.

The main difference between the partial (Scheme 1) and integral model (Scheme 2) is in fact that with integral model the values of quantity of goods that are reloaded on reloading nodes are optimised, i. e. goods flow through reloading centres. Unlike partial model, integral model selects one or more optimal transport lines, therefore the goods flows are grouped. Scheme 2 shows that optimal transport lines consist of nodes N7-N10-N14 and N9-N12-N14.

Initial centres

i \ j	N5	N6	N7	N8	N9	a_i
N1	0	0	0	0	12500	12500
N2	10800	2200	0	0	1000	14000
N3	0	0	9000	4000	0	13000
N4	0	8800	0	6700	0	15500
b_j	10800	11000	9000	10700	13500	55000

Minimal costs
1.151.230

TRANS1	=	142370
TRANS2	=	865500
TRANS3	=	90280
TRANS4	=	53080

Transloading nodes

i \ j	N10	N11	N12	N13	a_i
N5	3500	7300	0	0	10800
N6	0	0	11000	0	11000
N7	9000	0	0	0	9000
N8	0	0	0	10700	10700
N9	0	6700	2000	4800	13500
b_j	12500	14000	13000	15500	55000

i \ j	N14	N15	N16	N17	N18	a_i
N10	0	0	3800	0	8700	12500
N11	8800	0	5200	0	0	14000
N12	2000	11000	0	0	0	13000
N13	0	0	0	10700	4800	15500
b_j	55000	11000	9000	10700	13500	55000

Destinations

i \ j	N19	N20	N21	N22	N23	N24	N25	N26	N27	a_i
N14	0	0	0	4600	0	0	0	0	6200	10800
N15	0	0	0	0	5300	5700	0	0	0	11000
N16	6500	2500	0	0	0	0	0	0	0	9000
N17	0	3700	6100	0	900	0	0	0	0	10700
N18	0	0	0	1100	0	0	6200	6200	0	13500
b_i	6500	6200	6100	5700	6200	5700	6200	6200	6200	55000

Scheme 1 - Model of partial multimodal transport solution

Initial centres

i \ j	N5	N6	N7	N8	N9	a_i
N1	0	0	0	0	**12500**	**12500**
N2	0	0	**14000**	0	**0**	**14000**
N3	0	0	**13000**	0	0	**13000**
N4	0	0	**15500**	0	0	**15500**
b_j	**0**	**0**	**42500**	**0**	**12500**	**55000**

Minimal costs

1.016.800

TRANS1	=	146500
TRANS2	=	770000
TRANS3	=	60000
TRANS4	=	40300

Transloading nodes

i \ j	N10	N11	N12	N13	a_i
N5	0	0	0	0	**0**
N6	0	0	0	0	**0**
N7	**42500**	0	0	0	**42500**
N8	0	0	0	0	**0**
N9	0	0	**12500**	0	**12500**
b_j	**42500**	**0**	**12500**	**0**	**33000**

i \ j	N14	N15	N16	N17	N18	a_i
N10	**42500**	0	0	0	0	**42500**
N11	0	0	0	0	0	**0**
N12	**12500**	0	0	0	0	**12500**
N13	0	0	0	0	0	**0**
b_j	**55000**	**0**	**0**	**0**	**0**	**55000**

Destinations

i \ j	N19	N20	N21	N22	N23	N24	N25	N26	N27	a_i
N14	**6500**	**6200**	**6100**	**5700**	**6200**	**5700**	**6200**	**6200**	**6200**	**55000**
N15	0	0	0	0	0	0	0	0	0	**0**
N16	0	0	0	0	0	0	0	0	0	**0**
N17	0	0	0	0	0	0	0	0	0	**0**
N18	0	0	0	0	0	0	0	0	0	**0**
b_j	**6500**	**6200**	**6100**	**5700**	**6200**	**5700**	**6200**	**6200**	**6200**	**55000**

Scheme 2 - Model of integral multimodal transport solution in circumstances without transhipment constraints

The methods for the first way are already well known and elaborated in numerous previous discussions, but herewith the method of integrating partial transport problems to unique complex transport network will be discussed and explained in details. This method, due to a large number of initial centres and numerous mathematical operations, in calculation of optimal solutions, requires the usage of sophisticated languages for modelling, supported by robust Solvers for solving transport problems.

6. METHODOLOGICAL SCOPE OF USAGE OF OPTIMAL COMPUTER PROGRAMS IN MODELLING OF MULTIMODAL TRANSPORT NETWORKS

General applicative model serves as the foundation for designing actual applicative model with the usage of certain computer tools and programs. Table 3 shows an example of the solved model of multimodal transport network in conditions of limitation of nodes capacity and capacity of arcs. The table shows the modelling of data and defining of variables of multimodal transport network in interface of spreadsheet Excel table. Columns in the table represent the input and output variables, where each column address area has its variable name.

Each address area of the model set in Table 3 is defined with relevant name through the function Insert/Name/Define.[10] Therefore, the address area U5: U109, which includes decision-making variables that should represent optimal flows, is marked as Flows. This enables clearer view and simpler way of entering model formulas. For example, if you wish to define a formula in Solver, it is required that flows must be higher than 0; instead of abstract expression U5: U109>=0, a simpler expression Flows >= 0 will be used. The model of spreadsheet data refers to partial matrix of the given problem of multimodal transport presented in Tables 2a, 2b, 2c and 2d.

Modelling languages enable presentation of the problem within the mathematical form of indexes and databases. The main feature of the modelling language is the possibility of grouping similar entities to sets. When entities are grouped into sets they are presented through the characteristics of that set. In this way the entity groups could be shown through one algebra expression.[11] Program language LINGO has the possibilities of direct two-way relation and usage of data sets in the Excel spreadsheet through OLE

Table 3 - Data modelling and variables defining in multimodal transportation network design

1049820 =SUMPRODUCT(COSTS;FLOWS)							
IS	OD	COST	CAPARCS	NODES	RCAPN	CAPNODE	FLOWS
1	5	2.2	10000	1	12500	30000	2500
1	6	3.1	10000	2	14000	30000	0
1	7	3.4	10000	3	13000	30000	0
1	8	2.7	10000	4	15500	30000	0
1	9	2.5	10000	5	0	30000	10000
2	5	1.9	10000	6	0	30000	7500
2	6	2.3	10000	7	0	30000	0
2	7	2.7	10000	8	0	30000	0
2	8	3.2	10000	9	0	30000	0
5	13	20	20000	24	-5700	30000	0
6	10	19	20000	25	-6200	30000	0
6	11	17	20000	26	-6200	30000	0
6	12	15	20000	27	-6200	30000	5500
6	13	21	20000				0
7	10	14	20000				20000
17	20	0.9	10000				0
17	21	0.8	10000				0
18	26	1.1	10000				0
18	27	1.4	10000				0

Table 4 - Framework of transformation of mathematical formulas in computer algorithms for multimodal transportation networks optimization

	Mathematical model	Excel	Lingo
Function	$Min = \sum_{i=1}^{n}\sum_{j=1}^{n} Cost_{ij} * Flow_{ij}$	TC=SUMPRODUCT(CO;FL) Set Target Cell: TC Equal To: Min	MIN=@SUM(ARCS: :COST*FLOWS)
Decision making var.	$Flow_i$	By Changing Cells: Flows	ARCS(NODES,NODES):FLOWS
Constraints	$\sum_{j=1}^{n} FlowN_{ij} - \sum_{j=1}^{n} FlowN_{ji} = \sum_{i=1}^{n} RCapN_i$	FlowNi= =SUMIF(Origins;H18;Flows)- SUMIF(Dests;H18;Flows) RCapNi=Number Solver: Subject to the Constraints: FlowN=RCapN	@FOR(NODES(I): @SUM(ARCS(I,J):FLOWS(I,J))- @SUM(ARCS(J,I):FLOWS(J,I))= RCAPNODES(I));
	$\sum_{i=1}^{n} FlowN_i <= \sum_{i=1}^{n} CapN_i$	Solver: Subject to the Constraints: FlowN <= CapN	@FOR(NODES(I): @SUM(ARCS(I,J):FLOWS(I,J))<= CAPNODES(I));
	$\sum_{i=1}^{n} Flow_i <= \sum_{i=1}^{n} CapA_i$	Solver: Subject to the Constraints: Flows<=CapArcs	@FOR(ARCS(I,J): FLOWS(I,J) <= CAPARCS);

command (Object Link Embedding) that enables the flow among data of the language LINGO and Excel table.

Table 4 shows the functions of the objective and limitation of the considered transport problem in the form of mathematical model in appropriate shape for LINGO program language and computer tool Solver through interface of the Excel table. The table shows the user orientation of the presented programs. The suggested methodological scope of forming the applicative model for optimization on the example of solving the transport problems could serve a manager as the end-user and encourage him to use computer programs and tools in solving the optimization problems.

Table 4 shows the transformation of the mathematical model formula to command of the Excel spreadsheet and program language LINGO that enables implementation of computer algorithms in automation and execution of mathematical formula for optimization of multimodal transport network. The table shows that the presented application in LINGO program language logically follows the syntax, functions and commands of the Excel spreadsheet, where entering mathematical formula referring to objective formula and limitations is largely analogue to mathematical model.

For example, by entering the formula for objective function, Excel uses the function SUMPRODUCT for summing the multiplication product of unit expenses and goods quantity on arcs (transport lines). The card of the Solver computer tool defines the address where the function has been entered and objective (marked as Min in the card). With LINGO program language the entire formula is entered directly where summing the function (SUM) and mathematical operator for multiplying (*) are entered through sequences. Arcs (transport relations) are defined as data sets, i. e. as groups of arranged pair of nodes where each pair of nodes refers to the unit expenses, capacities and quantities.

The function for limitation is somewhat more complex. Defining the conditions of equality between the flow through nodes and nodes capacities is the same in the Excel application as in the LINGO program. The complex part of the formula, which differs from the usage between Excel and LINGO, is the calculation of the flow through nodes as well as difference between goods quantities that enter the node and leave the node. Both programs use the same function SUM. The difference is in the method of identifying the relevant nodes. Excel, in connection to function SUM, uses IF function, which selects relevant arcs comparing the addresses in the table with indications of the initial centre and destination and sums the flows from the selected arcs of the relevant node.

With program LINGO, the flow through nodes is also calculated by selecting the flows from the arcs that are relevant to that node and summing of these flows. The difference is in the syntax where opposite to Excel and used function SUMIF, LINGO uses function SUM in connection to the command FOR which defines the program loop. Data preparation in the form of sets in program language LINGO is possible through multi-index indication of variables. Therefore, on calculation for each node (defined by command @FOR(NODES(I): ...), the values of the flows are selected in the way of one index being fixed and the other being variable. This means that for each node the values of flows where values of variable index correspond to the value of fixed index are summed as defined in the set of input data.

7. CONCLUSION

This scientific discussion deals with the problems of designing and functioning of computer programs in modelling and solving problems of multimodal transport networks. The hypothesis of possibility of defining the applicative model of multimodal transport network that has the ability to adjust to different computer programs for integral solving of multimodal transport problems and rationalization of transport network has been proved.

Spreadsheets in connection to the computer tools and programs stand for representative software package for complex problems of mathematical programming and as such enables designing and implementation of the model of multimodal transport networks. User orientation of spreadsheets enables clear view of input and output variables as a computer-supported process of optimization which is the foundation for the recognition and understanding of integration of mathematical and computer logics. LINGO program language is more abstract in relation to the Excel spreadsheet and requires certain knowledge on programming. Defining and presentation of problem logics in Excel in the way which is acceptable to the computer program represents ideal basis for modelling in program language LINGO, as well as faster and more effective implementation of mathematical model.

This paper compares the partial and integral method of solving multimodal transportation networks. In cases where there are no limitations to transhipment capacities, or when these limitations are minimal, it is not reasonable to solve the multimodal transportation network problem by using the partial method; instead, the integral method should be applied. The integral method of multimodal transportation network problem solving is more complex and, as opposed to the partial method, requires more sophisticated programs as far as spreadsheets are concerned. The use of the mathematical modelling programming language LINGO is demonstrated in this paper. The basic hypothesis confirmed in this paper is that the integral method is more effective as far as the rationalization of multimodal transportation networks is concerned, in comparison with the partial method. With the partial solving method, the optimum result amounts to 1,151,230 monetary units, and with the integral multimodal transportation network problem-solving method the optimum result is 1,016,800 monetary units, the savings being 11.68%. This proves that it is more rational to solve multimodal transportation network problems with the integral method, rather than the partial method. The integral method for multimodal transportation network problem solving is more complex and, as opposed to the partial method, it requires much more sophisticated programs, in comparison to spreadsheets

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SAŽETAK

RAČUNALNO PODRŽANO MODELIRANJE RACIONALIZACIJE MULTIMODALNIH TRANSPORTNIH MREŽA

U radu je obrađena problematika oblikovanja i funkcioniranja računalnih programa u modeliranju i rješavanju problema multimodalnih transportnih mreža. Definirana je metodologija integrirane uporabe programskog jezika za matematičko modeliranje i proračunske tablice u rješavanju problema složene multimodalne transportne mreže. Uspoređene su parcijalna i integralna metoda rješavanja multimodalnih transportnih mreža. Temeljna hipoteza postavljena u ovom radu je da se integralnom metodom postižu bolji učinci racionalizacije multimodalnih transportnih mreža, pri čemu se jednom izgrađeni model multimodalne transportne mreže temeljen na integralnoj metodi, može koristiti kao temelj za sve vrste transportnih problema u multimodalnom transportu. Za razliku od linearnih transportnih problema multimodalna transportna mreža može poprimiti vrlo složene oblike. U radu su uspoređeni parcijalni i integralni pristup rješavanja transportne mreže. Kod parcijalnog pristupa dovoljan je jednostavniji model transportne mreže koji se može riješiti uporabom računalnog alata Solver u sučelju proračunske tablice Excel. U rješavanju multimodalnog transportnog problema integralnom metodom, potrebno je koristiti sofisticirane programske jezike za matematičko modeliranje koji podržavaju uporabu složenih matričnih funkcija i procesiranje velikog broja varijabli i ograničenja. Programski jezik LINGO je apstraktniji u odnosu na proračunsku tablicu Excel i zahtijeva određena znanja o programiranju. Definiranje i prezentacija logike problema u Excelu na način prihvatljiv računalnom programu predstavlja idealnu osnovu za modeliranje u programskom jeziku LINGO, te bržu i učinkovitiju implementaciju matematičkog modela. U radu je dokazano da je problem multimodalne transportne mreže racionalnije rješavati integralnom, nego parcijalnom metodom.

KLJUČNE RIJEČI

multimodalni transport, transportne mreže, proračunske tablice, programski jezici za matematičko modeliranje, Lingo, Solver

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