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OPTIMIZATION OF MULTIMODAL TRANSPORTATION CHAINS IN THE KALEIDOSCOPE OF INFORMATION TECHNOLOGY

ABSTRACT

The basic aim of this treatise is to research relevant features of multimodal transportation chains, their advantages and disadvantages as well as the problems of the synchronization of work of all the participants in multimodal transport. With the development of information technology the method of optimisation of multimodal transportation chains is more and more based on the computer programs being representative tools in solving of comprehensive tasks.

It is believed that the present research, the methodology applied and its findings should promote and improve multimodal transportation chains in order to cope with the complex contemporary logistic demands of global economy.

KEY WORDS

optimisation, multimodal transportation chains, information technology

1. INTRODUCTION

A transportation chain is an integrity of technical, technological and organisational operations, synchronised in space and time (e. g. packaging, loading, discharging, transhipment, warehousing and delivery of goods), providing fast, secure and optimal flow of goods from their raw basis to the consumer. This research focuses on the container transportation chain with the aim of optimising it and identifying its advantages. Even though the system of optimal functioning of international transportation chains depends on several factors (traffic infrastructure, modern transportation technologies, development of foreign trade exchange etc.), it seems that the integral information system based on modern information technology represents its fundamental precondition.

Constant development and the quality improvement of computer hardware and software for the optimisation and algorithm technology paves the way for faster and more sophisticated software solutions of the problems occurring in traffic systems. The new software generation based on the integration of object technology and econometric engineering provides a substantial change, thus reducing the complexity and time of carrying out applications. The software components, which bridge the gap between the linear and limitation programming, are based on the generation of automatic codes. With the development of information technology the methods of optimisation of transport are increasingly based on the application of spreadsheets. Accordingly, a *hypothesis* is proposed: *The electronic Excel spreadsheet, being a representative packet for mathematical programming in the function of solving the transportation problems, enables effective optimisation of multimodal transportation chains.*

In order to prove the proposed hypothesis the following methods are used: analysis, synthesis, system, mathematical modelling and mathematical programming.

2. SPREADSHEET AND THE QUANTITATIVE ANALYSIS

The spreadsheet includes computer programs that may be used for computation and publication of the quantitative analysis. A spreadsheet may compute the majority of mathematical problems totally or partially. Even though there are numerous spreadsheet programs available on the market, the most popular is the Excel spreadsheet. The standard spreadsheets, which solve the problems of quantitative analysis, are further supported by specialised programs in order to widen their capacity. They are called "add-in" programs and once they are added, they may be used as an integral part of the spreadsheet. An example of an "add-in" program is the Solver. It is used to solve problems with many variables and assists in finding a combination of variables, which raise the target value to the maximum or reduce it to the minimum. The Solver also enables the setting of one or more constraints – conditions that have to be fulfilled for a satisfactory solution.

The quantitative analysis is a scientific approach for the managerial decision-making. Concepts, emotions and guessing are not considered to be part of such analysis. This approach begins with data. These are, like raw materials in factories, handled, i. e. transformed in information used by managers at all levels of decision-making. Such handling of raw data, shaping them into important information is the essence of the quantitative analysis. The approach of the quantitative analysis consists of defining the problem, developing a model, acquiring inputs, developing solutions, testing them, analysing results and applying them. The transportation problems take an important place in the operation research as well as in the application of quantitative methods for the solution of complex problems. The transport problem of linear programming occurs when the transport of definite goods from several points of departure and several points of destination has to be programmed (e. g. transport of containers with cargo from production points to seaports and from there to consumer points) with minimum costs. It should be pointed out here that addressing the transportation problems has a wider application and greater importance than usually believed. Namely, apart from the transport problems different other problems may also be methodologically solved in a similar way, as they are formally manifested in the same way.

The problem of transport is shown in Table 1 - quantity of transport, followed by the matrix of costs - Table 2.

Table 1 – Quantity of transport

Starting point	Destination point B_1 B_2 $\cdots$ B_n	Quantity despatched
A_1	x_{11} x_{12} $\cdots$ x_{1n}	$= a_1$
A_2	x_{21} x_{22} $\cdots$ x_{2n}	$= a_2$
$\vdots$	$\vdots$ $\vdots$ $\ddots$ $\vdots$	$\vdots$
A_m	x_{m1} x_{m2} $\cdots$ x_{mn}	$= a_m$
Quantity received	$= b_1 = b_2 = \ldots = b_n$	

Table 2 – Matrix of costs

Starting point	Destination point B_1 B_2 $\cdots$ B_n
A_1	c_{11} c_{12} $\cdots$ c_{1n}
A_2	c_{21} c_{22} $\cdots$ c_{2n}
$\vdots$	$\vdots$ $\vdots$ $\ddots$ $\vdots$
A_m	c_{m1} c_{m2} $\cdots$ c_{mn}

The quantities of dispatch at starting points are distributed to the quantities at destinations, so that the obtained optimal program yields the minimum transportation costs.

3. RELEVANT FEATURES OF MULTIMODAL TRANSPORTATION CHAINS

Being a subsystem of the international system, the programmed multimodal transport should provide undisturbed functioning of the door-to-door transportation chain. The latter represents in fact an integrated chronological transportation process from the manufacturer to the consumer. Since the process includes several traffic branches, technological integration of all links in the chain should be guaranteed in time and space. Should one link in the whole door-to-door process fail, the costs would rise and the multimodal or combined transport would prove to be ineffective.

The timing of multimodal transport as well as the synchronisation of all the participants in the transportation chain represents an important factor in providing regular, safe and fast functioning of modern transport. Therefore, without considering the established criteria - the synchronisation and co-ordination of work, the accomplishment of individual functions and relations – the transportation chain cannot work. Important conditions for the formation of a transportation chain are as follows:

- exact establishment and synchronisation of possible transport combinations on the basis of qualitative advantages as well as acquiring procedures of criteria evaluation;
- the choice of the most favourable variant, i. e. an optimal solution of forming the transportation chain considering the interests of all participants in it and avoiding risks at the same time;
- co-ordination of functions of the industrial and public or general transport, particularly during warehousing of goods and loading/discharging operations of containers, swap bodies, vehicles, trailers or pallets;
- regular provision (without standstills or waiting) of necessary transportation capacities in the chain of different traffic branches;
- provision of uninterrupted, regular and fast flows of goods in the process of reproduction, so that no phase is affected in "its production";
- use of modern unified technical and technological means in transport, production, despatch, packaging, warehousing etc.

4. DEFINING THE PROBLEM IN THE CONTAINER TRANSPORTATION CHAIN

The international multimodal transport operator is often faced with the problem of continuous distribution of containers with heterogeneous or homogeneous cargoes from numerous starting and destination points using several different traffic branches, meeting the entire supply and demand with minimal manipulation and transportation costs. In that case the operator may first identify partial transportation problems for the individual traffic branch and then for the whole transportation chain.

Further, partial theoretical problems of container transport in TEU are formulated. It is presumed that the multimodal transport operator should arrange dispatch of a greater number of containers with cargo from several shore terminals in the US by road vehicles through several US ports (i. e. port container terminals); from there to the European ports (i. e. port container terminals); further to distribute containers with cargo by rail to several shore terminals (i. e. rail-road terminals); and finally from these terminals, the distribution would continue by road vehicles to consumers in the countries of Eastern Europe.

In order to simplify the complicated multi-index problem of container transport (all in TEU) in the multimodal transport chain comprising four traffic branches with their technical, technological, organisational, economic and legal specificity, first, four individual, partial problems are formulated. Then, after having solved these problems and after having found the optimal solutions, the problem is formulated for the whole multimodal transport chain. Each partial problem of the multimodal transportation chain has generally been formulated in Tables 1 and 2.

In Table 3 the first partial problem is formulated, regarding container transport (TRANS-1) by road vehicles from four American continental container terminals (i. e. $ACCT_1$, $ACCT_2$, $ACCT_3$, $ACCT_4$) to five American port container terminals (i. e. $APCT_1$, $APCT_2$, $APCT_3$, $APCT_4$, $APCT_5$). The price is given in hundred € per 20-foot container unit.

The second problem (cf. Table 4) shows transportation and distribution of containers with cargo (TRANS-2) by container ships of the fourth and fifth

Table 3 – The model of the transport problem of containers with cargo – TRANS-1

j / i	$APCT_1$	$APCT_2$	$APCT_3$	$APCT_4$	$APCT_5$	a_i
$ACCT_1$	2.2	3.1	3.4	2.7	2.5	8 200
$ACCT_2$	1.9	2.3	2.7	3.2	3.3	8 500
$ACCT_3$	2.9	3.4	2.5	3.3	4.2	8 000
$ACCT_4$	3.2	2.7	2.9	3.4	3.8	8 300
b_j	6 500	6 600	5 400	6 200	8 300	33 000

Table 4 – The model of the transport problem of containers with cargo – TRANS-2

j / i	$EPCT_1$	$EPCT_2$	$EPCT_3$	$EPCT_4$	a_i
$APCT_1$	15	17	19	20	6 500
$APCT_2$	19	17	15	21	6 600
$APCT_3$	14	18	17	19	5 400
$APCT_4$	21	20	19	18	6 200
$APCT_5$	19	15	14	16	8 300
b_j	6 500	6 600	5 400	6 200	33 000

Table 5 – The model of the transport problem of containers with cargo – TRANS-3

j / i	$ECCT_1$	$ECCT_2$	$ECCT_3$	$ECCT_4$	$ECCT_5$	a_i
$EPCT_1$	1.0	1.2	1.4	1.5	1.7	8 200
$EPCT_2$	1.2	1.5	1.6	1.7	1.9	8 500
$EPCT_3$	1.4	1.6	1.9	2.1	2.2	8 000
$EPCT_4$	2.0	2.1	2.3	1.9	2.2	8 300
b_j	6 500	6 600	5 400	6 200	8 300	33 000

Table 6 – The model of the transport problem of containers with cargo – TRANS-4

j / i	$ECCT_1$	$ECCT_2$	$ECCT_3$	$ECCT_4$	$ECCT_5$	$ECCT_6$	$ECCT_7$	$ECCT_8$	$ECCT_9$	a_i
$ECCT_1$	0.8	0.7	0.6	0.7	0.8	0.9	0.8	0.7	0.6	6 500
$ECCT_2$	1.0	1.1	1.2	1.3	1.2	1.0	1.1	1.3	1.4	6 600
$ECCT_3$	0.9	1.0	1.2	1.3	1.4	1.5	1.6	1.3	1.2	5 400
$ECCT_4$	1.0	0.9	0.8	1.2	1.1	1.3	1.5	1.4	1.3	6 200
$ECCT_5$	1.2	1.3	1.4	1.5	1.6	1.7	1.3	1.1	1.4	8 300
b_i	3 800	3 600	3 500	3 700	3 750	3 850	3 600	3 600	3 600	33 000

generation from five American port container terminals (i.e. $APCT_1$, $APCT_2$, $APCT_3$, $APCT_4$, $APCT_5$) across the Atlantic Ocean to four European port container terminals (i.e. $EPCT_1$, $EPCT_2$, $EPCT_3$, $EPCT_4$).

The third partial problem (cf. Table 5) of transportation and distribution of containers with cargo (TRANS-3) shows transportation of containers by rail from four European port container terminals (i.e. $EPCT_1$, $EPCT_2$, $EPCT_3$, $EPCT_4$, $EPCT_5$ to five European continental container terminals (i.e. $ECCT_1$, $ECCT_2$, $ECCT_3$, $ECCT_4$, $ECCT_5$).

The fourth partial problem (cf. Table 6) of transportation and distribution of containers with cargo (TRANS-4) shows transportation of containers by road vehicles from five European continental container terminals (i.e. $ECCT_1$, $ECCT_2$, $ECCT_3$, $ECCT_4$, $ECCT_5$) to nine European continental container terminals (i.e. $ECCT_1$, $ECCT_2$, $ECCT_3$, $ECCT_4$, $ECCT_5$, $ECCT_6$, $ECCT_7$, $ECCT_8$, $ECCT_9$).

5. OPTIMISATION OF MULTI-MODAL TRANSPORTATION CHAINS WITH THE APPLICATION OF SPREADSHEET

The multi-index problems of transport generally as well as the problems of container transport in the multimodal transportation chain are solved by different methods (simplex method, stepping-stone method, Vogel method, MODI method or the modified method of distribution, Hungarian method as well as other linear or non linear methods). Table 7 shows the solution to a transportation problem by means of Excel software Solver. The model is set up for the first partial problem of container transport from four starting points to five destination points. The data and formulae are arranged in the addresses of the working list prepared for the computation of minimum costs.

In order to solve the given problem it is necessary to set up the chart Solver Parameters, so that the set target is entered in the window Set Target Cell or the

Table 7 – The model of the transport problem of containers (TRANS-1)

	A	B	C	D	E	F	G	H	I
1				Odredišta					
2		[illegible]	0	0	0	0	0		
3	Izvori	[illegible]	0	0	0	0	0		
4		[illegible]	0	0	0	0	0		
5		[illegible]	0	0	0	0	0		
6			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
7				Odredišta					
8			1	2	3	4	5		
9			6600	6600	5400	6200	8300		
10		8200	2,2	3,1	3,4	2,7	2,5		
11	Izvori	8500	1,9	2,3	2,7	3,2	3,3		
12		8000	2,9	3,4	2,5	3,3	4,2		
13		8300	3,2	2,7	2,9	3,4	3,8		
14		0	0	0	0	0	0		
15									
16									
17									
18	Upisane formule i naredbe u MSExcelu								
19									
20	B2 --> = SUM (C2:G2)				C14 --> = SUM(C2*C10+C3*C11+C4*C12+C5*C13				
21	B2 --> EDIT/COPY								
22	B3:B5 --> EDIT/PASTE				C14 --> EDIT/COPY				
23					D14:G14 --> EDIT/PASTE				
24	C5 --> =SUM(C2:C4)								
25	C5 --> EDIT/COPY				B14 --> SUM(C14:G14)				
26	C5:G5 -->EDIT/PASTE								

address containing the target function is selected; in the window Equal the option Min is selected considering the tendency to have minimal costs; in the window By Changing Cells the address series is entered containing all the variables; and the necessary constraints are entered in the window Subject to the Constraints.

When all parameters are entered, the key Solve on the chart Solver Parameters is clicked, thus activating

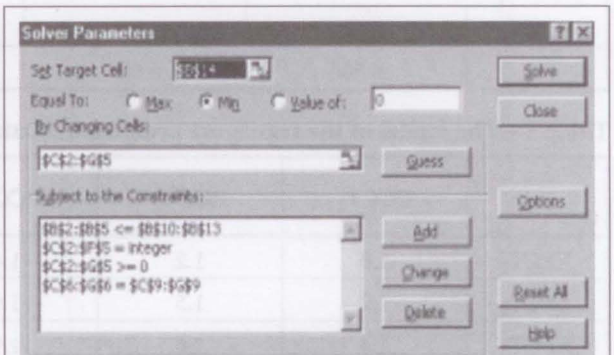

Figure 1 - Solver solving the problem of container transport TRANS-1

the Solver program, which calculates the decisive variable values in the address series. The most important result is calculated in the address representing the result of the transport problem TRANS-1. The decisive variables calculated in the address series C2: F4 define the cheapest transport route. Table 7 has shown the optimal solution to the problem with the application of MS Excel.

Table 8 – Optimal solution to the problem of container transport TRANS-1

	A	B	C	D	E	F	G	H	I
1				Odredišta					
2		0	0	0	0	0	8200		
3	Izvori	0	6500	1900	0	0	100		
4		0	0	0	5400	2600	0		
5		0	0	4700	0	3600	0		
6			6500	6600	5400	6200	8300		
7				Odredišta					
8			1	2	3	4	5		
9			6500	6600	5400	6200	8300		
10		8200	2,2	3,1	3,4	2,7	2,5		
11	Izvori	8500	1,9	2,3	2,7	3,2	3,3		
12		8000	2,9	3,4	2,5	3,3	4,2		
13		8300	3,2	2,7	2,9	3,4	3,8		
14		8456	1235	1706	1350	2082	2083		
15									
16		min T = 84560,00							
17									
18	Upisane formule i naredbe u MSExcelu								
19									
20	B2 --> = SUM (C2:G2)				C14 --> = SUM(C2*C10+C3*C11+C4+C12+C5*C13				
21	B2 --> EDIT/COPY								
22	B3:B5 --> EDIT/PASTE				C14 --> EDIT/COPY				
23					D14:G14 --> EDIT/PASTE				
24	C5 --> =SUM(C2:C4)								
25	C5 --> EDIT/COPY				B14 --> SUM(C14:G14)				
26	C5:G5 -->EDIT/PASTE								

Table 8 shows that the total cost of container distribution is 84,560.00 €. Analysing the optimal solution to the problem of container transport and distribution (TRANS-1) from the operator's viewpoint, it can be concluded that it is necessary: 1) from the starting point $ACCT_2$ to transport 6500 TEU per unit price of 190 € to the destination point $APCT_1$; 2) from the starting point $ACCT_2$ to transport 1900 TEU per unit price of 230 € to the destination point $APCT_2$; 3) from the starting point $ACCT_4$ to transport 4700 TEU per unit price of 270 € to the destination point $APCT_2$; 4) from the starting point $ACCT_3$ to transport 5400 TEU per unit price of 250 € to the destination point $APCT_3$; 5) from the starting point $ACCT_3$ to transport 2600 TEU per unit price of 330 € to the destination point $APCT_4$; 6) from the starting point $ACCT_4$ to transport 3600 TEU per unit price of 340 € to the destination point $APCT_4$; 7) from the starting point $ACCT_1$ to transport 8200 TEU per unit price of 250 € to the destination point $APCT_5$; 8) from the starting point $ACCT_2$ to transport 100 TEU per unit price of 330 . In such distribution the costs are minimal and they are lower than those obtained by the (least favourable) empirical program by 27%. Such substantial saving in transport costs is extremely important in setting competitive sale price of exported goods.

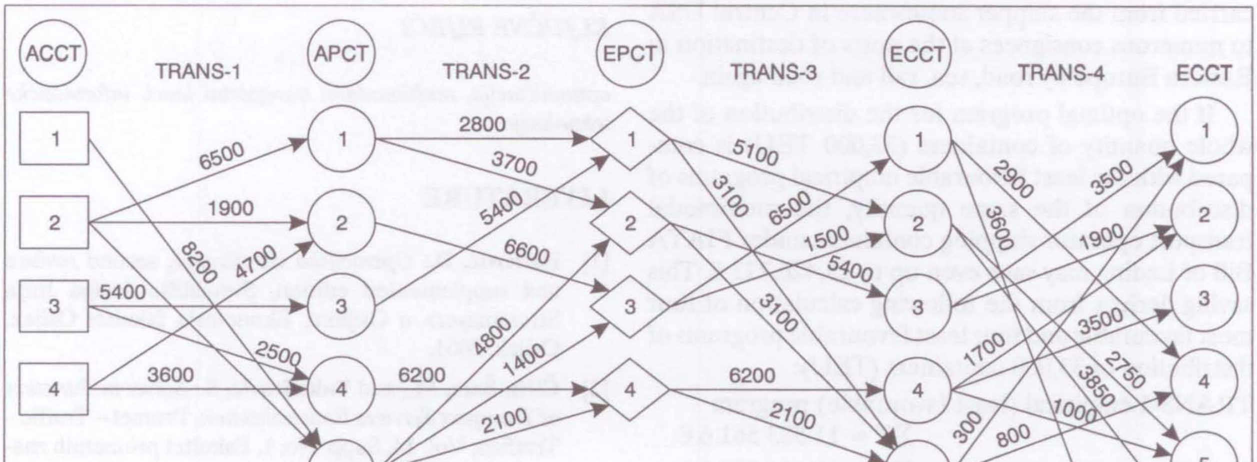

Figure 2 - Distribution of containers (TEU) presented by all four optimal programs: TRANS-1, TRANS-2, TRANS-3, TRANS-4 with the number of containers and the sum of the manipulating transport costs

The second, third and fourth partial transport problems are solved according to the same pattern with the same procedures as elaborated in the previous program TRANS-1. These procedures therefore do not need to be repeated. The costs of optimal partial distribution programs and their comparison with the (least favourable) empirical program will be discussed in more detail in the conclusion of this study. Further in the text the distribution of containers (TEU) is illustrated in all four optimal programs: TRANS-1, TRANS-2, TRANS-3 and TRANS-4 together with the number of containers and the total manipulation and transportation costs.

6. CONCLUSION

The development of utilitarian orientational programs for the quantitative analyses to be applied in the optimisation of transport shows the extension of possibilities of the program and the solving of complex strategic transport problems. The example is the multi-index transport problem presented in this study. The total manipulation costs amount to 68,670,000 € or 2080.9 € per container unit (TEU) of multimodal transportation chains for 33,000 full containers (TEU) carried from the shipper somewhere in Central USA to numerous consignees at the ports of destination in Eastern Europe by road, sea, rail and road again.

If the optimal program for the distribution of the whole quantity of containers (33,000 TEU) is compared with the least favourable empirical programs of distribution of the same quantity, the multimodal transport operator shipping containers under FIATA Bill of Lading may save even up to 25,426,773 €. This saving derives from the following calculation of four most favourable and four least favourable programs of distribution of 33,000 containers (TEU):

TRANS-1 empirical (least favourable) program

$\sum T = 11\ 583\ 561.6$ €

Least favourable program $\sum T = 8\ 456\ 000$ €

Saving (27%) $\sum T = 3\ 127\ 562.6$ €

TRANS-2 empirical (least favourable) program

$\sum T = 71\ 708\ 333.3$ €

Least favourable program $\sum T = 51\ 630\ 000$ €

Saving (28%) $\sum T = 20\ 078\ 333.3$ €

TRANS-3 empirical (least favourable) program

$\sum T = 6\ 900\ 000$ €

Least favourable program $\sum T = 5\ 382\ 000$ €

Saving (22%) $\sum T = 1\ 518\ 000$ €

TRANS-4 empirical (least favourable) program

$\sum T = 3\ 904\ 878$ €

Least favourable program $\sum T = 3\ 202\ 000$ €

Saving (18%) $\sum T = 702\ 878$ €

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SAŽETAK

OPTIMALIZACIJA MULTIMODALNIH TRANSPORTNIH LANACA U KALEIDOSKOPU INFORMATIČKIH TEHNOLOGIJA

Temeljni cilj ove znanstvene rasprave jest istražiti relevantna obilježja multimodalnih transportnih lanaca, njihove prednosti i nedostatke te problematiku sinkronizacije rada svih sudionika u multimodalnom transportu. Razvojem informatičkih tehnologija metode optimalizacije muldimodalnih transportnih lanaca sve se više temelje na uporabi računalnih programa kao reprezentativnoga alata u rješavanju složenih više-indeksnih problema optimalizacije multimodalnih transportnih lanaca.

Po svojim obilježjima, primijenjenoj metodologiji i rezultatima istraživanja, dobivene spoznaje u ovoj raspravi trebaju predstavljati kvalitetna polazišta za promicanje multimodalnosti, optimalizaciju multimodalnih transportnih lanaca, odnosno efikasno odvijanje mutimodalnoga transporta kako bi bio u stanju zadovoljiti sve složenije logističke zahtjeve globalne ekonomije.

KLJUČNE RIJEČI

optimalizacija, multimodalni transportni lanci, informatičke tehnologije

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