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Characteristics of the Functioning of Agricultural Products Transportation Networks

Jacek Wawrzosek, Szymon Ignaciuk

Department of Applied Mathematics and Computer Science, University of Life Sciences in Lublin, 20-950 Lublin, 13 Akademicka Street, Poland, e-mail: jacek.wawrzosek@up.lublin.pl

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Summary. The management of complex transportation networks of agricultural producers requires the centralisation of management. In the study we present the method of determination of simple economic characteristics of complex transportation networks in the form of a few optimisation barriers. They reflect the border values of the parameters of the network operating under various management methods. The interpretation of the achieved barriers was provided. The methodology of the assessment of the synergy effect of the operation of the agricultural producer group was indicated. A relevant example was presented.

Key words: optimisation, multistage transportation problem, centralisation of management, producer groups.

INTRODUCTION

TRANSMISSION CENTRALISATION PROBLEMS IN THE AGRICULTURAL TRANSPORTATION NETWORK

The use of operational research methods in the agricultural economics problems as well as in the agricultural and food industry has been dealt with in subject literature on a number of occasions. The transportation issue in agriculture as well as the agricultural and food industry can be viewed upon in various aspects. It can be a decisive factor as regards the location of the agricultural and food production facilities or it can optimise transportation costs incurred in the existing structure of the agricultural transportation network. For example Platt [15], Siarkowski et al [16] indicate the mathematical programming models used for the needs of the dairy industry while determining the range of products and in the dairy transportation problems, whereas Nowicka-Skowron [14], Baryła-Paśnik et al [2] presents heuristic models used in dairy transportation. Kłapeć and Marszałkowicz [8] use multi-stage transportation problems for the needs of forest economy. Marczuk [10÷13] considers the problems of transportation of agricultural products and deals with inter alia the determination of the quantity of the means of transport necessary for the execution of transportation tasks [see also 9]. Ignaciuk and Wawrzosek [7] touch upon the new issues regarding the optimisation of transportation as regards agricultural producer groups [18÷21]. They indicate new possibilities of the application of various tools of operational research, including modified models of multi-stage problems for the needs of determining the economic justifiability of adopting the rules applicable to the members of a producer group and regarding the transport of agricultural products. In this study the authors refer to the methodology of this article. They consider here different conditions resulting this time from the network capacity. They address the issue of the cost effectiveness of synergistic actions taken up by a number of entities through the operation of producer groups. Moreover, they compare the cost effectiveness of joint management as regards decentralised way of product transportation. At the same time, the authors stress the fact that centralised management within an agricultural producer group is connected with the costs of its implementation and maintenance.

The continuous improvement of suboptimum operating parameters of the entire transmission network entails using simple indices of improvement of its operation that should reflect the most significant economic features connected with the network at issue. In the study it is indicated that the method of determining economic characteristics of usually complex transportation networks should refer to existing optimization barriers. The optimization barriers determined in this study constitute border values of parameters which can be achieved by the network under management decentralization conditions.

A multistage transportation problem *(MTP)* is a transportation problem consisting in moving one, uniform type of goods from consignors (sources) to consignees (destinations), where the transportation can be effected via other nodes (that are not ultimate consignees). *MTP* can be presented in a graphic way as a transportation network.

SYMBOLS

Each of n nodes o_i (i = 1,2,...,n) for *MTP* is characterised by coefficient: p_i – i.e. a difference in the supply possibility and demand possibility of a given node. If the difference between the supply and demand possibility is:

1. $p_i > 0$ for $1 \le i \le n_1$ it means that n_1 nodes are ***consignors (sources) S_i***,
2. $p_i = 0$ for $n_1 + 1 \le i \le n_1 + n_2$, then a node cannot stop incoming goods i.e.. n_2 nods are ***intermediate storage facilities (warehouses) W_i***,
3. $p_i < 0$ for $n_1 + n_2 + 1 \le i \le n_1 + n_2 + n_3 = n$ it means that n_3 nodes are ***consignees (destinations) D_i***.

$\boldsymbol{A}$ – a set of ordered pairs (i, j) for which there exists a possibility of transportation between i-th and j-th node of the *MTP* network, where we assume a priori that $(i, i) \notin \mathbf{A}$, for each $1 \le i \le n$ (we assume that the shipping from o_i node to itself is not possible). Set $\boldsymbol{A}$ constitutes a fragment – a subset of square matrix elements $\boldsymbol{A}_0$ of dimension $n \times n$.

$c_{i,j}$ – unit transport cost between i-th and j-th node *MTP* for $(i, j) \in \boldsymbol{A}$. We assume that such a cost is always nonnegative.

$d_{i,j}$ – capacity between i-th and j-th *MTP* node for $(i, j) \in \boldsymbol{A}$.

$x_{i,j}$ – decision variables determining the quantity of goods shipped between i-th and j-th *MTP* node for $(i, j) \in \boldsymbol{A}$.

Additionally the sums of $x_{i,j}$ for all columns and rows of matrix $\boldsymbol{A}_0$ (the sums of $x_{i,j}$ for members of the set $\boldsymbol{A}$) of decision variables are denoted by:

$k_j = \sum_{\substack{(i,j)\in A \\ 1\le i\le n}} x_{i,j}$ (total quantity of goods supplied to the j-th *MTP* node),

$r_i = \sum_{\substack{(i,j)\in A \\ 1\le j\le n}} x_{i,j}$ (total quantity of goods shipped from the i-th *MTP* node),

$u_i = r_i - k_i$ (difference between the quantity of shipped and received by the i-th *MTP* node).

MATERIAL AND METHODS

CHARACTERISTICS OF THE TRANSPORTATION NETWORK

The transportation network as regards economic transportation indices is characterised by three particular parameters:

1. m_T maximum transmission of the network (quantity of goods that can be transported in a definite time from consignors to consignees via storage facilities),
2. $f_{\min}(m_T)$ minimum cost of transport executing the maximum transmission of the network,
3. $f_{\max}(m_T)$ maximum cost of transport executing the maximum transmission of the network,

as well as two basic functions that characterise the network $f_{\min}(m)$ and $f_{\max}(m)$ for transmission execution level m, where $0 \le m \le m_T$. Function $f_{\min}(m)$ corresponds to the centralised and optimum network management in an economical way, whereas function $f_{\max}(m)$ describes a maximally uneconomical way of operating the network (which can be achieved while employing central, expedient management). Function $f(m)$ is such that $f_{\min}(m) \le f(m) \le f_{\max}(m)$ dependent on the transmission execution level m corresponds to the decentralization in the network management.

The ways to estimate possible functioning of the network can be the function plot being the average $\frac{f_{\min}(m) + f_{\max}(m)}{2}$, range $f_{\max}(m) - f_{\min}(m)$ or ratio $\frac{f_{\min}(m)}{f_{\max}(m)}$. To give an example, while considering that the range $f_{\max}(m) - f_{\min}(m)$ to function $f_{\min}(m)$ ratio takes on small values as compared to the costs of network control or the ratio $\frac{f_{\min}(m)}{f_{\max}(m)}$ is close to one there is a need to consider a possibility of abandoning centralised management of the network. An example where some of the above network characteristics for a multistage transportation problem *MTP* have been analysed is presented at the end of the study.

TWO-PHASE ALGORITHM

Below a two-phase algorithm was proposed for *MTP*. This algorithm modifies classical transportation models of linear programming [1, 3÷6, 8, 13, 17, 22÷24]. Its first phase consists in determining the ***maximum transmission of m_T network*** from established consignors to consignees (see Definition 2 below), whereas the second phase by optimizing the total shipping costs determines the following:

1. optimum goods transport plan,
2. network characteristics defined above,

at the determined (not necessarily maximum) use of its transmission capacity. The concurrent examining of the minimum and maximum shipping cost in the second phase is connected with the consideration of the centralised and decentralised network management mentioned at the beginning.

The maximum transmission of transportation ***network*** m_T is the maximum quantity of goods that can be transported at a given *MTP* in a network with o_i from the consignors (sources) through storage facilities to consignees (destinations) while complying with limitations imposed as to the demand and supply possibilities and route capacity i.e. weight limitations regarding both nodes o_i and arches (o_i, o_j) of a graph.

PHASE 1: DETERMINATION OF THE MAXIMUM TRANSMISSION IN THE NETWORK

Model ***MTP–P1***:

ObjF (maximum transmission of the network): $m_T = \sum_{1\le i\le n_1} u_i \to \max$,

*LC-P*1 were presented in Table 1.

Table 1. Presentation of limiting conditions for phase 1 of the algorithm; model MTP–P1.

Nodes	Shipping – receiving
Consignors (sources)	$0 \le u_i \le p_i$
Intermediate storage facilities	$u_i = 0$
Consignees (destinations)	$p_i \le u_i \le 0$

LC-C (capacity): $x_{i,j} \le d_{i,j}$ for each pair $(i,j) \in \boldsymbol{A}$,
BC: $x_{i,j} \ge 0$ for each pair $(i,j) \in \boldsymbol{A}$.

PHASE 2: OPTIMUM COST OF TRANSPORT

Transmission execution level (*T.E.L.*) is any number m such that $0 \le m \le m_T$.

Model ***MTP–P2***:

ObjF (minimisation or maximisation of the total transport cost in the network for selected m as *T.E.L.*):

$$f_{\min}(m) \text{ or } f_{\max}(m) = \sum_{\substack{(i,j)\in A \\ 1\le i,j\le n}} x_{i,j} \cdot c_{i,j} \to \min \text{ or } \max,$$

$$LC\text{-}P2: \begin{cases} LC\text{-}P1, \\ LC\text{-}C, \\ LC\text{-}T.E.L. \text{ (determined } T.E.L. \text{ in the network): } \sum_{1\le i\le n_1} u_i = m \end{cases}$$

BC: $x_{i,j} \ge 0$, for each pair $(i,j) \in \boldsymbol{A}$.

LC-P2 is composed of *LC-P1* and *LC-C* complemented by an additional condition *LC-T.E.L.* that can guarantee achieving *T.E.L.* at m level.

RESULTS AND DISCUSSION

EXAMPLE OF USE OF THE CHARACTERISTICS OF THE TRANSPORTATION NETWORK OF AN AGRICULTURAL PRODUCER GROUP

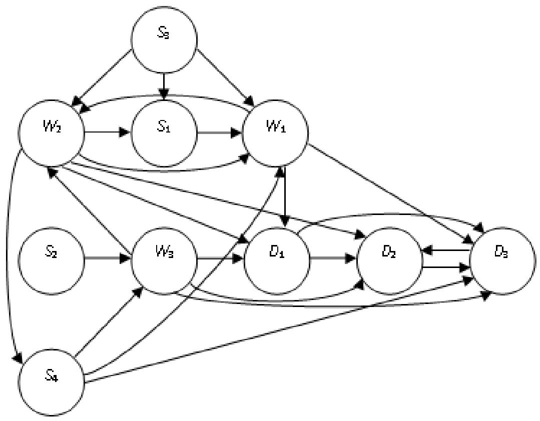

Fig. 1. Directed graph with weights on edges and nodes

The agricultural producer group is engaged in the goods transportation in the network presented graphically in Figure 1. The weights ($c_{i,j}$, $d_{i,j}$) were collected in Table 2 as two sparse matrices. Weights (p_i) are column vectors in Table 2. Table 2 also contains a sparse matrix $x_{i,j}$ of the solution minimising of the total shipping costs for *T.E.L.* of $m = m_T = 56$ goods units. The minimum transport costs for $m = 56$ goods units amount then to 3216 monetary units. Let us notice that (Table 2) the limiting conditions *LC-C* $x_{i,j} \le d_{i,j}$ are fulfilled.

THE MAXIMUM AND THE MINIMUM SHIPPING COSTS FOR THE AGRICULTURAL PRODUCER GROUP

The analytical tools of economic aspects of network transmission considered here are directly or indirectly connected with two basic functions $f_{\min}(m)$ and $f_{\max}(m)$, describing, respectively, the minimum and maximum total costs of network transportation for *T.E.L.* in the amount of m. These functions enable the economic assessment of the network transportation possibilities without getting into its detailed structure and they allow uncomplicated comparison of networks. At the same time the presented characteristics allow the examination of the options of the network structure as regards the assumed parameters. The relevant characteristics of the network for the presented example were presented in graphs (Figure 1), created using a two-phase algorithm for the transportation network. All necessary calculations can be made using any optimisation software.

ABSOLUTE AND RELATIVE COST-EFFECTIVENESS OF THE OPTIMISATION OF THE AGRICULTURAL PRODUCT TRANSPORTATION

Let us define the cost-effectiveness of transportation optimisation.

The absolute indicator of cost-effectiveness of network transportation $E_A(m)$ at the set execution level of transmission $m \in (0, m_T)$ is the difference:

$$E_A(m) = f_{\max}(m) - f_{\min}(m). \tag{1}$$

The relative indicator of cost-effectiveness of network transportation $E_R(m)$ at the set level of transmission execution $m \in (0, m_T)$ is the quotient:

$$E_R(m) = \frac{f_{\min}(m)}{f_{\max}(m)} \cdot 100\%. \tag{2}$$

CONCLUSIONS

1) The presented example can constitute a miniature of complex systems and refers only to the transportation in the determined time unit.
2) The network is characterised by two economic barriers in the form of functions $f_{\min}(m)$ and $f_{\max}(m)$. They describe the minimum and the maximum transportation cost obtained by adopting various ways of the network management. The minimum one corresponds to the desired effect of management. The maximum one would mean possible greatest losses related to ineffective transportation in the network (Figure 2). An additional economic barrier that characterises the network is the maximum transmission m_T.

Table 2. Adjacency table for transportation network in the analysed example

$c_{ij};d_{ij};x_{ij}$	S_1	S_2	S_3	S_4	W_1	W_2	W_3	D_1	D_2	D_3	r_i	p_i
S_1					10;8;8						8	21
S_2							34;8;8				8	11
S_3	13;11;0				37;13;5	37;16;16					21	21
S_4					46;8;0		27;7;7			34;12;12	19	24
W_1						28;6;2		22;5;5		31;6;6	13	0
W_2	39;7;0			19;12;0	22;6;0			29;8;8	36;10;10		18	0
W_3						36;9;0		32;5;4		38;12;11	15	0
D_1										20;6;0	0	-17
D_2										16;5;0	0	-12
D_3									38;10;0		0	-35
k_j	0	0	0	0	13	18	15	17	10	29		

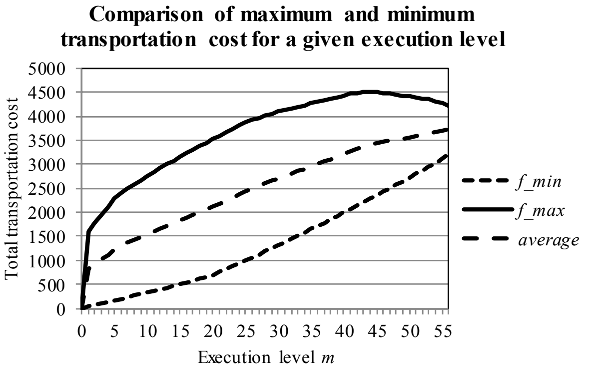

Fig. 2. Graphs of function $f_{\min}(m)$ and $f_{\max}(m)$ as well as function $\frac{f_{\min}(m)+f_{\max}(m)}{2}$ constituting their arithmetic mean

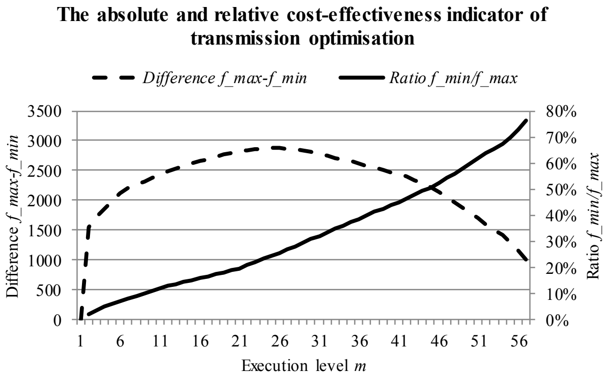

Fig. 3. Graphs of functions $E_A(m)=f_{\max}(m)-f_{\min}(m)$ and $E_R(m)=\frac{f_{\min}(m)}{f_{\max}(m)}\cdot 100\%$ for the analysed example

3) The barriers named in item 2) constitute the limitation to the possible realisations of network operation while adopting various ways of management (Figure 2).
4) The lack of centralised control of the entire network poses a loss risk. The loss extreme size is described by the function $E_A(m)$. These losses should be compared to the costs of various forms of network management, which do not constitute the subject matter of this study (Figure 3).
5) The absolute cost-effectiveness ratio of transportation optimisation in the examined network reaches the highest value 2879 within the range of 24 – 25 of transmission units. It means that decentralization or suboptimum control risk increase up to the threshold of 24 – 25 transfer units. The negative results of the decentralization of agricultural transportation network control decrease along with the transfer increase beginning from this threshold value (Figure 3).
6) In Figure 2 we can notice that for 44 transmission units the function $f_{\max}(m)$ reaches the highest value of 4518. Beginning from this level of transmission execution we can additionally observe the coercion of more effective self-organising of network transportation which is described by the decrease of function value $f_{\max}(m)$. The self-organising of network is forced by free market competition.
7) For the maximum transmission m_T the greatest losses resulting from management decentralisation do not exceed 1008 of monetary units. For m_T the minimum costs of transportation accounts for 76% of the maximum cost, which justifies the concern for optimum parameters of transportation, whereas including the costs of centralised management for transmission close to the limit value (m_T) can sometimes suggest abandoning the central control even of a relatively small network.
8) Knowing the cost appropriated for transportation (e.g. 2000 units) within the producer group, the graph of the function $f_{\min}(m)$ (Figure 2) can show the limit level of the execution of transmission (in this case 40 units). This level can be achieved only the most efficient method of network management is applied.
9) The awareness of economic barriers in the form of maximum network transmission capacity and the relevant function of $f_{\min}(m)$ and $f_{\max}(m)$ type prevents submitting erroneous requirements both from the members of the producer group and the coordinator of the operation of the entire network.
10) The awareness of these barriers enables one to control the process of improvement of the management of the agricultural producer group transportation network.

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CHARAKTERYSTYKI FUNKCJONOWANIA SIECI TRANSPORTU PRODUKTÓW ROLNYCH

Streszczenie. Zarządzanie złożonymi sieciami transportowymi grup producentów rolnych wymaga centralizacji zarządzania. W pracy wskazuje się sposób wyznaczania prostych charakterystyk ekonomicznych złożonych sieci transportowych w postaci kilku barier optymalizacyjnych. Odzwierciedlają one wartości graniczne parametrów sieci pracującej przy różnych sposobach zarządzania. Podano interpretację uzyskanych barier. Wskazano metodykę oceny efektu synergicznego działania grupy producenckiej. Zaprezentowano odpowiedni przykład.

Słowa kluczowe: optymalizacja, wieloetapowe zagadnienie transportowe, centralizacja zarządzania, grupy producenckie.