ORGANIZATION OF WORK OF TRANSPORTATION MEANS IN COMBINED TRANSPORT

Andrzej Marczuk, Wojciech Misztal

Department of Agricultural Machines and Devices
University of Life Sciences in Lublin
Poniatowski Street 1, 20-060 Lublin, Poland
e-mail: andrzej.marczuk@up.lublin.pl, wojciech.misztal@up.lublin.pl

Abstract

The paper deals with an analysis of selected scheduling methods in a view of their use in planning the work of transportation means. The implementation plans for specific transport processes, for which duration of the project procedure is aimed at creating the optimal is the criterion. The authors will attempt to develop a coherent procedure for the combined transport, i.e. transport processes carried out by means of transportation means in more than one mode of transport. It may be also applied for the use of a number transportation means from the same transport branch, when there is a necessity to perform the handling works. Optimization of the execution time for the transport project, that is a modified version of classical transportation problem and scheduling method were applied for creating the method. The procedure can also be used to capture solutions resulting in an excessive use of transportation means, e.g. in case, when too many sets of transport are used. The method is a very useful tool for creating the scheduling of transportation means work. it lets on to fitting an appropriate response to the existing situation resulting from potential delays. It provides valuable information in terms of dispatchers, other managers handling with loads, as well as those involved in the determination of parameters related to contracts for transport projects.

Keywords: *transport, schedule, Gantt chart, PERT method, critical path*

1. Introduction

Modern transport market puts high demands to the functioning entities. This is due to a strong competition caused by a large group of all sizes companies involved in the provision of transport services. Such situation makes it extremely difficult task not only to come onto the market, but also to meet its requirements, and to remain by the functioning entities. The existence of a transport company in the market is largely determined by the demand for its services. This value depends on both the price of services as well as their quality, including the duration and reliability of their realization. This time is extremely important, regardless of the nature of the transport service. In the case of courier companies, the speed of delivery is often the main or even the only factor taken into account by the customer. In the case of companies involved in the transport of goods with larger weights and dimensions, the most important thing is to keep deadlines. The fulfilment of certain requirements related to the transport time requires a proper planning of transportation means work. High efficiency in supporting the activities associated with planning is attributed to the schedules [2, 5].

2. The aim of study

The purpose of this study is to analyse the selected scheduling methods for possible use during planning of transportation means work. The procedure aimed at creating optimal plans for implementation of specific transport processes, for which the task duration will be the purpose criterion, will be presented. The authors will attempt to develop a coherent procedure for the combined transport. The method can be applied also in the case of using several means from the same branch, when there is a need to make any reloading work. Optimization of transport project times and PERT method will be used during the process of method creating, with use of all advantages associated with the construction of schedules for transportation means work.

3. Optimizing the execution time for transport projects

To minimize the time of delivery is a very important issue both in the cases discussed in the introduction, as well as during the replacement of perishable cargo. The effect of works focused on this problem is the transport issue with a time criterion that is a modified version of classical transportation problem. Mathematical formulation of the problem is as follows: There is a system **(T, M)** consisting of m x n dimensional matrix of times for transport works realization $\mathbf{T = [t_{ij}]}$, where $t_{ij} \geq 0$ and $m + n$ dimensional vector of provider supplies and receiver demands $\mathbf{M} = (a_1, \ldots, a_m; b_1, \ldots, b_n)$; m is the number of providers of a given product, while n is the number of receivers interested in its obtaining. It is assumed that there is a balance of provider supplies and receiver demands, i.e. following condition is met (1).

$$\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j \, , \tag{1}$$

It is a matrix $\mathbf{T_x = [t^*_{ij}]}$, where:

$$t^*_{ij} = \begin{cases} t^*_{ij}, & \text{when } x_{ij} > 0, \\ 0, & \text{when } x_{ij} = 0. \end{cases} \tag{2}$$

Matrix $\mathbf{T_x}$ is univocally determined by any flow matrix $\mathbf{X = [x_{ij}]}$, where $x_{ij} \geq 0$. The procedure aims at finding such m x n dimensional flow matrix $\mathbf{X = [x_{ij}]}$, for which the largest element of matrix $\mathbf{T_x}$ would be the smallest (condition 3) and for which conditions (4) and (5) would be met.

$$\max_{x_{ij} > 0} \{t^*_{ij}\} \rightarrow \min \, , \tag{3}$$

$$\sum_{j=1}^{n} x_{ij} = a_i \quad \text{for i = 1, 2, \ldots, m,} \tag{4}$$

$$\sum_{i=1}^{m} x_{ij} = b_j \quad \text{for j = 1, 2, \ldots, n.} \tag{5}$$

Among the most common ways of optimizing the duration of transportation projects, there are: elimination process of time-consuming routes and procedure simplifying the transport task with the time criterion to the transport task with cost criterion. This procedure is carried out in three stages. The first one is to set the initial flow matrix and is implemented using the methods suitable for transport issues relevant to the cost criteria. The second stage consists of three activities, the first of which involves the determination of the longest transport time t_{max} of the matrix elements corresponding to the initial flow matrix. The second activity is aimed at replacing the elements t_{ij} of time matrix with pseudo-cost elements $c`_{ij}$ according to the following procedure:

$$c`_{ij} = \begin{cases} 0, & \text{when } t_{ij} < t_{max}, \\ 1, & \text{when } t_{ij} = t_{max}, \\ H, & \text{when } t_{ij} > t_{max}, \end{cases} \tag{6}$$

where **H** stands for sufficiently large positive number providing the lack of opportunity to select this element during the optimization process. The third activity of the second stage involves the construction of a zero matrix equivalent to the pseudo-cost matrix and building a graph. This action takes place in an analogous manner to the procedure carried out during solving the transport task with cost criterion. The first phase of the third stage of optimization procedure includes such steps as incorporating the smallest element from the pseudo-cost matrix into the graph and then removing the resulting cycle. In case, when these operations result in a situation that the zero matrix still contains negative elements, they should be repeated. If, however, after the cycle liquidation, the zero matrix does not contain any negative elements, the resulting solution should be incorporated into the time matrix times and then go back to the second stage of the procedure. If, after incorporating new element t_{max} into the graph and creating the zero matrix, it does not contain any negative elements, the solution should be accepted as optimum [1, 6-8].

4. Methods for creating the route schedules

”Scheduling” means all activities aimed at assigning the operations to particular transportation means, by which they will be realized, as well as at determining the sequence of operations and setting up dates for their start and end. To determine the end of the project or its particular stages is a very important function of scheduling. This feature is very important for the proper setting the deadlines of the work provided in contracts. Knowledge of the expected date of action completion also allows the implementation of appropriate measures in the case when predictions indicate a very late date of work completion. In its simplest definition, scheduling combines all efforts to create a schedule (work plan), which is an ordered list of ongoing activities, that includes dates of start and end time (or duration) and the list means used for their realization [6-8]. The most common and recognized for its advantages, form of schedule representation is “*Gantt chart*” [1]. The abscissa is the time axis, while tasks (in cases of task-oriented graph) or means used to implement them (when the graph is oriented towards means) are provided on the ordinate axis. Starting dates and duration of each task or times, during which the resources are used, can be read from the graph. Optimization of schedule creating to carry out any work, including transport ones, involves the execution of a number of operations including: separating and listing all actions to be executed; evaluating the parameters of particular actions and events; creating a network illustrating inter-relations (sequence of events) between particular actions; determining general characteristics of the network; determining a critical path.

Up-to-date works upon scheduling resulted in the development of different types of methods. Among them, there is Complete Search Method, Random Search Method, Divisions and Limitations Method, as well as Critical Path Method and PERT method (Program Evaluation and Review Technique) [9, 12].

The Complete Search Method is an approach to generate all permissible schedules and searching them for the assumed purpose function. The advantage of this procedure is that it leads to an accurate solution of analysed scheduling problem. A big disadvantage of this method is, however, the significant effort that should be expended even at relatively little complex problems. Reduction of the labour-consumption is achieved by limiting analysed cases to a subset of the active schedules, because it is known that the optimal solution can be found exclusively within that subset. Random Search is a method of searching that is derived from The Complete Search Method. The assumption of this method is in fact to random generate of active and inactive schedules, that are subsequently analysed. This procedure is designed to significantly reduce the labor intensity, however, it leads to a reduction in the accuracy of the results.

The Division and Limitations, is a method of relatively wide-ranging applications, which belongs to the group of the most common methods used for creating the schedules. The method functioning is based on reducing the search area by cutting the appropriate branches of the feasible solutions tree. Identification of branches to be removed is realized via so-called “*upper and lower limits of the purpose function*”, wherein the upper limit is determined by the best solution among all generated so far, and the lower limit is the path leading from the top of the tree to the node currently being analysed. Initial value of the upper limit is usually determined using heuristic methods. The search of the final solution is carried out by means of comparison of the upper and lower limits values, yet the lower value is accepted as the preferred solution [9].

The CPM and PERT methods, the essence of which is to analyse the critical path, are particularly noteworthy. The main difference between them lies in the approach to the variables (start and end dates for realizing the activities planned). The CPM method assumes that variables are in the determined form, i.e. they are recognized to be completely certain. The PERT method allows for some exemptions of actual values of variables from the assumed values, treating them as stochastic variables. Nature of the PERT method provides a more accurate fit to the actual conditions, in which some deviations from the earlier assumed start or completion dates for the activities, can occur due to various reasons [3, 4, 10]. The procedure characteristic for PERT method assumes realization of the following actions: identification of any activity included within a project; determination of the sequence of all activities; setting up the duration of particular activities; creating the network; determination of the critical path; making the schedule.

Activities that include identification of all tasks necessary in order to realize the entire process, defining the consequences of these tasks, as well as setting up the time for their implementation, are the starting point for the PERT method. The first of these activities rely on specification and placement of all the activities on a list according to their order of execution, as well as giving them the right marks to facilitate their subsequent identification and to make the record transparent. The second action aims at making the identification and assigning the tasks that are directly prior to those that had been previously featured on the list. The third measure is to estimate the expected duration of each activity. As mentioned earlier, the PERT method expresses a specific approach to variables. It enables the three ratings of time provided for the implementation of particular activities. To do this, a notion of expected time value t_e, was introduced; it can be calculated using the following formula (7) [3, 4, 9, 10]:

$$t_e = \frac{t_o + 4t_m + t_p}{6}, \tag{7}$$

where:
t_o – optimistic time,
t_m – the most probable time,
t_p – pessimistic time.

The network project aims to reflect the consequences and the time needed to carry out the activities intended for execution within realized project. The critical path is the longest path leading from the start to the end of entire project, consisting of so-called *critical operations*, i.e. tasks that have the smallest positive extra times. These activities have a significant impact on the whole task; meeting the deadlines set for their completion is equivalent to the completion of the entire project at the right time. Determination of the critical path is performed by means of two types of activities, which include the determining the earliest and latest dates for particular events, as well as calculation of clearances and extra time. Determining the earliest possible date of the events $T_i(e)$ requires implementation of a specific procedure. The procedure takes the form of a successive network analysis carried out from the initial event through the final event in terms of possible delays caused by the necessity of certain events preceding the event that is currently under consideration. The mathematical formulas for the procedure are as follows:

$$T_i(e) = 0, \tag{8}$$

$$T_i(e) = \max\{T_i(e) \neq t_{ij}\}, \tag{9}$$

where:
i – event directly preceding the event j,
i = 1, 2, …, n-1; j = 2, 3, …, n,
t_{ij} – duration of the activity between event i and event j.

Determination of the latest possible date of the events $T_i(l)$ is performed in similar way as for the earliest ones. The difference is that the analysis of consequences and expected values of time provided for the execution of particular activities is carried out in a direction from the final to the beginning event. Mathematical formulation for determining the latest possible dates of the events is as follows:

$$T_n(l) = T_n(e), \tag{10}$$

$$T_i(l) = \min\{T_j(l) - t_{ij}\}, \tag{11}$$

where:
j – event directly following event i.

The event clearance L_i allows for defining if (and to what extent) some delays from assumed date of the event occurrence, are possible. The event clearance can be calculated applying the following formula:

$$L_i = T_i(l) - T_i(e). \tag{12}$$

Zero clearance value means that the event cannot be delayed without changing the date of realizing the entire project. Such events are referred to as critical events and are included within the critical path. However, due to the fact that knowledge of critical events does not provide any univocal information describing the course of the path, it is necessary to determine the value of the total time reserves $Z_{ij}(c)$, that can be assessed using formula 7.

$$Z_{ij}(c) = T_j(l) - T_i(e) - t_{ij}. \tag{13}$$

Like for the event clearance, the total time reserve is referred to as critical when its value is equal to zero. Besides total time reserve, also free time reserve $Z_{ij}(s)$ and independent time reserve $Z_{ij}(n)$ are distinguished. The first one allows to specify an acceptable delay of a given task not causing any violation of the earliest date of event j. Independent time reserve allows for defining the permissible delay of a task in a case when event i would occur in the latest date, while event j should appear in the earliest possible time. Values of these time reserves can be calculated from the following formulas:

$$Z_{ij}(s) = T_j(e) - T_i(e) - t_{ij}, \tag{14}$$

$$Z_{ij}(n) = T_j(e) - T_i(l) - t_{ij}. \tag{15}$$

Creation of the schedule in order to facilitate, increase transparency, and reduce the likelihood of confusion must be preceded by the development of appropriate table that contains a column of data on: expected values of duration for particular activities; the earliest and the latest dates of the start and end of particular tasks and activities; time reserves [1, 3, 9, 10].

5. The method for work organization of transportation means in combined transport

The procedure developed in this work assumes a mutual interaction of previously presented method for optimizing the project duration and the method of scheduling PERT. The initial stage of the procedure is to perform activities pertaining to the PERT method, such as: identifying and determining the order of execution of works done within the framework of the analyzed transport project, as well as determining the expected values of time for their realization. Second step includes activities related to matrix illustration of the analyzed transport problem and the performance of the optimization procedure. To enable the optimization of combined transport task requires its proper reflection. For this purpose, the combined transport was treated as a transportation problem with intermediate storage points representing places where changes of transportation means are made. The corresponding matrix form is obtained by assigning particular providers and intermediate points to the rows of the matrix, as well as the same intermediate points and customers to the columns. Appropriate identification of possible routes to overcome, made by assigning them to the appropriate realization times and leaving the empty fields in matrix where they are absent, is also significant. The optimization process is performed using the expected values of execution times for each activity calculated applying formula (7); this is used to standardize the data. The final stage of the procedure aims at creating a network representing the analyzed transport project, determining the critical path, and creating a schedule.

6. Verification of the method

Verification of presented procedure will include activities associated with minimizing the total time and creation of the transport project schedule. The purpose of the transport process is to relocate goods from senders in Chełm, Lubartów, Kraśnik, Tomaszów Lubelski, Ostrów Świętokrzyski, Sandomierz, and Stalowa Wola to customers located in Koszalin, Stargard Szczeciński, and Konin. The entire project consists of three stages. The first one is done with the use of sets of tractor coupled to a semi-trailer, which receive and conveyance loads to terminals located in Zamość or in Wola Baranowska. The second stage consists in transporting the cargo by rail to the terminal located in Szczecin. The final stage involves the execution of activities related to the delivery of goods to customers and is carried out as in the case of transportation works performed during the first stage using the sets of tractors with trailers. The list of works provided to complete including their duration is included in Tab. 1.The optimization procedure allowed for creating the plan of the transport project realization, the execution of which will let to achieve time savings in the amount of 27 hours 33 minutes. Tab. 2. contain result of optimization procedure (values in the upper index illustrate the quantities of loads designed to the transport on routs joining individual subjects).

Tab. 1. Chosen tasks and their durations [hours/t]

Activity	t_o	t_m	t_p	t_e
Loading the transport set and passing from Chełm to Zamość	0.1	0.12	0.15	0.12
Loading the transport set and passing from Lublin to Zamość	0.14	0.15	0.19	0.15
Loading the transport set and passing from Chełm to Wola Baranowska	0.26	0.29	0.36	0.3
Loading the transport set and passing from Lublin to Wola Baranowska	0.2	0.23	0.28	0.23
Transhipment and rail transport from Zamość to Szczecin	0.7	0.68	0.99	0.73
Transhipment and rail transport from Wola Baranowska to Szczecin	0.67	0.65	0.94	0.7
Transport from Szczecin to Koszalin and unloading the transport set	0.22	0.22	0.31	0.23
Transport from Szczecin to Konin and unloading the transport set	0.46	0.36	0.61	0.42

Tab. 2. Matrix resulting from optimization procedure

	Zamość	Wola Baranowska	Szczecin	Koszalin	Stargard Szczeciński	Konin	a_i
Chełm	0.12	0.3^{20}					20
Lublin	0.15	0.23^{24}					24
Kraśnik	0.16	0.17^{23}					23
Tomaszów Lubelski	0.09	0.25^{21}					21
Ostrowiec Świętokrzyski	0.24	0.13^{24}					24
Sandomierz	0.23	0.09^{20}					20
Stalowa Wola	0.18	0.11^{24}					24
Zamość	0^{156}		0.73^{0}				156
Wola Baranowska		0^{0}	0.7^{156}				156
Szczecin			0^{0}	0.23^{32}	0.1^{64}	0.42^{60}	156
b_j	156	156	156	32	64	60	

Figure 1 presents the project network worked out using earlier described instructions on network building. Values placed on a both sides of individual vertices represent the earliest and the latest possible dates of the appear of individual actions. The numbers of vertices of the graph represents the order of operations mentioned in the above description of the analysed case. Fig. 2 presents Gantt chart illustrating range of starting (the brighter colour) and ending (the darker colour) dates of particular activities included in the transport project The signs of individual operations are adequate to the ones who were used on Fig. 1.

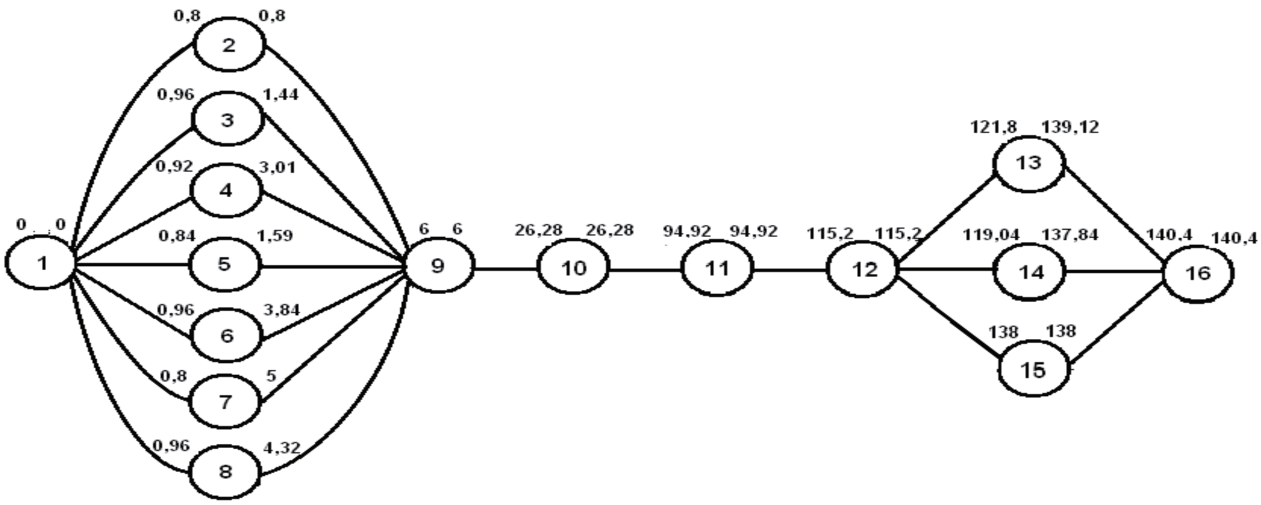

Fig. 1. Network of transport project

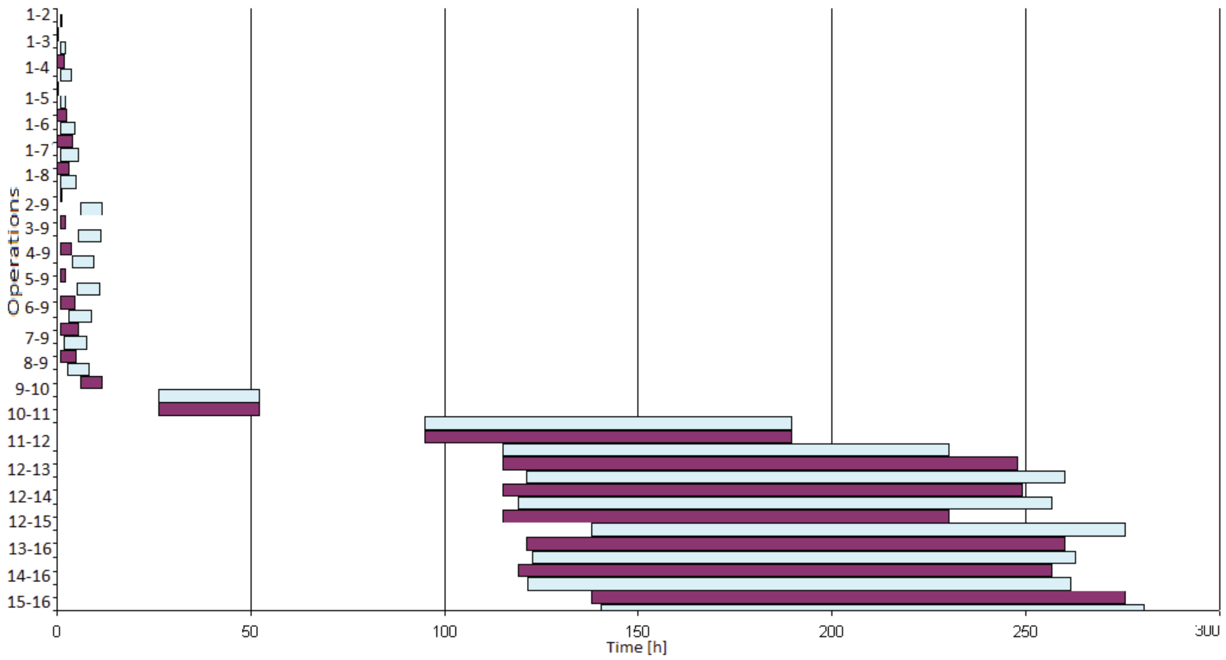

Fig. 2. Gantt chart illustrating range of starting and ending dates of particular activities included in the transport project

7. Discussion and conclusions

This paper deals with an analysis of selected methods of scheduling in a view of possible use during planning the transportation means work. The authors proposed a procedure aimed at the development of implementation the plans for combined transport processes. The criterion for optimization was to reduce the execution time. In the present case, the use of this method allowed to achieve time savings in the amount of 27 hours 33 minutes. It also led to the creation of an appropriate schedule, on the basis of which further conclusions were drawn. Size of the total time reserves define permissible (not causing any delays of the entire project realization) deviations from the dates of start or end of particular activity. The zero value of the total time reserves for critical operations means that the delay in the implementation of these activities result in delays in relation to earlier assumed date of the entire project completion. Due to the fact that the critical path is the longest path of the realized project, it allows to specify its duration. In present example, the sum of the durations of critical activities, i.e. the sum defining the length of the entire project realization time took 140.4 hours. Using a created chart or a network of the project, it is possible to estimate the deadlines for individual works execution. An important benefit of using PERT method for scheduling is to facilitate fitting an appropriate response to the existing situation resulting from potential delays. In cases, where there is a risk of non-compliance with deadlines for specific actions, it is necessary to undertake some dynamic action. Such actions need not be performed in situations, in which some delay is allowed. Knowledge of the estimated execution time for each activity also allows determining, which transport set can most successfully replace a set that failed. The procedure can also be used to capture solutions resulting in an excessive use of transportation means, e.g. in case, when too many sets of transport are used. The method is a very useful tool for creating the scheduling of transportation means work. It provides valuable information in terms of dispatchers, other managers handling with loads, as well as those involved in the determination of parameters related to contracts for transport projects.

References

[1] Całczyński, A., *Metody optymalizacyjne w obsłudze transportowej rynku,* Polskie Wydawnictwo Ekonomiczne, Warszawa 1992.

[2] Jurca, V., Zdenek, A., *System zarządzania utrzymaniem ruchu w przedsiębiorstwach rolnych w Republice Czeskiej*, Eksploatacja i Niezawodność – Maintenance and Reliability, 14 (3), pp. 233-238, Lublin 2012.

[3] Kerzner, H., *Project management. A system approach to planning, scheduling and controlling*, John Wiley & Sons, New Jersey 2009.

[4] Kramarz, M., Kramarz W., Bendkowski J., *Metody i techniki ilościowe w logistyce stosowanej,* Wydawnictwo Politechniki Śląskiej, Gliwice 2010.

[5] Marczuk, A. A, *Computer system for optimization of soft fruit transportation in diffused purchasing networks*, Eksploatacja i Niezawodność – Maintenance and Reliability, No. 4, (44), pp. 82-90, Lublin 2009.

[6] Marczuk, A., *Computer system for managing the sugar beet transport to sugar factory*, Journal of KONES Powertrain and Transport, Vol. 15, No. 2, pp. 301-310, Warsaw 2008.

[7] Marczuk, A., Misztal, W., *Evaluating the efficiency of continuous handling means*, Journal of KONES Powertrain and Transport, Vol. 18, No. 4, pp. 265-271, Warsaw 2011.

[8] Marczuk, A., Misztal, W., *Optimum planning of connections between suppliers and receivers under circumstances of demand-supply imbalance and existing restraints*, Journal of KONES Powertrain and Transport, Vol. 18, No. 3, pp. 237-243, Warsaw 2011.

[9] Pawlak, M., *Algorytmy ewolucyjne jako narzędzie harmonogramowania produkcji*, Wydawnictwo Naukowe PWN, Warszawa 1990.

[10] Punmia, B. C., Khandelwal, K. K., *Project planning and control with PERT and CPM*, Laxmi Publications, New Delhi 2006.

[11] Scharma, S. C., *Operation research. PERT, CPM & cost analysis*. Discovery Publishing House, New Delhi 2006.

[12] Yu, J., Buyya, R., *Scheduling Scientific Workflow Applications with Deadline and Budget Constraints using Genetic Algorithms*, Scientific Programming - Scientific Workflows, Vol. 14, Is. 3-4, pp. 217-230, New Delhi 2006.