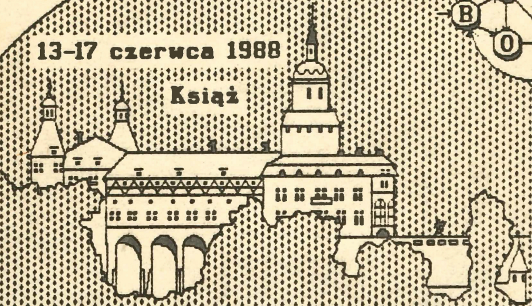
Redaktorzy:

A.Straszak
Z.Nahorski
J.Sikorski

13-17 czerwca 1988

Książ



1. Krajowa Konferencja Badań Operacyjnych i Systemowych

Tom 1

BOS'88

POLSKIE TOWARZYSTWO BADAŃ OPERACYJNYCH I SYSTEMOWYCH

INSTYTUT BADAŃ SYSTEMOWYCH POLSKIEJ AKADEMII NAUK

POLSKIE TOWARZYSTWO BADAŃ OPERACYJNYCH I SYSTEMOWYCH

TOM 1

OPTYMALIZACJA
METODY I ZASTOSOWANIA

I KRAJOWA KONFERENCJA

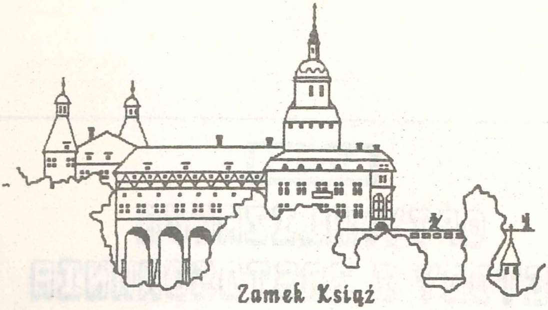
BADAŃ OPERACYJNYCH i SYSTEMOWYCH

Książ, 13 - 17 czerwca 1988

BOS'88

INSTYTUT BADAŃ SYSTEMOWYCH POLSKIEJ AKADEMII NAUK

1989
WARSZAWA



Zamek Książ

I Krajowa Konferencja Badań Operacyjnych i Systemowych

Organizator konferencji

Polskie Towarzystwo Badań Operacyjnych i Systemowych
przy współpracy
Instytutu Badań Systemowych PAN

Komitet naukowy konferencji

Jerzy Hołubiec, Andrzej Kałuszko, Jerzy Kisielnicki, Henryk Kowalowski, Roman Kulikowski, Franciszek Marecki, Zbigniew Nahorski, Stanisław Piasecki, Jarosław Sikorski, Jan Stachowicz, Jan Stasierski, Andrzej Straszak, Maciej Sysło, Władysław Świtalski

Redaktorzy naukowi materiałów

Andrzej Straszak, Zbigniew Nahorski, Jarosław Sikorski

1. Referaty gości zagranicznych

1.2

I Krajowa Konferencja
Badań Operacyjnych i Systemowych
Książ, 13 - 17 czerwca 1988r.

THE LONG TERM PLANNING OF CHINESE COAL TRANSPORTATION SYSTEMS*

Tiantai Song
Institute of Applied Mathematics
Academia Sinica

The long term planning of Chinese coal transportation system can be formulated as a fixed charged transshipment problem with extra constraints. We introduce a new transformation to get an equivalent 0-1 generalized network model. A software on IBM PC was developed to solve such problem. The initial computation experience indicates that the new method is very efficient.

---

* This research is supported by Chinese Nature Science Foundation under the name of key project

1. INTRODUCTION

In China we have built a huge transportation system including railway, highway, sea ports and inner river ports. Comparing what we have done and what we will do, todays transportation system become a bottle neck in developing our economy. There are so many different plans or packages to build new rail way, new ports and new highways. On the other hand we have only very limited amount of capital investments, material and construction capabilities; therefore we can not do all of them. Actually even we have enough resources to do every thing, we would rather not to do it. Because some package only according to local necessity, from a global point of view such project may make the whole system less efficient even is totally useless. For example, we built a huge seaport to ship coal from northern part of China to southern part of China and abroad. However after the construction finished, we found no coal can be shipped to the new harbor, since the railway has some bottle neck in other parts. Such things reflect the mistake in the decision process of planning new projects in the past. For improvement we did some research in developing an operations research model and a software to solve it. Now we are in much better position to provide advise for evaluation of several alternative packages.

It was very clear, we should start from a rather simple model in which only single commodity is shipped around. We wish that we could get some experience and solve the multicommodity situation in the future. We choose coal transportation problem as our subject, since coal is major energy resource in China as well as one of the major transportation goods.

In section 2 we will discuss the model for new project evaluation and in section 3 present a new transformation to get a 0-1 generalized network model. In section 4 some computation consideration and experience are presented.

2. The Investment Decision Model

The current Chinese coal transportation system consists of railway, highway, seaports, ocean cargo ship, river ports. Nowadays only in short distance coal is shipped by trucks through highway and in the future the long distance transportation of coal will still rely on the train and cargo ships. Hence in the long term planning of coal transportation the highway system will not be considered. If we only consider a transportation problem of coal through railway and connected water transportation system, the most appropriate model is minimum cost transshipment model. However, there are some thing need more discussion.

Generally, the bottle neck of water transportation is the limited capacity of the seaports and river ports, since they take longer time to be built and need large investment. Therefore, we will assume that there are enough cargo ship available to carry coal. The capacity of transportation by water will be restricted by the capacities of these ports.

Like harbor, some railway intersection also has limited capacity. It is known such node capacity can be expressed as arc capacity in a network. The only thing we need to do is to split the node into two nodes connected by a single arc. The capacity of the new arc' is the capacity of the node.

In order to meet the long term requirement of coal transportation, we need greatly improve our transportation system. Therefore a lot of new project should start now, or delayed. A new railway, harbor even a coal transportation pipe can be represented as a new arc in the planned transportation network. Besides that some old harbors and railway segments also need to be upgraded; for example, make some segment of rail road electricalness, build new loading or unloading facility for old piers. For such project we use a different arc with the same end nodes as the old one. Sometimes we use multiple arcs with the same end nodes for several alternative projects.

The basic problem we are going to solve is to select a set of new projects which will be added into the old system such that the extended transportation system meets the future requirement for coal transportation and make the total capital investment plus operating cost minimum. If we don't consider any further constraints for the projects, the fixed charge problem first introduced by Heirs and Dantzig is a suitable model as following.

$$\min c^T x + \sum_k f_k y_k$$

$$\text{s.t. } Ax = b$$

$$\text{(PF)} \qquad 0 \le x_k \le y_k u_k \quad \text{for } k \in K$$

$$l_k \le x_k \le u_k \quad \text{for } k \in N \setminus K$$

$$y_k \in \{0, 1\}$$

where A is an m x n incidence matrix corresponding a directed graph having m node and n arcs; $N = \{1,2,\ldots,n\}$, and K is a subset of N which is the set of potential new projects; f_k is the fixed charge (investment) for project k; y_k is called decision variable and is either 1 or 0 corresponding to build or not build respectively.

In practice we often have to impose some constraints to the decision variables. Suppose that we are going to give a long term multiple period plan such as 3 year plan, 5-year plan, 10-year plan, 15-year plan. In a r period case, the basic structure of the program will be following.

$$\min \sum_{t=1}^{r} (c^{Tt} x^t + \sum_k f_k y_k^t)$$

$$\text{s.t.} \quad Ax^t = b^t$$

$$0 \le x_k^t \le y_k^t u_k \quad \text{for } k \in K$$

$$l_k \le x_k^t \le u_k \quad \text{for } k \in N \setminus K$$

$$y_k^t \in \{0, 1\} \quad \text{for } k \in K$$

$$t = 1,\ldots,r$$

where the decision variable $(y_k^1, \ldots, y_k^r)$ represents the same project over different period. It is clear the following logical constraints should be held.

$$0 \le y_k^1 \le y_k^2 \le \ldots \le y_k^r \le 1$$

Also there are some other logical constraints depending on the real world situation or political consideration. Besides that there are some resource constraints like budget. In general, the long term coal transportation problem can be formulated as a fixed charge problem with extra constraints as following.

$$
\text{(P)} \qquad
\begin{array}{ll}
\min \; c^T x + \sum_k f_k y_k & \\
\text{s.t. } Ax = b & \\
\quad Dy \le g & \\
\quad 0 \le x_k \le y_k u_k & \text{for } k \in K \\
\quad l_k \le x_k \le u_k & \text{for } k \in N \backslash K \\
\quad\quad y_k \in \{0, 1\} &
\end{array}
$$

where A is an incidence matrix of network which may consist of several identical disjoint parts. Each of them is the one period network itself. $Dy \le g$ corresponds to the constraints imposed on decision variables. In general the size of matrix A is much larger than the size of matrix D. In order to take the advantage of the special structure of matrix A, one may use Binder's decomposition, solve a sequence 0-1 integer program and minimum cost transshipment problems. It is known that the convergence of Bender´s decomposition is rather slow. We introduce a new transformation which transform the fixed charge problem with extra constraints into a 0-1 generalized network problem. The computational effort of solving such equivalent is slightly more than one iteration of Bender´s decomposition.

3. The 0-1 Generalized Network

The generalized network also is called a network with gain. The flow through an arc may gain or loss. Graphically the k-th arc can be represented as follows.

$$\textcircled{i} \xrightarrow{\{c_k,\ (l_k,\ u_k),\ a_k\}} \textcircled{j}$$

Figure 1. the k-th arc of a generalized network

If the flows on some arcs in a generalized network have to be either 0 or 1, then it is so called 0-1 generalized network. A such arc is depicted as below.

$$\textcircled{i} \xrightarrow{\{c_k,\ (0,\ 1)^*,\ a_k\}} \textcircled{j}$$

Figure 2. the 0-1 arc of a 0-1 generalized network

where $(0, 1)^*$ indicate the flow of the arc is either 1 or 0.

Since the special generalized simplex code can solve generalized network problem at least 20-30 times faster than a state of the art general purpose linear program simplex code, the 0-1 generalized network is much easier to solve than a 0-1 mixed integer program. Furthermore, Glover etc. point out that the general 0-1 integer program can be transformed to an equivalent 0-1 generalized network. Suppose that there is a 0-1 integer program (PI).

$$\text{(PI)} \qquad \begin{aligned} &\min \ \sum_k f_k y_k \\ &\text{s.t. } Dy \le g \\ &\qquad y_k \in \{0, 1\}, \qquad k = 1, \ldots, q. \end{aligned}$$

where D is a p x q matrix. Construct a 0-1 generalized network having p+q+1 nodes such that every 0-1 variable y_k corresponds to a node denoted as y_k for convenience and i-th constraint to a node i having demand g_i. In addition there is an origin node s with supply q. If the k-th column vector d_k of matrix D has r_k non-zero components, then compose an 0-1 arc (s, y_k) having gain multiplier r_k, cost f_k; if d_{ik} is non-zero, compose an ordinary arc (y_k, i) having its upper bound 1, lower bound zero and the gain multiplier d_{ik}. All together there are q + $||\{(i, k): d_{ik} <> 0\}||$ arcs. We can draw following graph.

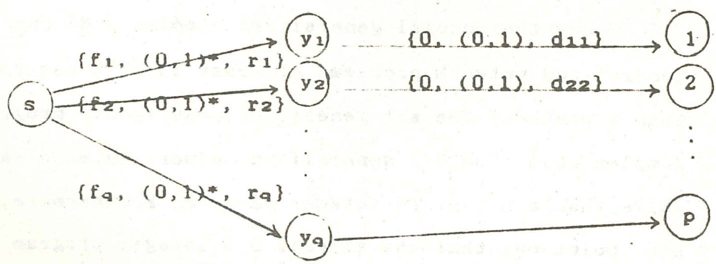


Figure 3. The equivalent 0-1 generalized network of (PI)

Denote the corresponding 0-1 generalized network as (PI*) which has the same number of 0-1 variables as program (PI) and very few nodes. Usually the matrix of program (PI) is pretty sparse, the size of (PI*) is moderate; hence, the program (PI*) can be solved a lot easier than program (PI). The equivalence of program (PI*) and (PI) is clear.

Below we will first show how to transform the fixed charge problem (PF) into an equivalent 0-1 generalized network problem then show how to combine such transformation with the one we just described together to get an extended 0-1 generalized network which is equivalent to the program (P)

For convenience, we divide the arcs in a fixed charge network problem into two parts, one is called fixed charge arc and the other ordinary arc. While keeping all ordinary arcs unchanged, we replace fixed charge arc (see Figure 4) with a three node five arc generalized network structure as Figure 5.

$$i \xrightarrow{\{c_k,\ [f_k,\ *(l_k,\ u_k)],\ a_k\}} j$$

Figure 4. The Fixed Charge arc

where the $[f_k,\ *(l_k,\ u_k)]$ indicate the fixed charge is f_k and the following inequality should be satisfied.

$$l_k\, y_k \le x_{ij(K)} \le u_k\, y_k .$$

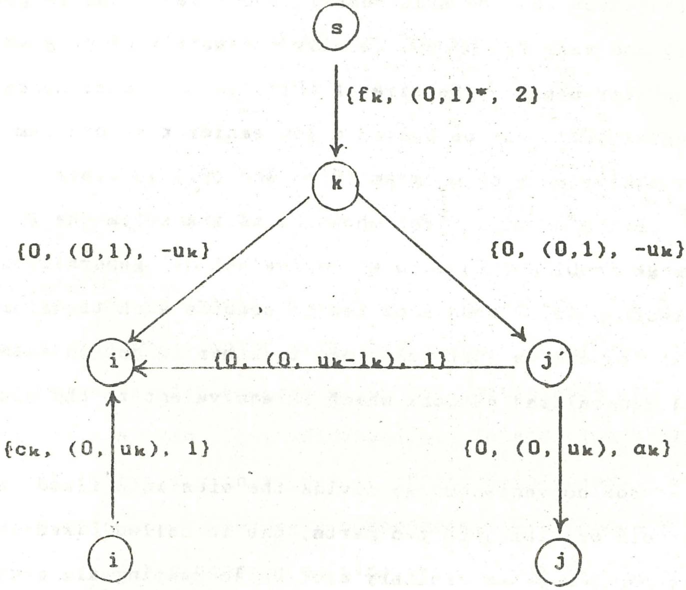


Figure 5. The corresponding 0-1 generalized network

In Figure 5 the node s is a general origin like the node s in Figure 3. The 0-1 generalized network extended by the Figure 5 type structure is denoted as (PF*).

Define a map Γ from the feasible solution (x, y) of program (PF) to a solution (x^*) of (PF*) as following.

Γ: $x_{sk}^* = x_{ki'}^* = x_{kj'}^* = y_k$

$x_{ii'}^* = x_{j'j}^* = x_{ij(k)}$

$x_{j'i'}^* = u_k \, y_k - x_{ij(k)}$ for $k \in K$

and

$x_{pq}^* = x_{pq(r)}$ for $r \in N \setminus K$.

where $x_{pq(r)}$ denotes the r-th (ordinary) arc from node p to node q.

Lemma 1. The map Γ map any feasible solution of program (PF) into a feasible solution of program (PF*) and the corresponding objective function values are equal.

Proof. Since

$$x_{sk}^* = y_k \in \{0,\ 1\}$$

$$0 \le x_{ki'}^* = x_{kj'}^* = y_k \le 1$$

$$0 \le x_{ii'}^* = x_{j'j}^* = x_{ij(k)} \le y_k\, u_k \le u_k$$

$$0 \le x_{j'i'}^* = u_k\, y_k - x_{ij(k)} \le u_k - l_k$$

the only thing we have to do is to verify the node flow conservation. Note all flows coming from or going into the nodes of (PF*) corresponding to the nodes of (PF) are same in program (PF) and (PF*). Because of feasibility of x in program (PF), x^* will satisfy node constraints for all old nodes. For new nodes of (PF*), there are following fact.

$$2x_{sk}^* - x_{ki'}^* - x_{kj'}^* = 2y_k - y_k - y_k = 0$$

$$\begin{aligned} &-u_k\, x_{ki'}^* + x_{ii'}^* + x_{j'i'}^* \\ &= -u_k\, y_k + x_{ij(k)} + (u_k\, y_k - x_{ij(k)}) = 0 \end{aligned}$$

$$\begin{aligned} &u_k\, x_{kj'}^* - x_{j'i'}^* - x_{j'j}^* \\ &= u_k\, y_k - (u_k\, y_k - x_{ij(k)}) - x_{ij(k)} = 0 \end{aligned}$$

This proves that x^* is feasible solution of program (PF*). It is obvious that the objective function values under map Γ is equal.

[Q.E.D.]

For the feasible solution x^* of program (PF*), define a map Γ' to the solution (x, y) of program (PF) as following.

Γ': $\quad y_k = x_{\bullet k}^*$,

$x_{ij(k)} = x_{ii'}^*$ $\qquad$ for $k \in K$

and

$x_{pq(r)} = x_{pq}^*$ $\qquad$ for $r \in N \setminus K$.

Lemma 2. The map Γ' map any feasible solution of program (PF*) into a feasible solution of program (PF) and the corresponding objective function values are equal.

Proof. Because of $x_{\bullet k}^* \in \{0, 1\}$, we always have

$$x_{ki'}^* = x_{kj'}^* = x_{\bullet k}^*.$$

In fact, if $x_{\bullet k}^* = 0$, then

$$0 \le x_{ki'}^* \le x_{ki'}^* + x_{kj'}^* = 2x_{\bullet k}^* = 0$$

we have

$x_{ki'}^* = 0$.

If $x_{\bullet k}^* = 1$, then

$$1 \ge x_{ki'}^* = 2x_{\bullet k'}^* - x_{kj'}^* \ge 2x_{\bullet k}^* - 1 = 1$$

we have

$$x_{ki'}^{*} = 1.$$

Hence $x_{ki'}^{*} = x_{sk}^{*}$.

For the same reason, $x_{kj'}^{*} = x_{sk}^{*}$.

Hence

$$\begin{aligned} x_{ii'}^{*} &= u_k \, x_{ki'}^{*} - x_{j'i'}^{*} \\ &= u_k \, x_{kj'}^{*} - x_{j'i'}^{*} \\ &= x_{j'j}^{*} \end{aligned}$$

we have

$$x_{ij(k)} = x_{ii'}^{*} = x_{j'j}^{*}$$

This indicate that the flows coming in or going out of nodes in the network of program (PF) is the same as the corresponding one of program (PF*). Therefore the node flow conservation constraints is satisfied. The rest is to prove

$$y_k \, l_k \leq x_{ij(k)} \leq y_k \, u_k$$

hold, because $y_k = x_{sk}^{*} \in \{0, 1\}$ and other inequality constraints are held automatically. The second part of above inequality is true since

$$\begin{aligned} x_{ij(k)} = x_{ii'}^{*} &= u_k \, x_{ki'}^{*} - x_{j'i'}^{*} \\ &\leq u_k \, x_{ki'}^{*} = y_k \, u_k. \end{aligned}$$

If $y_k = x_{sk}^* = x_{ki'}^* = 1$, by $x_{j'i'}^* \leq u_k - l_k$,

$$
\begin{aligned}
x_{ij(k)} = x_{ii'}^* &= u_k\, x_{ki'}^* - x_{j'i'}^* \\
&= u_k - x_{j'i'}^* \\
&\geq l_k = y_k\, l_k;
\end{aligned}
$$

If $y_k = 0$, $y_k\, l_k = 0 \leq x_{ij(k)}$. This proved that the map Γ' transform a feasible solution of program (PF*) to a feasible solution of program (PF). It' is easy to see that the values of corresponding objective function under map Γ' are equal.

[Q.E.D]

By Lemma 1 and Lemma 2, the following theorem is true.

Theorem 1. Program (PF) and program (PF*) is equivalent

Now we are going to introduce a transformation which transform the fixed charge problem with side constraints program (P) to a 0-1 generalized network. The new transformation is the combination of above two transformations. For easy representation, we still use a graphical representation for the new 0-1 generalized network.

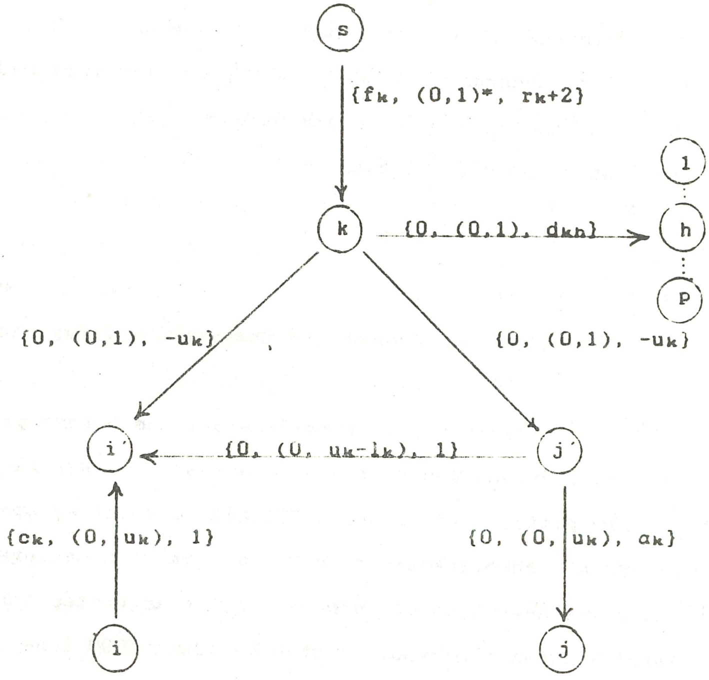


Figure 6. The equivalent 0-1 generalized network of (P)

where the gain multiplier of 0-1 variable x_{sk} is r_k+2 and r_k is the number of non-zero elements of k-th column vector of matrix D. Denote the 0-1 generalized network program of Figure 6 as (P*). Similar to theorem 1 we can prove following.

Theorem 2. Program (P) and program (P*) is equivalent

Note the two programs have the same number 0-1 variables, program (P*) has a very good structure and few more arcs and nodes. Therefore we can expect the program (P*) can be solved efficiently.

4. Implementation and Computational Experience

Since the transformation from a fixed charge problem with extra constraints to a 0-1 generalized network follows a fixed pattern, it is not difficult to do it automatically. We add a such procedure to a 0-1 generalized network code which was developed by ourselves using augmented thread plus level indices. The whole system is about 3000 line of FORTRAN - 77 code, therefore it has pretty high portability. Due to the power of special generalized network simplex method we can use even home computer to solve pretty large system. In a IBM PC/AT machine using Microsoft Fortran compiler we can solve problem with up to 1000 nodes and 3000 arcs.

By IBM AT we solved some real problems as well as some randomly generated problems.

A real coal transportation problem is one period planning in Chinese transportation system which involve 47 nodes, 79 arcs including 5 decision arcs, and a budget constraint. This problem can be solved in two minutes. The experience we got is the procedure should have a preprocess to scaling input data otherwise the procedure tends to be unstable due to the tremendous different magnitude of fixed charge and transportation cost. After doing that the program seems pretty robust and a single precision procedure get the same results as double precision one.

The experience for solving randomly generated problems indicate that the difficulty of the problem is not only related to the number of 0-1 variables but also to the distribution of these variables. A problem with 120 nodes and 720 arcs can be solved in 2 and an half minutes; the same structure containing 12 decision variable can be solved in 10 minutes and the other test problem having 39 decision variables can be solved in 30 minutes. Due to the difficulty of the network design these results indicate the new procedure is very efficient.

REFERENCE

1. R.S. Barr, F. Glover, and D. Klingman, " A New Optimfzation method for Large Scale Fixed Charge Transportation Problems," Operations Research Vol. 28 (1981), 448-463.

2. R. Doinne, and M. Floriam, "Exact and Appropriate Algorithm for Optimal Network Design," Networks, vol. 9 (1979), 37-59.

3. F. Glover, D. Klingman, and J. Stutz, "The Augmented Threaded Index Method for Network Optimization," INFOR, 12, 3(1974), 293-298.

4. F. Glover, and J. Mulvey, "Equivalence of the 0-1 Integer Programming Problem to Discrete Generalized and Pure Networks," MSRS 75-19, University of Colorado, Boulder, Colorado, 1975.

5. W.M. Hirsed and G.B. Dantzig, "The Fixed Charge Problem," Naval Research Logistics Quarterly, Vol. 15, No. 3. (1968), 412-424.

6. J.P. Ignizio, and S.C. Daniels, ' Fuzzy Multicriteria Integer Programming via Fuzzy Generalized Networks," Fuzzy Sets and Systems 10 (1983), 261-270.

7. D.S. Johnson, J.K. Lenstra, and A.H.G. Rinnooy Kan, "The Complexity of the Network Design Problem," Vol. 8 (1978), 279-286.

8. P.G. Mac Keown, "A Branch and Bound Algorithm for Solving Fixed Charge Problems," Naval Research Logistics Quarterly, Vol. 28, (1981), 607-618.

9. T.L. Magnanti, and R.T. Wong, "Network Design and Transportation Planning Methods and Algorithms," Trans. Sci. Vol. 18 (1984), 1-55.

10. R.T. Wong, "Probabilistic Analysis of a Network Design Heuristics," Networks, Vol. 15, (1985), 347-364.

L I T E R A T U R A

(1) Crabill T. B., Gross D., Magazine M. J. (1977) A Classified Bibliography of Research on Optimal Design and Control of Queues. Operations Res. Vol. 25, No. 2 pp. 219-232.

(2) Deb R. K., Serfozo R. F. (1973) Optimal Control of Batch Service Queues. Advances Appl. Probability 5, 340-361.

(3) [illegible] (1979) [illegible] Theory of Service Systems [illegible] Ferguson [illegible], New York [illegible]

(4) Weiss H. J. (1979) The Computation of Optimal Control Limits for a Queue with Batch Services. Manag. Sci. 25 [illegible]

(5) [illegible] (1984) [illegible], Praca doktorska, [illegible]

(6) Королюк В., Турбин А. (1976) Полумарковские процессы и их приложения. Киев [illegible]

(7) [illegible] (1982) [illegible] zastosowania w zadaniach [illegible]

(8) Neuts M. (1967) A general class of bulk queues with Poisson input, Ann. Math. Stat. 38, 759-770.

(9) ______ (1979) Queues solvable without Rouché's theorem. Operations Res. 27.

(10) [illegible] (1966) The ergodic queue length distributions for queueing systems with finite capacity. J. Roy. Stat. Soc. B28.

Zarząd

Polskiego Towarzystwa Badań Operacyjnych i Systemowych

Prezes

prof.dr hab.inż. Andrzej Straszak
Instytut Badań Systemowych PAN

Wiceprezes

prof.dr hab.inż. Jan Stasierski
Wojskowa Akademia Techniczna

Wiceprezes

prof.dr hab.inż. Stanisław Piasecki
Instytut Badań Systemowych PAN

Sekretarz generalny

dr inż. Zbigniew Nahorski
Instytut Badań Systemowych PAN

Sekretarz

dr inż. Jarosław Sikorski
Instytut Badań Systemowych PAN

Skarbnik

dr inż. Andrzej Kałuszko
Instytut Badań Systemowych PAN

Członkowie

prof.dr hab. Jerzy Kisielnicki
Wydział Zarządzania UW

doc.dr hab.inż. Bohdan Korzan
Wojskowa Akademia Techniczna

doc.dr hab.inż. Jan Stachowicz
Zakład Nauk Zarządzania PAN

doc.dr hab.inż. Maciej Sysło
Instytut Informatyki UWr.

Komisja rewizyjna

PRZEWODNICZĄCY

dr Władysław Świtalski
Katedra Cybernetyki i Badań Operacyjnych UW

CZŁONKOWIE

dr inż. Janusz Kacprzyk
Instytut Badań Systemowych PAN

dr inż. Marek Malarski
Instytut Transportu PW

doc.dr hab.Henryk Sroka
Akademia Ekonomiczna w Katowicach

dr inż. Leon Słomiński
Instytut Badań Systemowych PAN

PION III