T-Comm "Телекоммуникации и транспорт", 2014, Том 8, №6, с. 81 – 84.

A. Sokolov, Ph. D, Senior Researcher of R&D center "SevenTest",
asokolov@seventest.ru
N. Sokolov, D. Sc., Chief Researcher of Research Institute "LOZNIIS",
sokolov@niits.ru

Rational solutions for development of telecommunications networks

Introduction

During the analysis of scenarios of telecommunications networks' development the problems of optimal solution determination often arise. Without doubt, optimization tasks comprise important set of problems that are often chanced upon in the course of developing construction and modernization solutions for different networks [1]. Also, a set of problems for which main objective is not to find optimum, but to develop *rational* [2] solution, should be taken into consideration.

Interest towards rational solutions can be explained by a number of factors including three following considerations. First, most of the elements in the telecommunication network have a long life cycle T_{LC} [3]. For this reason the solution that was optimal at the moment of time $t_1 < T_{LC}$ can be nonoptimal at the moment of time $t_2 \leq T_{LC}$. Second, initial data, that are available to a person justifying the solution, are rarely accurate enough [4]. This fact severely complicates the work of the decision-maker. Third, for choice of scenario of telecommunication network development, emerging risks should also be accounted for. Such operations can be undertaken by means of analysis of each studied scenario as an investment project [5].

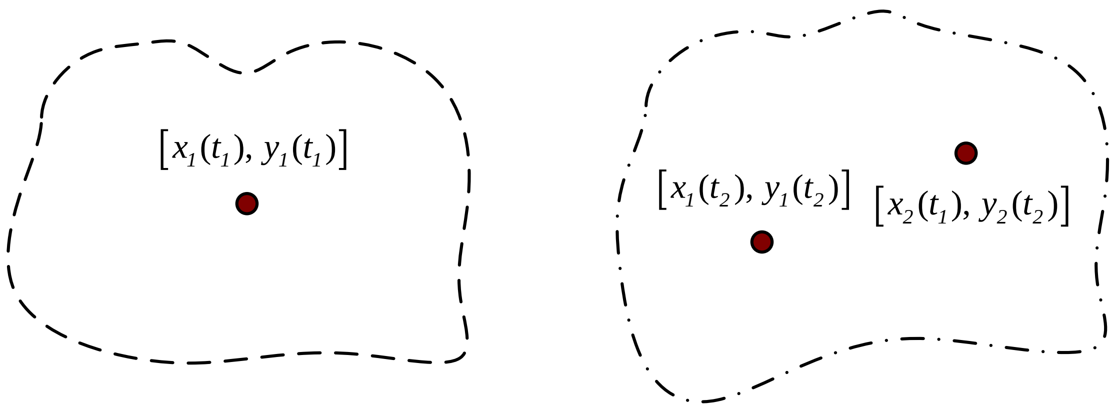
In the next paragraphs of this article, three main issues are considered. At first the historical aspects of telecommunication networks are given. Usefulness of optimal solutions search approach is proved using these aspects as an example. Then the methodological approach for finding the rational solutions is described.

And the practical example of the proposed method application for hypothetical telecommunications network modernization scenario concludes the article.

Historical aspects of telecommunication networks development

Telephone network was the first telecommunication system supporting real-time dialogue. In big cities, telephone networks were created by means of installation of one switch node (SN) with subscriber lines plugged into it. Search method for the placement of this single SN that minimizes Operator's investments in telephone network creation is known in technical literature as Rapp's problem [4].

Assume that such placement of SN was found. It can be defined by coordinates $[x_1(t_1), y_1(t_1)]$. Point with these coordinates is shown in the left part of the first figure. Dash-dot line marks the borders of the city territory by the moment of time t_1.



a) Optimal solution by the time t_1 b) Optimal solution by the time t_2

Figure 1. Deployment of SNs in the borders of city's territory

Growth of telephone network capacity and territory expansion of the city whose borders are shown in the right part of the considered model with dash-dot line stimulate introduction of the second SN at the moment of time t_2. Optimal placement points for both SNs (not taking into account already implemented project) can be described in the following form $[x_1(t_2), y_1(t_2)]$ and $[x_2(t_1), y_2(t_2)]$. Obviously $x_1(t_1) \neq x_1(t_2)$ and $y_1(t_1) \neq y_1(t_2)$.

Similarly for each i^{th} SN at any random moment of time t_k the following two conditions apply: $x_i(t_{k-1}) \neq x_i(t_k)$ and $y_i(t_{k-1}) \neq y_i(t_k)$. From the practical point of view, each of the implemented beforehand projects (new SN placement in the telephone network) can't be changed. This means that starting from the moment of introduction of the second SN, the structure of the telephone network can't be considered optimal.

It's easy to confirm, that the last statement stays true for the telecommunications network of any kind. Changes happen not only to the optimal solutions in the part of SN placements during expansion of the telecommunications network. For example, during the transition towards digital transport and switching systems optimal solution for development was achieved by means of reduction of SNs number [3]. Moreover, considered examples are related only to one (though very important) aspect of telecommunications system development. It is a choice of telecommunication network structure. It's also important to find rational solutions for calculation of bandwidth of telecommunication network elements, for development of a numbering plan (addressing), and for other operations directly or implicitly related to problems of telecommunications network development.

Methodological approach towards search of rational solutions

One of the possible methodological approaches towards search of rational solutions is described in [2, 3]. It should be noted that *rational decision* is considered in these publications. The number of similar decisions can be more than one. The task of preparing them is assigned to a person justifying the solution. Choice of the solution that will be implemented is done by decision-maker.

In practice, the criterion of the optimal solution for a telecommunications network project was capital expenditures minimum [4]. In addition each analyzed scenario had to conform to the set of technical requirements that were defined in the form of inequations or verbal statements. In recent years, Net Present Value curves became main economic estimates of the considered scenarios [5, 6]. For the scenario number z at the t time period function of net present value is further denoted as $NPV(z,t)$.

Choice of $NPV(z,t)$ curves instead of habitual criterion "minimum capital expenditures" is determined by the fact that usually analyzed project is extended in time. Functions $NPV(z,t)$ are calculated by the following formula [5, 6]:

$$NPV(z,t) = \sum_{t=1}^{n} \frac{CF_t(z)}{(1+r)^t} - \sum_{t=0}^{n} \frac{I_t(z)}{(1+r)^t}. \quad (1)$$

$CF_t(z)$ value determines cash flow for the t time period provided that z^{th} scenario of network modernization was implemented. Variable $I_t(z)$ is the sum of investments in t^{th} period for scenario z. The discount rate [6] is denoted as r. Value n is equal to the number of periods marked out in the considered project of telecommunications network modernization.

At first sight, the preferred scenario of telecommunications network modernization should be the one whose function $NPV(z,t)$ is maximal during reasonable time period t. This value belongs to time interval that comes after payback period and stops when it is planned to start new project of telecommunications network development.

In addition, the risk level [5] should be taken into consideration. To some extent, risk level can be estimated by means of plotting three $NPV(z,t)$ curves that will correspond to pessimistic, pragmatic and optimistic course of events. These curves can be plotted under the condition that thorough marketing investigations were carried out or necessary values were obtained by some other means before implementation of the project.

On the second figure functions of net present value for two possible scenarios are depicted in the form of histograms. They are defined for values $z = 1$ and $z = 2$ respectively. For the chosen values t pessimistic, pragmatic and optimistic estimations of $NPV(z,t)$ are given within bounds of columns of both histograms.

Values $NPV(1,t)$ and $NPV(2,t)$ were conventionally shifted relatively to one another on abscissa axis so that histogram columns did not merge.

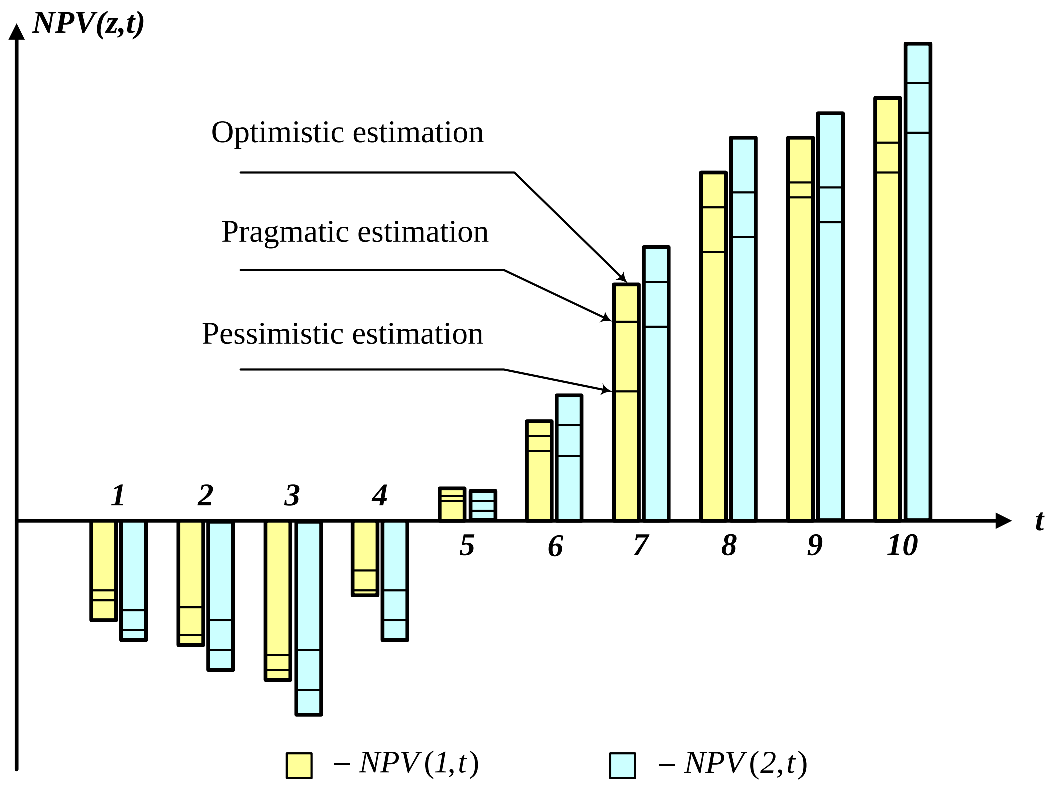


Figure 2. Example of behavior of functions $NPV(1,t)$ and $NPV(2,t)$

Suggested example should be considered as hypothetic one. Nevertheless it represents realistic scenarios of telecommunications network modernization. Consider values of $NPV(1,t)$ and $NPV(2,t)$ for $t=7$. It is hard to give preference to any of the scenarios taking into account possible course of events. Assume that for the first and second scenarios the most probable outcome is the optimistic and pessimistic events respectively. Then $NPV(1,t) > NPV(2,t)$. This means that first scenario is preferable. For the optimistic events for both scenarios, the opposite inequation is true: $NPV(1,t) < NPV(2,t)$. Therefore the second scenario becomes preferable. For the successful choice of telecommunications network scenario the Delphi method should be used [7] to improve results of the analysis of person justifying decision.

Example of rational solution development

A model of telecommunications network fragment suggested in [2] is used for illustration of previously stated theses. This model is given in the third figure. In the left part of the figure, the graph that corresponds to the structure of fragment that is supposed to be modernized is depicted. In both graphs, vertex a_i denotes i^{th} SN, and graph's edge b_{ij} represents information transfer channel between SNs numbered i and j.

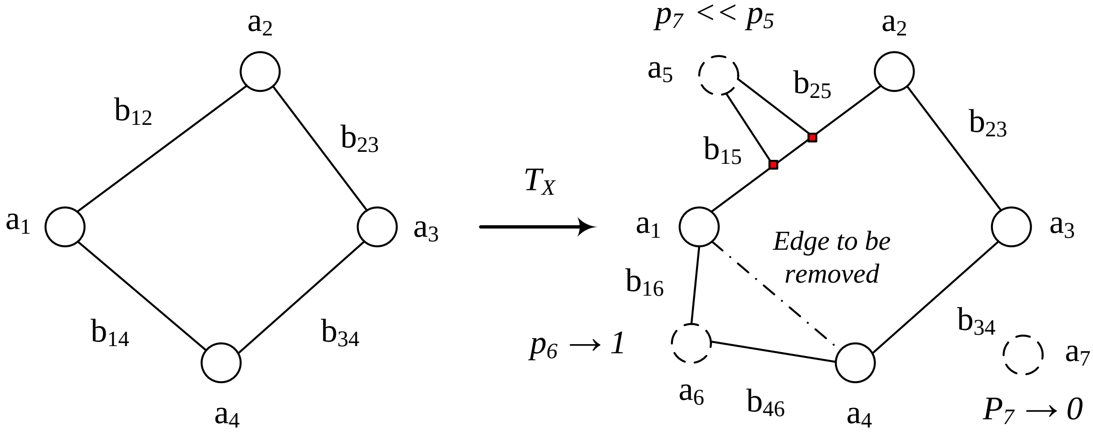


Figure 3. Model of fragment of telecommunications network

In the right part of the figure, there is a picture of transport network structure that will be created after time T_X. During development of the network model by the moment T_X three assumptions are used [2]:

1. With almost 100% probability, a new vertex a_6 will appear on the graph. If the channel between nodes a_1 and a_4 needs to be replaced during network modernization then edge between vertices a_1 and a_4 is removed. Instead of it a new route is designed: $a_1 - a_6 - a_4$ that comprises edges b_{16} and b_{46}. Exactly such case is considered further. If the cable between nodes a_1 and a_4 conforms to all necessary requirements, then it stays in operation. Then edges b_{16} and b_{46} should be considered as means of inclusion of new vertex a_6. Transport network model in that case will consist of two rings.

2. Probability of vertex a_7 appearing denoted as p_7 is close to zero. Therefore, if cable between third and fourth nodes of the network (edge b_{34} between vertices a_3 and a_4) needs to be replaced, there is no sense in complete change of the cable routing. In this case the existing cable duct can be reused, if its condition conforms to requirements of the foreseeable prospect. This statement holds true only if laying new cable is sufficient.

3. Vertex a_5 will appear with probability p_5 that is far from 1, but much greater than p_7. Possible solution is to allot two points (they are depicted by little squares on the edge between vertices a_1 and a_2) through which at some moment of time two cable routings to vertex a_5 will be built in order to create a ring.

Placements of three new SNs (graph vertices a_5, a_6 and a_7) can be defined not by precise coordinates, but by some regions S_5, S_6 and S_7. In that case, each region S_i $\left(i=\overline{5,7}\right)$ defines boundaries of the territory for the placement of network node.

Maximal number of new vertices in the model equals three. Hence, a list of all variants of possible graph changes can be made. This list is given in the first table. Sign "+" means that considered variant is based on addition of i^{th} vertex. If the sign "–" used then i^{th} vertex is not added.

Table 1. List of variants of possible graph changes

Variant number	Name of the new graph vertex		
	a_6	a_5	a_7
1	+	–	–
2	+	+	–
3	+	–	+
4	+	+	+
5	–	–	–
6	–	–	+
7	–	+	–
8	–	+	+

It is obvious that the number of considered variants can be decreased if unacceptable solutions are discarded. Typical examples of such solutions are variants from fifth to eighth. Third variant also can be excluded taking into account given probability values of new vertices introduction. As a result it is sufficient to study only three functions $NPV(1,t)$, $NPV(2,t)$ and $NPV(4,t)$.

With that formulation of problem definition it is incorrectly to talk about the search of optimal solution. For any possible variants of course of events (first, second and fourth) that imply introduction of new SNs, proposed structure of transport network won't be optimal.

Discussion of proposed methodology

In the "Historical aspects of telecommunication networks development" part it was shown that by the moment of start of next network modernization phase, the network is strictly speaking nonoptimal. Thus it is necessary to consider established situation according to "as is" principle [3].

Proposed approach implies that a number of preliminary studies should be carried out. Firstly, emphasis should be put on development of long-term plan of telecommunications network modernization. Long-term planning is based on forecast. After analysis of corresponding estimations, the model of perspective telecommunication network can be suggested. From this point of view, considered methodology can be expressed by motto "*as should be*". By the moment of time T_X, goal of telecommunications network modernization will be achieved with investment volume I_R. Index "*R*" formed from the first letter in word "rational" that was chosen as the name for the proposed methodology.

The alternative is approach based on definition and solution of problem only at that point in time when the relevance of network modernization becomes apparent. As a result of sequence of operations finished by the moment T_X, telecommunications network will be built that corresponds to the "*as will*" principle. For the T_X time period a volume of investments I_A is required. Here index "*A*" formed from the first letter in word "alternative" emphasizing the difference from approach proposed in this article.

Studies in [3] show that as a rule $I_R < I_A$. Difference between I_R and I_A values can be used as a measure of efficiency of the investigations that lead to the choice of rational solution.

Conclusion

Proposed approach towards development of telecommunications networks bases on the search of rational solutions. This approach seems productive from the point of view of long-term perspectives of telecommunications network development. Currently, for the lengthy period T_X, a number of projects related to telecommunications networks modernization are developed sequentially. Each project spans some period of time that is less than T_X. Network structure established by the start of works on each project is considered as status quo. It corresponds to principle "as is" mentioned above.

It is possible that each project contains optimal solution. On the other hand, such approach does not guarantee that during period of time T_X telecommunications network will be modernized optimally. This fact in particular serves as incentive for search of solutions that were called rational.

In the article general thoughts about expediency of search for solution that can be considered as rational for problems of telecommunications networks development are stated. The most important direction for further study is acquiring of forecasting estimates determining quantitative and qualitative characteristics of perspective telecommunication system.

Литература

1. Davidov G.B., Roginsky V.N., Tolchan A.J. Telecommunication networks. – Moscow: Svyaz, 1977.

2. Zvyagintzev M.V., Maslov D.S., Sokolov N.A. Selecting a communication network's structure taking into account its elements' life cycle. – Electrosvyaz Magazine, 2010, №8.

3. Sokolov N.A. Problems of the telecommunication network planning. – St. Petersburg: Communication Technology, 2012.

4. Bessler R., Doich A. Telecommunication network planning. – Moscow: Radio and Communications, 1988.

5. Kotov V.I. Risk analysis of investment projects on the basis of the sensitivity functions and the theory of fuzzy sets. – St. Petersburg: Shipbuilding, 2007.

6. Lifiz I.M. Theory and Practice of the competitiveness of goods and services. – Moscow: Urait, 2001.

7. Orlov A.I. Organizational and economic modeling. Part 2: Expert estimates. – Moscow: Moscow State Technical University, 2011.

Abstract

The number of complicated problems has to be solved during modernization of the telecommunication networks. Some problems can be defined as a search for rational solutions instead of the traditional approach that consists in finding the cost function optimum. This new approach minimizes the risk that inevitably arises when elaborating a long-term plan for the telecommunication networks development. The article discusses the proposed methodological approach of finding rational solutions. Problems for the further study are listed.

Keywords**:** *telecommunication network, rational decision, optimal decision, scenario, life cycle.*