Planning of the Development of Indonesia's Transport Infrastructure using Linear Programming Methods

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Keywords: Indonesia's transport system, rail transport, National Transport Development Strategy (RIPNAS), simplex method, canonical transport problem, combinatorial methods of solution, dynamic programming, integer linear programming, industrial and economic relations, suppliers and consumers, contracting organizations.

Abstract: The article presents the results of a study of transport problems in Indonesia to solve the problems of transportation of both passengers and cargo, to ensure energy savings, a high level of safety during operation, environmental safety and greater efficiency compared to road transportation (in terms of mass transportation). This task is assigned to rail transport, which is included in the program for the development of transport on the islands of Sumatra, Sulawesi, Kalimantan and Papua, developed in the National Strategy for the Development of Transport (RIPNAS) until 2030. The objective of the study is to apply linear programming methods for the formation of municipal budgets for the construction or reconstruction of railway infrastructure facilities in Indonesia, taking into account the production plan of contractors in accordance with the comprehensive strategic plan for the development of infrastructure in the region of Indonesia. Variants of the considered matrices are formed on the basis of the existing production and economic relations between contractors and customers, for example, municipalities. They reflect not only the current benefit, but also the stability of the interaction, which is ignored in the usual formulation of the transport task. These matrices serve as the basis for obtaining a reference solution. For example, on the island of Sumatra, it is planned to develop a suburban (between provinces) railway network to reduce the traffic load on highways and are considered as a link of economic activity.

1 INTRODUCTION

Indonesia is an archipelago with more than 17,000 islands with a total area of 735,355 square miles. Currently, Indonesia is the fourth of the 10 countries with the largest population in the world, which is about 269.6 million people. One of the problems of Indonesia, as an archipelago country, is the unification of all its territories by sustainable transport links (Jakarta. 2011; Peraturan Presiden Republik Indonesia Nomor 18, 2020; Peraturan Presiden Republik Indonesia Nomor 38, 2015). Therefore, transport is an important macroeconomic aspect of the national, regional and local economy, both in rural and urban conditions (Proyek KPBU Kereta Api Makassar-Pare-pare, 2018; Jinca, 2009). An important task in solving Indonesia's transport problems is assigned to rail transport, which allows transporting both passengers and cargo, ensuring energy savings, having a high level of safety during operation, being environmentally safe and more efficient compared to road transportation (in terms of mass transportation volumes). The beginning of the development of railway transport in Indonesia was the end of the 19th century. Currently, work on the development and improvement in this area continues and is included in the program for the development of railway transport on the islands of Sumatra, Sulawesi, Kalimantan and Papua (Peraturan Daerah Provinsi Sulawesi Selatan Nomor 1, 2019; Peraturan Daerah Provinsi Sulawesi Barat Nomor 8, 2017; Peraturan Daerah Provinsi Sulawesi Utara Nomor 1, 2014). The development program is laid down in the National Railway Development Strategy (RIPNAS) until 2030. For example, the goal of developing a railway network on the island of Sumatra is to connect existing unrelated railway lines in Aceh, North Sumatra, West Sumatra, South Sumatra and Lampung into a single network of interconnected railways (Provinsi Sulawesi Tengah dalam Angka, 2018; Provinsi Sulawesi Barat dalam Angka, 2021). By 2030, it is planned to stage-by-

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stage construction of railway infrastructure, including railway tracks and facilities (Jakarta. 2011; Peraturan Presiden Republik Indonesia Nomor 18, 2020; Peraturan Presiden Republik Indonesia Nomor 38, 2015). According to the planned strategy (Provinsi Sulawesi Tengah dalam Angka, 2018; Provinsi Sulawesi Barat dalam Angka, 2021), the development of a railway network, for example, Sumatra Island, is planned in the capital of each province, which includes the following cities: Medan (North Sumatra) length – 230 km; Pekanbaru (Riau) – 120 km; Padang (West Sumatra) – 330 km; Palembang (South Sumatra) – 250 km; Bandar Lampung (Lampung) - 170 km and Batam (Batam Islands) – 330 km.

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2 MATERIALS AND METHODS

In accordance with Indonesia's National Strategy for the Development of Railways (RIPNAS) until 2030, it is necessary to develop the most effective solutions to this task.

To analyze the factors affecting the construction of railway transport infrastructure, the development of the most effective plan for the distribution of material and labor resources, a canonical transport task can be considered. Two components are considered as criteria for optimizing the solution of the transport problem:

- minimum costs for the construction of new lines and reconstruction of existing ones;
- minimum time for construction and reconstruction.

In the classical view, the task is called transport. The transport problem (Milovidov, 1982; Borodinova, 2010) has an identical mathematical model covering a wide range of tasks. Such problems are considered and solved by linear programming methods (Dantzig, 2016; Gass, 2004). For the conditions of Indonesia as an island state, its application goes beyond just the same type of transport.

The classical transport problem can be solved by the simplex method (Nelder, 1965; Tsvetkov, 2001), but taking into account its features characteristic of Indonesia, the result of the solution may be different. As a rule, when solving transport problems, the interests of only one market participant are taken into account. For the conditions of Indonesia, such a customer is the relevant municipality, on the territory of which the construction of a railway section is planned. This is a common disadvantage of the formulation and solution of the transport problem. Thus, it is not a market, as it represents the interests of one market participant and is characterized by its offer. In the conditions of market planning, there are several options, both applications and proposals, which are an additional factor that are not taken into account in solving transport problems.

The formulation of the transport problem in the classical view has the following basic conditions:

- there are m – work producers (contractors) (resource vector);
- there are n – construction objects (consumption vector);
- * cost coefficients c_{ij} are set, that is, the cost of a unit of construction operation from the i-th manufacturer for the j-th construction object (cost matrix).

Based on the results of solving the tasks, it is necessary to determine (x_{ij}) the volume of construction and installation works from the i-th contractor) for the j-th municipality, which are considered as the desired solution. In addition, it is necessary to determine the most rational plan for the volume of construction and installation work for each contractor - customer pair, for which the following conditions have been met:

1 - the capacities of the construction and installation works involved in the implementation of the project for contractors have been implemented;

2 - the applications for construction and installation work of all involved municipalities would be satisfied;

3 - the total costs of construction and installation work would be minimal.

When setting a classical transport problem , the features are:

- in canonical form , the system of constraints is given in the form of equalities;
- with variable parameters, the coefficients of the system are assumed to be equal to 1 or 0;
- each variable enters the constraint system twice.

The system of restrictions has the form:

$$\sum_{i=1}^{n} x_{ij} = M_j \quad (j = 1.....m) \tag{1}$$

m - number of contractors (producers of works):

$$\sum_{j=1}^{m} \sum x_{ij} = N_i \quad (i = 1.....n) \qquad (2)$$

n - the number of objects of construction and installation works.

The linear function can be expressed as:

$$F = \sum_{i=1}^{n} \sum_{j=1}^{m} c_{ij}\, x_{ij} \Rightarrow min \qquad (3)$$

When solving the problem of determining the number of contractors to perform construction and installation work, taking into account the set of constraints presented in formulas (1, 2), it is required to find a solution X in which the linear function F (formula 3) will take a minimum value. In other words, the construction and installation work will be minimal. In solving the canonical form of the transport problem, a sequential number of contracting organizations has an arbitrary distribution $\boldsymbol{X}$ **(** $x_{11}, x_{12},...x_{1n}, x_{ij},... x_{m1}, x_{mn}$ **).** Such distribution should be considered as a plan of applications (or proposals) for construction and installation works.

The most convenient form of such distribution is presented in the form of a table of applications (or proposals) from contracting organizations to customers (municipalities).

In the canonical form, it is considered that if the total capacity to perform construction and installation works of contractors is equal to the total needs of municipalities, then this type of tasks is called closed. Otherwise, the task has an open character with the need to include a fictitious contractor model in the algorithm.

In the canonical form, the solution of the transport problem includes two stages. The first stage is that the initial or basic solution is determined. At the second stage, the initial solution is adjusted and optimized in order to obtain an optimal result.

After finding a basic solution to the construction and installation work plan, it is necessary to apply one of the algorithms for improving it and approaching a rational plan.

A transport task taking into account the interests of the customer and the competition of contractors. In the practical activities of construction and installation organizations in the construction of railway infrastructure facilities in Indonesia, the transport problem is solved taking into account the experience of interaction between municipalities and contracting organizations. The task is to take into account the interests of contractors and the requirements of municipalities.

When creating an algorithm for calculating the model of interaction between municipalities and contracting organizations, the interests of contracting organizations can be reflected in the form of a graph of proposals (matrix A in Figure 1) on the one hand and a matrix of the capabilities of contracting organizations to perform construction and installation work (Figure 2). Conventionally, the matrix of capabilities of contracting organizations is designated as the matrix B.

The graph of proposals (Figure 1) shows that the relationship between contractors is not complimentary. There is competition between them for their municipality. In the matrix, B sentences are indicated by the v – tender symbol. The presence of the symbol v in the matrix row qualitatively reflects the contractor's interest in performing a certain amount of construction and installation work, quantified by the value of v for its municipality.

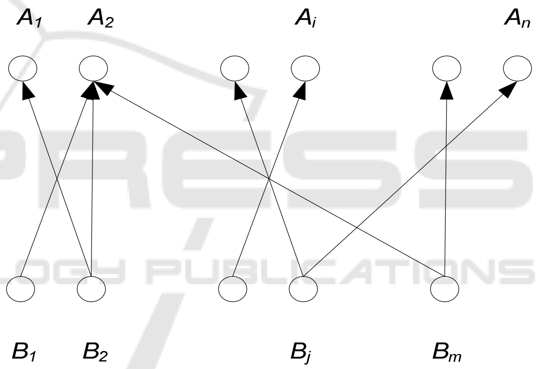

Figure 1: Graph of proposals for construction and installation works of contractors.

	A_1	A_2	**….**	**….**	**….**	A_n
B_1			**v**			
B_2	**v**			**v**		**v**
….			**v**		**v**	
….		**v**				**v**
….			**v**		**v**	
B_m	**v**	**v**		**v**		

Figure 2 - Matrix for contractors: proposals A and opportunities for their implementation B. v – compliance of proposals and opportunities for their implementation.

For municipalities (or the customer), there is a similar situation to meet their interests. The interests of the municipality are reflected by the demand graph (Figure 3), as well as the applicant matrix (Figure 4).

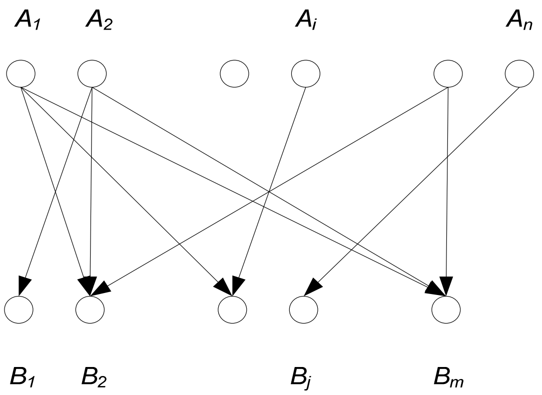

Figure 3: Graph of applicants' demand (for example, municipalities).

Graphoanalytic interpretation of the interests of municipalities can be conditionally represented in the form of matrix A Figure 4. The demand graph (Figure 3) shows that there is competition between municipalities, as well as between contractors, and the determination of preferences for their contracting organization.

	A_1	A_2	….	….	….	A_n
B_1	w		w			w
B_2		w		w		
….			w		w	
….		w		w		
….	w	w				w
B_m			w		w	

Figure 4: Matrix of the customer (for example, municipalities) A. w – correspondence of the contractor's proposals and the possibilities of municipalities to meet them.

In matrix A (Figure 4), the proposals are indicated by the symbol w – request. The w symbol in the matrix row reflects the municipality's interest in this contracting organization. This interest can be expressed quantitatively in the form of the cost of construction and installation work or the volume of such work, as well as the duration of construction and installation work. The planned parameters of the obtained results of the work are quantitatively indicated by the value w.

The values w and v should have opposite signs, due to the fact that the environment in question has a market formation structure. In graphs, such a statement of the problem is indicated by the opposite directions of the vectors in Figure 1 and Figure 3.

As a rule, this formulation of the problem leads to not one, but two matrices. These matrices reflect not only the different interests of the customer (for example, in the person of the municipality) and the contracting organization, but also the internal competition between the interests of the contracting organization and the tasks of municipalities.

In the practical implementation of real objects, matrices A and B differ from the mathematical formulation of the problem, since they are formed on the basis of real annual plans for the construction of railway infrastructure facilities or investment plans for the construction of facilities. The most acceptable option is when the plan of the previous year is repeated with adjustments made to it. In this case, they can be used as a realistic reference plan. The solution of the tasks in matrix form can be obtained by superimposing vector schemes or adding matrices A and B with elements having opposite signs.

The optimal solution to the problem of a rational relationship between the satisfaction of the interests of the customer (for example, in the person of the municipality) and contractors for construction and installation works can be achieved ideally in a balanced customer–contractor system (formula 4).

$$A + B = 0 \tag{4}$$

In a real situation, as a rule, there is a discrepancy (discrepancy Z), formula 5:

$$A + B = Z \tag{5}$$

Where Z is defined as the residual matrix (Figure 5):

	A_1	A_2	…	…	…	A_n
B_1	**w**	**0**	**w**	**0**	**0**	**w**
B_2	**v**	**0**	**0**	**0**	**0**	**v**
….	**0**	**0**	**0**	**0**	**0**	**0**
….	**0**	**0**	**0**	**w**	**w**	**0**
….	**v**	**v**	**v**	**w**	**0**	**0**
B_m	**w**	**v**	**0**	**0**	**0**	**v**

Figure 5: The residual matrix *Z*.

The elements of the matrix of inconsistencies (inconsistencies) Figure 5, the values of the values w (possibilities of municipalities) and v (proposals of contracting organizations), as well as Δw and Δv are accepted.

The values of the values Δw and Δv show the presence of a partial discrepancy between the capabilities of municipalities and the proposals of contracting organizations. For example, with partial financing of construction and installation works by the municipality, or, on the other hand, only partial production of construction and installation works by a contractor.

The values of w and v are considered as a complete discrepancy between the capabilities of municipalities and the proposals of contracting organizations. For example, on the one hand, there is an excess of resources on the part of the work producer, for example, contractor v, or, on the other hand, there is a lack of resources w (lack of funding) on the part of the customer, for example, the municipality. When a variant of the problem arises with the appearance of a matrix of residuals, the solution of such a problem is reduced to minimizing the base matrices by mutual absorption of its elements (formula 6):

$$A + B = min\ (N) \qquad (6)$$

Such a problem (formula 6) is solved by methods of combinatorial mathematics.

3 RESULTS

Combinatorial methods for solving Indonesia's transport infrastructure. Matrix minimization (Figure 4 or Figure 5) can be considered as an integer programming problem. The minimization problem is called the "Knapsack Problem", which is always solved. This problem is formulated as follows (Rosenberg, 2019). There are n railway transport infrastructure construction facilities in Indonesia ($\boldsymbol{c}_{ij}$ = 1,… n) and various production costs of cj works. It is required to select such types of construction and installation works that have a minimum total value of no more than b_1 (the specified budget value). We denote $x_j = 1$ if the j – th variant of the organization of work is selected. For the case of choosing another solution option, $x_j = 0$. For the considered problem of the construction of railway transport infrastructure in Indonesia, the task is to minimize costs when organizing the construction of linear transport infrastructure facilities (FL) (formula 7):

$$F_L(x) = \sum_{j=1}^{n} (c_j x_j) \Rightarrow \text{......}\ \min \qquad (7)$$

Under linear constraints:

$$\sum_{o=1}^{m} (c_j x_j) \le b_i, \qquad x_j = \{0,1\} \qquad (8)$$

To solve the problem of minimizing costs when organizing the construction of linear transport infrastructure facilities, algorithms based on the dynamic programming method are mainly used (Bellman, 1965).

In general, the listed tasks are reduced to the parameters of integer linear programming. Therefore, the variant of integer linear programming will be the solution of the transport problem. For the construction of railway infrastructure in Indonesia, it is required to minimize the cost of construction and installation works (f_r).

$$f_r(x) = \sum_{i=1}^{n} (c_j x_j) \qquad j = 1, \dots n \qquad (9)$$

As restrictions for solving the tasks, the following conditions are accepted:

$$\sum_{j=1}^{n} (a_{i,j}) \le b, \qquad (10)$$

$$i = 1.....\ m; \quad j = 1.....n; \quad x_j = \{0,1\}$$

4 DISCUSSION OF THE RESULTS

Gomori's research (Gomory, 1963; Gilmore, 1965) proposed algorithms for solving integer linear programming problems using additional secant planes.

The developed software, conducted with these algorithms (Teplitsky, 1968), showed that the method of "secant planes" gives good results, mainly for problems of small dimension. At the same time, for such problems, there are cases when the algorithms of "secant planes" either do not provide a reliable solution in real time, or require a complete search of calculations.

For problems of combinatorial type, as a rule, two groups of solutions can be distinguished based on the method of local optimization and the second group using the method of step-by-step obtaining solutions. The most common is the method of "step-by-step obtaining solutions", which includes iterative, incremental and spiral algorithms (Tsvetkov, 2018). In the studies of Pyatetsky-Shapiro A.B. (Pyatetsky-Shapiro, 1966), the application of the random search method to solve the integer programming problem is given under the additional condition that all parameters a_{ij}, c_j, b are non-negative.

The formation of the budget of municipalities for the construction and reconstruction of railway infrastructure facilities in Indonesia, taking into account the volume of production plans of contracting organizations, is carried out sequentially, starting from the linear level formed by the production and technical department of the contracting organization (Volkov, 2018; Volkov, 2019) in accordance with the comprehensive strategic plan for the development of infrastructure in the region of Indonesia.

Taking into account the interests of not only contractors, but also the customer, for example, municipalities, leads to the need to set a new type of transport task.

In this task, instead of one matrix that takes into account "supply and demand", two matrices are used, independently reflecting the interests of both contracting organizations for the construction of new and reconstruction of the existing infrastructure of railways in Indonesia, and the customer – customer, for example, municipalities. Each of these matrices is formed on the basis of the existing production and financial relations between contractors and customers represented, for example, by municipalities. Together, these "matrices of interests" reflect not only the current benefits of each of the participants in the overall process, but also the reliability of interaction, which is ignored in the usual formulation of the transport task. When considering the process of creating an algorithm for the construction and reconstruction of railway infrastructure facilities in Indonesia, these matrices serve as the basis for obtaining a reference solution. For example, on the island of Sumatra, it is the development of a suburban (between provinces) railway network to reduce the traffic load on highways as a link of economic activity.

5 CONCLUSIONS

Further optimization is obtained by processing the resulting matrix, and such a matrix can be supplemented by new construction and repair companies and new customers. One of the options for solving general or resultant matrices, in which, on the one hand, the interests of the customer, for example, the municipality, are taken into account, on the other – the interests of the contracting organization, methods that are characteristic of the "Dynamic transport problem with delays" or combinatorial methods can be used.

To develop the suburban railway network on Sumatra Island, it is planned to build a main highway to connect the following cities: Banda Aceh – Sigli – Bireun – Lokseumave (284 km); Lokseumave – Langsa – Besitang (199.5 km); Binjai – Besitang (156 km); Rantauprapat – Duri –Dumai (251 km); Duri – Pekanbaru (100 km); Pekanbaru – Muaro (297 km); Pekanbaru – Rengat – Jambi (274 km); Jambi – Betung (188 km); Betung – Simpang (124 km); Tarahan – Bakauhen (70 km); Pematang Siantar – Danau Toba (117 km); Shortest way Rejosari – Tarakhan (37,752 km); The shortest route is Indarung – Solok (36.2 km); Reconstruction of the Belavan – Gabion line; Reconstruction of the Padang – Pulo Aer line; Reconstruction of the Naras – Sungai Limau line, and Reconstruction of the Moiro Calaban – Logas line.

When using an integrated approach of planning for the development of the railway infrastructure of Indonesia based on linear programming methods, it is possible to obtain a balanced version of the financial and economic plan of expenditures and expenditures for the development of the railway infrastructure of Indonesia. And also determine the components of the share of financing, both private capital and the state. Thus, the development of the suburban train network is impossible without state financial support for infrastructure to achieve maximum quality of service.

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