SELECTION OF OPTIMAL VARIANTS FOR ULAANBAATAR RAILWAY DEVELOPMENT

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ABSTRACT

Modern single-track lines allow to develop cargo traffic for up to 16–18 million tons net per year in the same direction. However, with significant traffic flow the delay of trains dramatically increases. This reduces service speed, worsens indicators of rolling stock use, causes additional fuel loss, and ultimately increases transportation costs, reduces productivity [1–3]. Then a moment comes when one track cannot master increased flow of goods and there is a need to strengthen the transport capacity [4]. Design traffic and carrying capacity of communications of transport nodes, as well as priorities for building infrastructure are linked to long-term prospects of development of productive forces, regions, foreign trade [5, 6].

Due to continuous growth of traffic on Ulaanbaatar railway, problems arise related to selection and economic feasibility of its technical equipment in the future. To solve these tasks, it is necessary to analyze conditions of modernization, strengthening of freight (processing) capacity of sections (stations), to choose circuits of staged development and optimization of technical equipment of lines of JSC «Ulaanbaatar Railway».

Keywords: railway, Ulaanbaatar railway, freight traffic, semi- automatic blocking, automatic blocking, transportation capacity, estimated capacity, development of sections, option graph, exhaustion period.

Background. *In a similar situation analysis of existing characteristics of the lines of Ulaanbaatar Railway has shown that it is possible to take following measures to increase carrying capacity:*

- *Construction of additional junctions to reduce distances between separate points.*
- *Extension of station receiving and departure tracks from 850 to 1050 meters.*
- *Equipping lines with automatic locking.*
- *Construction of the second main track as a final stage of a phased increase in carrying capacity of railway sections.*

Depending on operating conditions of the lines specified options for strengthening carrying capacity can be used in various combinations of their consistent implementation [7]. In each case, there is a definite optimal sequence of measures, and the most appropriate distribution of technical terms, under which the total transportation costs for the whole period of operation of the line until its conversion to double track will be the lowest.

Development of sections and lines is expected to be phased. The authors used the method of selecting a plurality of possible states of the technical equipment of the railway line [7]. The detailed description of this process can be given by the concept of the state vector and the stage of section development. The set of parameters that characterize technical equipment, management and technology of work, is called the state of the section.

Objective. *The objective of the authors is to show possible solutions for development of Ulaanbaator Railway.*

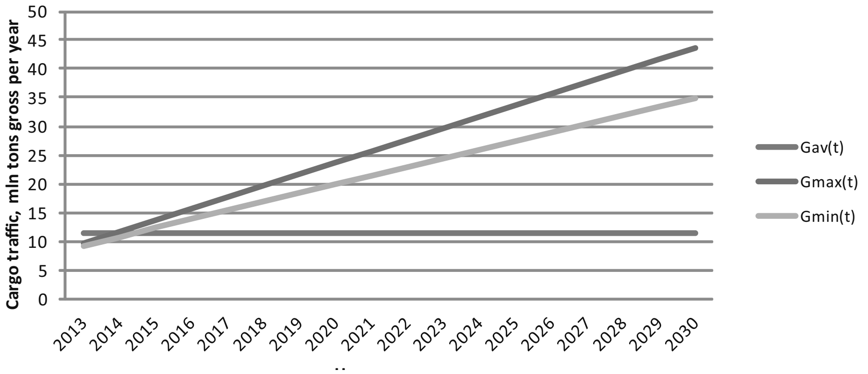
Methods. *The authors use analysis, comparative method, evaluation approach.*

Results. *For different sections there is always a certain set of states. It is denoted by C and its elements (state vector) by c_i. It is necessary to define*

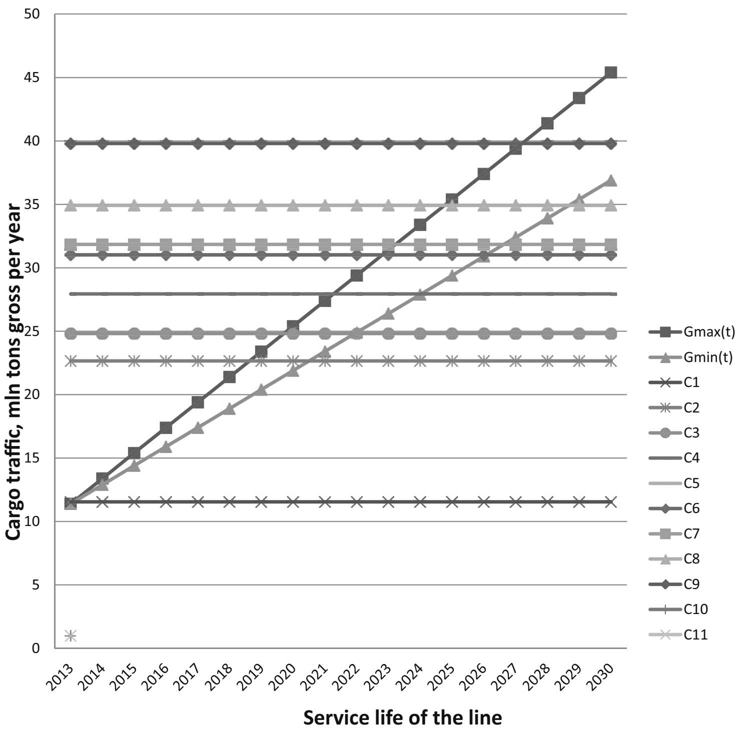
Table 1

Characteristics of conditions of the section Sainshand-Dzamyn-Ude

	Technical state of the section
C_1	Single track line is equipped with semi-automatic locking (hereinafter- SAL). The length of station receiving and departure tracks Lst = 850 m (original state)
C_2	Single track line is equipped with SAL, construction of seven additional separate points. The length of station receiving and departure tracks Lst = 850 m
C_3	Single track line is equipped with SAL. Construction of seven additional separate points. The length of station receiving and departure tracks Lst = 1050 m
C_4	Single track line, construction of seven additional separate points, equipped with automatic locking γ_{pack} = 0 (AL). The length of station receiving and departure tracks Lst = 850 m
C_5	Single track line, construction of seven additional separate points, equipped with automatic locking γ_{pack} =0,3 (AL). The length of station receiving and departure tracks Lst = 850 m
C_6	Single track line is equipped with automatic locking γ_{pack} = 0,6 (AL). Construction of seven additional separate points. The length of station receiving and departure tracks Lst = 850 m
C_7	Single track line is equipped with automatic locking γ_{pack} = 0 (AL). Construction of seven additional separate points. The length of the station receiving and departure tracks Lst = 1050 m
C_8	Single track line is equipped with automatic locking γ_{pack} = 0,3 (AL). Construction of seven additional separate points. The length of station receiving and departure tracks Lst = 1050 m
C_9	Single track line is equipped with automatic locking γ_{pack} = 0,6 (AL). Construction of seven additional separate points. The length of station receiving and departure tracks Lst = 1050 m



Pic. 1. Diagram of available and required carrying capacity at the section Sainshand- Dzamyn -Ude.



Pic. 2. Multi-stage scheme to increase the carrying capacity of the section Sainshand- Dzamyn -Ude.

a set of states C, which will serve as an original material for construction of schemes of section development, and then to find a set of competitive schemes S.

Single-track railway line Sukhbaatar- Dzamyn-Ude is equipped with semi-automatic locking. On the line there are five sections.

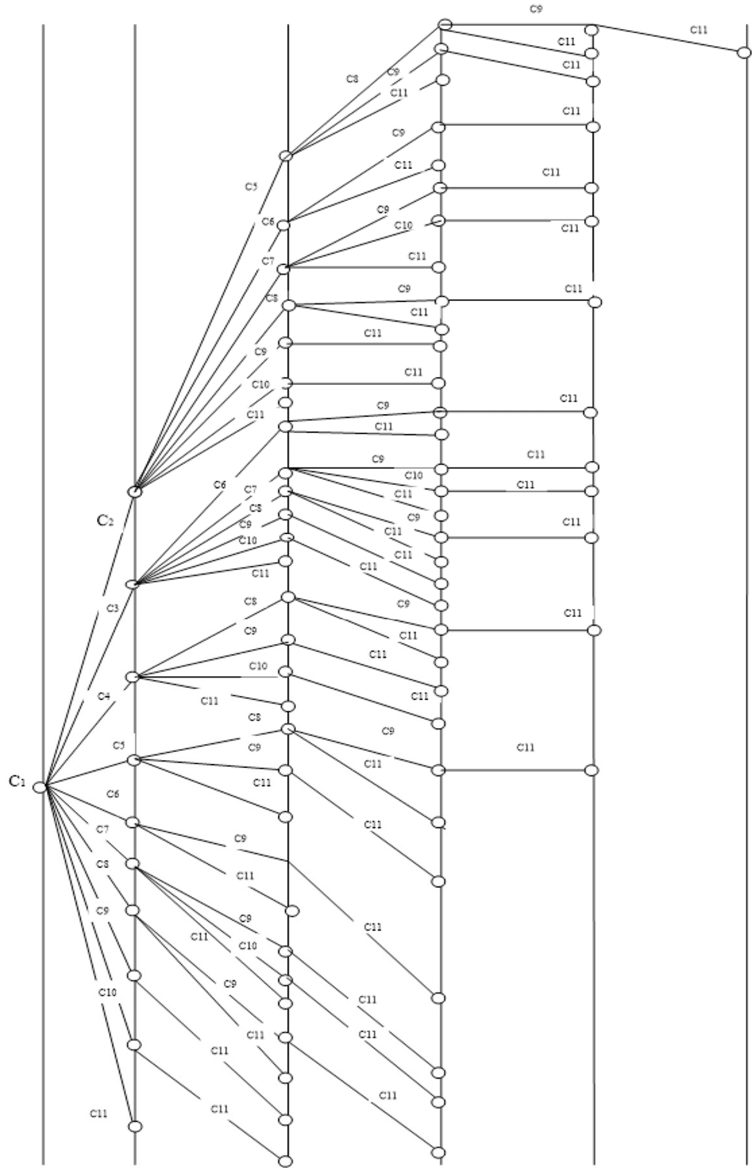
Let's take, for example, section № 5: Sainshand-Dzamyn-Ude. Its length is 235 km. It has 10 separate points and two technical stations. The average length of a haul is 23 km. Average effective length of separate points is 850 m. The limiting haul is Tushleg-Orgon, where travel time is 47 minutes. The average weight of the train in an even direction is 3981 tons gross, and in an odd direction it is 2316 tonnes gross. Characteristics of possible states for a period of up to 15 years for this section is presented in Table 1. These states are taken into account in the construction of the line development schemes. For a given set of C_i it is necessary to list all possible competitive development schemes.

Determination of a technical term is a task which is solved for each section and each state of its development. Term of carrying capacity exhaustion is a technical term of reconstruction, which is determined by equation of available and required carrying capacity (the intensity of the traffic) [7].

Knowing available and required carrying capacity of the line for each year t, it is possible to build a graph of their changes over time. We build a graph $G_r(t)$ of required carrying capacity by setting the value of traffic by five-year periods, i. e. for 5^{th}, 10^{th}, 15^{th} and 20^{th} year.

Simiraly, technical terms of renovation are found for states C_1 ... C_{11} (see Table 1) for each section in even and odd directions. States of sections are arranged on terms of reconstruction, so knowing these technical terms ($t_{tech}i$, ..., $t_{tech}j$), we obtain: $C_1 \rightarrow C_2 \rightarrow C_4 \rightarrow C_5 \rightarrow C_6 \rightarrow C_7 \rightarrow C_8 \rightarrow C_9 \rightarrow C_{10} \rightarrow C_{11}$. The results of calculations where states are arranged by terms of reconstruction, are shown in Table 2.

Table 2 shows that the technical term of reconstruction of the section in the original state (single track line, SAL, L_{rdt} = 850 m) in the even direction is almost exhausted. This indicates a significant growth rate of traffic.



Pic. 3. Option graph of competitive development schemes for the railway line of the section Sainshand -Dzamyn-Ude.

As technical terms of the reconstruction of the section of even and odd direction the period is taken into account, which has the lowest value (in the table, these terms are shown in bold). Focusing on technical terms of reconstruction, for each state, it is possible to build a multi-step scheme to increase the carrying capacity that is shown in Pic. 2 for the section Sainshand -Dzamyn-Ude.

The increase in transportation facilities of the railway line on the selected scheme of development is carried out in stages, with each stage can be characterized by one or more parameters of technical equipment. In this case, with the equipment of the line with automatic locking with organization of partially packet traffic such parameters are ratio of graph's package γ_{pack} and the standard length of station receiving and departure tracks L_{st}.

Technical reconstruction of the line cannot only significantly increase its carrying capacity, but also drastically reduce transportation costs. Therefore, reconstruction moments of the line must be justified by technical and economic calculations [4].

To select multiple competitive schemes it is necessary to define a set of logically inconsistent state. Such states are, for example, C_3 and C_5 – contradiction is in that at the third stage the section is equipped with a self locking with a package coefficient $\gamma_{pack} = 0$, and at the fifth stage – with semi-automatic locking. There are 10 such conflicting pairs at the section.

Table 2

Technical term for reconstruction

State of the section	Characteristics of the technical state of the section	Direction	Technical service life				
			Section№ 1	Section№ 2	Section№ 3	Section№ 4	Section№ 5
C1	Single track line, equipped with semi-automatic locking (SAL). The length of station receiving and departure tracks Lst = 850 m	Чет Even	2015	2016	2015	2013	2014
		Odd	>2030	>2030	2015	2013	2015
C2	Single track, equipped with semi-automatic locking (SAL), construction of seven additional separate points. The length of station receiving and departure tracks Lst = 850 m	Even	2019	2018	2022	2020	2019
		Odd	>2030	>2030	2022	2018	2021
C3	Single track line, construction of seven additional separate points, equipped with automatic locking γ_{pack} = 0 (AL). The length of station receiving and departure tracks Lst = 850 m	Even	2019	2018	2022	2020	2020
		Odd	>2030	>2030	2022	2019	2022
C4	Single track line, construction of seven additional separate points equipped with automatic locking γ_{pack} = 0,3 (AL). The length of station receiving and departure tracks Lst = 850 m	Even	2021	2019	2024	2022	2021
		Odd	>2030	>2030	2022	2020	2023
C5	Single track line, equipped with semi-automatic locking (SAL). Construction of seven additional separate points. The length of station receiving and departure tracks Lst = 1050 m	Even	2022	2020	2026	2023	2023
		Odd	>2030	>2030	2025	2021	2025
C6	Single track line is equipped with automatic locking γ_{pack} = 0 (AL). Construction of seven additional separate points. The length of station receiving and departure tracks Lst = 1050 m	Even	2022	2020	2026	2023	2023
		Odd	>2030	>2030	2025	2021	2025
C7	Single track line is equipped with automatic locking γ_{pack} = 0,6 (AL). Construction of seven additional separate points. The length of station receiving and departure tracks Lst = 850 m	Even	2023	2021	2026	2024	2023
		Odd	>2030	>2030	2025	2021	2025
C8	Single track line is equipped with automatic locking γ_{pack} = 0,3 (AL). Construction of seven additional separate points. The length of station receiving and departure tracks Lst = 1050 m	Even	2024	2022	2028	2025	2025
		Odd	>2030	>2030	2027	2022	2027
C9	Single track line is equipped with automatic locking γ_{pack} = 0,6 (AL). Construction of seven additional separate points. The length of station receiving and departure tracks Lst = 1050 m	Even	2027	2024	2030	2028	2028
		Odd	>2030	>2030	2029	2024	2030
C10	Double track line, equipped with automatic locking γ_{pack} = 0,6 (AL). The length of station receiving and departure tracks Lst = 850 m	Even	>>2030	>>2030	>>2030	>>2030	>>2030
		Odd					
C11	Double track line, equipped with automatic locking γ_{pack} = 0,6 (AL). The length of station receiving and departure tracks Lst = 1050 m	Even	>>2030	>>2030	>>2030	>>2030	>>2030
		Odd					

Note. Section № 1: Sukhbaatar-Zunhara; section № 2: Zunhara-Ulaanbaatar;; section № 3: Ulaanbaatar-Choyr; section № 4: Choyr-Sainshand; section № 5: Sainshand- Dzamyn-Ude.

Table 3

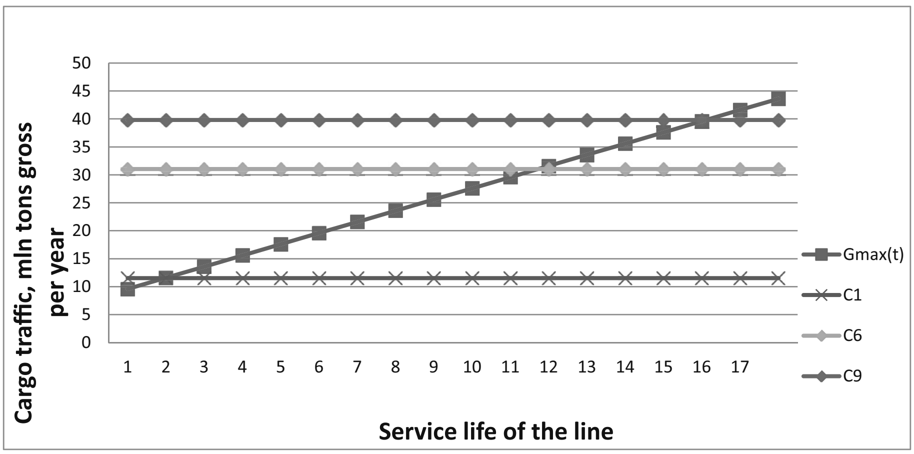
Development schemes of the section Sainshand -Dzamyn-Ude

№ of the track on the graph	Development scheme of the section	№ of the track on the graph	Development scheme of the section	№ of the track on the graph	Development scheme of the section
1	$C_1 \to C_{11}$	15	$C_1 \to C_5 \to C_9 \to C_{11}$	29	$C_1 \to C_2 \to C_6 \to C_{11}$
2	$C_1 \to C_{10} \to C_{11}$	16	$C_1 \to C_5 \to C_8 \to C_{11}$	30	$C_1 \to C_2 \to C_5 \to C_{11}$
3	$C_1 \to C_9 \to C_{11}$	17	$C_1 \to C_4 \to C_{10} \to C_{11}$	31	$C_1 \to C_5 \to C_8 \to C_9 \to C_{11}$
4	$C_1 \to C_8 \to C_{11}$	18	$C_1 \to C_4 \to C_9 \to C_{11}$	32	$C_1 \to C_4 \to C_8 \to C_9 \to C_{11}$
5	$C_1 \to C_7 \to C_{11}$	19	$C_1 \to C_4 \to C_8 \to C_{11}$	33	$C_1 \to C_3 \to C_8 \to C_9 \to C_{11}$
6	$C_1 \to C_6 \to C_{11}$	20	$C_1 \to C_3 \to C_{10} \to C_{11}$	34	$C_1 \to C_3 \to C_7 \to C_{10} \to C_{11}$
7	$C_1 \to C_5 \to C_{11}$	21	$C_1 \to C_3 \to C_9 \to C_{11}$	35	$C_1 \to C_3 \to C_7 \to C_9 \to C_{11}$
8	$C_1 \to C_4 \to C_{11}$	22	$C_1 \to C_3 \to C_8 \to C_{11}$	36	$C_1 \to C_3 \to C_6 \to C_9 \to C_{11}$
9	$C_1 \to C_3 \to C_{11}$	23	$C_1 \to C_3 \to C_7 \to C_{11}$	37	$C_1 \to C_2 \to C_8 \to C_9 \to C_{11}$
10	$C_1 \to C_2 \to C_{11}$	24	$C_1 \to C_3 \to C_6 \to C_{11}$	38	$C_1 \to C_2 \to C_7 \to C_{10} \to C_{11}$
11	$C_1 \to C_8 \to C_9 \to C_{11}$	25	$C_1 \to C_2 \to C_{10} \to C_{11}$	39	$C_1 \to C_2 \to C_7 \to C_9 \to C_{11}$
12	$C_1 \to C_7 \to C_{10} \to C_{11}$	26	$C_1 \to C_2 \to C_9 \to C_{11}$	40	$C_1 \to C_2 \to C_6 \to C_9 \to C_{11}$
13	$C_1 \to C_7 \to C_9 \to C_{11}$	27	$C_1 \to C_2 \to C_8 \to C_{11}$	41	$C_1 \to C_2 \to C_5 \to C_9 \to C_{11}$
14	$C_1 \to C_6 \to C_9 \to C_{11}$	28	$C_1 \to C_2 \to C_7 \to C_{11}$	42	$C_1 \to C_2 \to C_5 \to C_8 \to C_{11}$
				43	$C_1 \to C_2 \to C_5 \to C_8 \to C_9 \to C_{11}$

Table 4

Technical and economic parameters of states of the section Sainshand- Dzamyn-Ude

State, Ci	Exhaustion term of the carrying capacity, t^i_{tech}	Reduced transportation cost function, E (t)	Capital investments, K^i, mln euros
C2	5	E2 (t) =20,47+3,579t–0,199t	1,4
C3	6	E3 (t) =20,69+3,442t–0,139t	7,28
C4	7	E4 (t) =20,87+4,023t–0,215t	0
C5	9	E5 (t) =19,06+1,014t+ 0,1121t	0,624
C6	9	E6 (t) =19,32+1,596t+ 0,0488t	7,904
C7	9	E7 (t) =22,65+1,513t+ 0,1369t	0,2
C8	11	E8 (t) =21,13+2,702t–0,036t	0,624
C9	14	E9 (t) =20,93+3,247t–0,055t	0,824



Pic. 4. Graph of the optimal development of technical equipment of the section Sainshand- Dzamyn-Ude.

The necessary information to construct an option graph of competitive schemes in accordance with the procedure [7] is defined. Pic. 3 shows a complete option graph for the section № 5. On the graph there are 43 schemes with the initial state C_1 and the final state C_{11}. Table 3 provides a complete list of competitive options.

In determining the optimum period of reconstruction algorithm of differential assessments is used [7].

In general, each state of the technical equipment of the object is considered from the first stage. For each state C_i checked the optimal timing of the reconstruction of the line is chacked at t = 0 and t = t^i_{tech}.

At the point t^i_{tech} reconstruction term will be optimal if the inequality is met

$$E_i(t^i_{tech}) - E_{i+1}(t^i_{tech}) - E_n \cdot K_i\left(t_{tech}i\right) \leq 0 , \quad (1)$$

where E_n is a value inserve of the payback period.

At the point of t = 0 reconstruction term is optimal if the inequality is met

$$E_i(0) - E_{i+1}(0) - E_n \cdot K_i \leq 0. \quad (2)$$

If these inequalities are not satisfied, then the optimal reconstruction period is in the range $0 \leq x_i \leq t^s_i$ *and follows from the equation*

$$E_i(x_i) - E_{i+1}(x_i) - E_n \cdot K_i = 0. \quad (3)$$

Similarly, the failure of restrictions is eliminated on all states in the scheme, since the number of such adjustments is also finite.

Based on the above algorithm and using technical and economic parameters shown in Table 4, optimal time of the section development is defined.

As a result of the calculation we get the optimal graph of technical equipment of the section (Pic. 4). From this it follows that the optimal development at the technical equipment at the site Sainshand-Dzamyn-Ude is provided by the scheme № 16. It turns out that by the end of 2015 it is necessary to build seven separate points and lengthen receiving and departure tracks to 1050 m. In this technical equipment f the line must be operated until 2023. In addition, by the end of 2022 on the section automatic locking will be equipped with a package coefficient of 0,6. This will prolong the operation of the line until 2028. Then, with vigorous growth of traffic, there are reasons to consider switching to a continuous second main track.

Conclusions. *The study applied to conditions of Ulaanbaatar Railway has a reason to conclude:*

1. Analysis of the technical equipment and advanced traffic volumes allowed us to determine measures to increase carrying capacity of sections. These include:

– Construction of additional junctions to reduce distances between separate points;

– Extension of station receiving and departure tracks from 850 to 1 050 m;

– Equipping lines with automatic locking.

2. For each sections were developed about 30–40 schemes of staged enhancement of carrying capacity.

3. Technical and economic calculations made it possible for each section of the railway to determine the optimum scheme of increasing carrying capacity and, consequently, those activities that are to be implemented in the next and subsequent five-year period.

4. Calculations showed that the sequence of selected activities is practically the same at all sections. In next five years it is necessary to build additional junctions and to lengthen receiving and departure tracks to 1050 m. With this technical equipment Ulaanbaatar line can be operated up to approximately 2020–2023 years. Next to the years 2019–2022 it is necessary to equip a line with automatic locking that will serve up to 2028–2030 years.

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