DOI 10.17816/transsyst201843s136-56

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RESULTS OF THE COMPLEX OPTIMIZATION OF MAGLEV

In this paper, the analysis of the *technology of complex optimization of transport* is performed on the example of various Maglev systems for the passenger and goods transport.

Keywords: Maglev technology, Maglev system, function model, optimization, system analysis.

1. INTRODUCTION

Maglev systems are in general regarding as more expensive and having a lower profitability in relation to its investment costs as wheel-rail systems or conventional bulk systems what substantially restricts the use of Maglev systems in the planning of transport infrastructure.

Therefore, in this paper the usefulness of the *technology of complex optimization of transport* [1] is shown how to reduce costs of Maglev systems. Using the results this can improve their chances in competition with traditional modes of transport on the existing transport market

2. METHODS OF SOLUTION

In accordance with the *technology of complex optimization of transport*, an *abstract model for a generalized transport system* was developed. This model determines mathematically the maximum balance between overall system components and provides adaptation of any guidedtransport system to its operation

Received: 01.10.2018. Revised: 30.10.2018. Accepted: 17.11.2018.

conditions. As a result, unnecessary costs are cut off to increase the efficiency of Maglev systems.

Two variants – internal and combined – for the optimization control of Maglev systems were implemented. For internal one, the optimal values of design parameters of Maglev systems are established automatically. For the combined one, the maximum train speed between the stops and the number of its sections are selected in a manual way while the values of other design parameters of the system are established automatically.

Also, for determination of the scopes of application of Maglev systems, a *dynamic model for the development of scopes for the effective application of transport systems* was developed to find the most effective transport system for every application case.

In this case the main evaluation criterion for determination of effective application of Maglev systems, as compared with the traditional types of transport, is the value of the specific travel tariff (Figure 1), which was received from the calculation of the payback of the total costs to the time of credit payment.

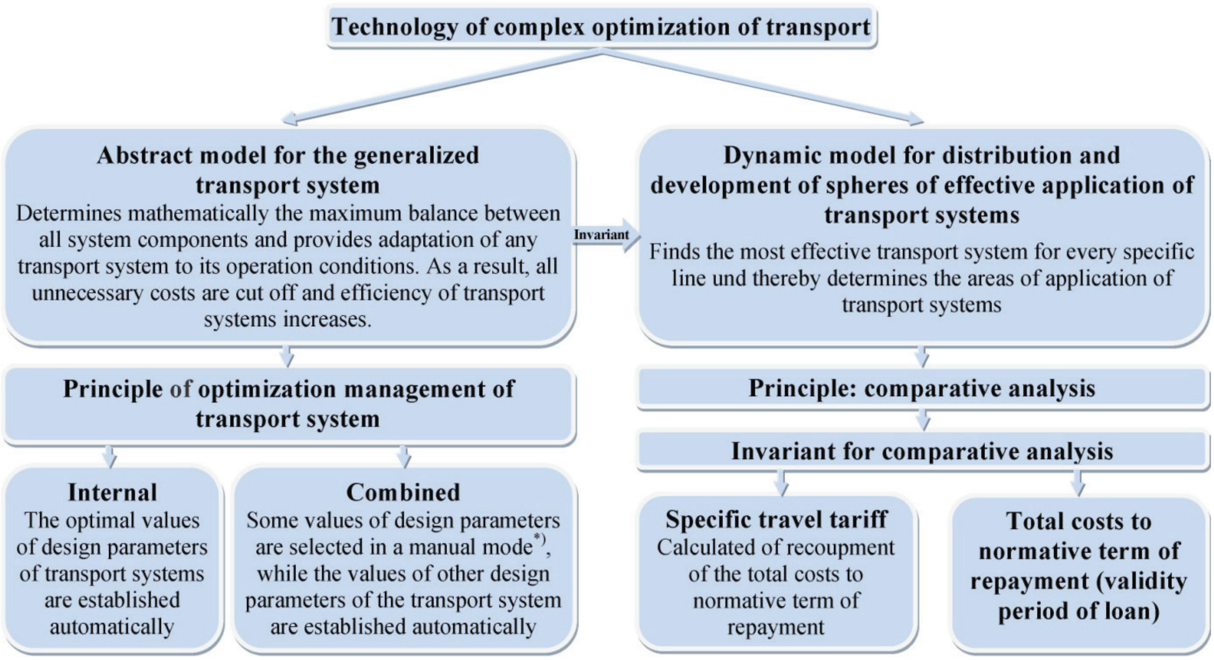

Fig. 1. Principles of the complex optimization process

3. INPUT DATA

The calculations were performed for four Maglevsystems:, TRANSMAG and TRANSPROGRESS as well as TRANSRAPID and MLX01.

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Transportation Systems and Technology. 2018;4(3 suppl. 1):36-56

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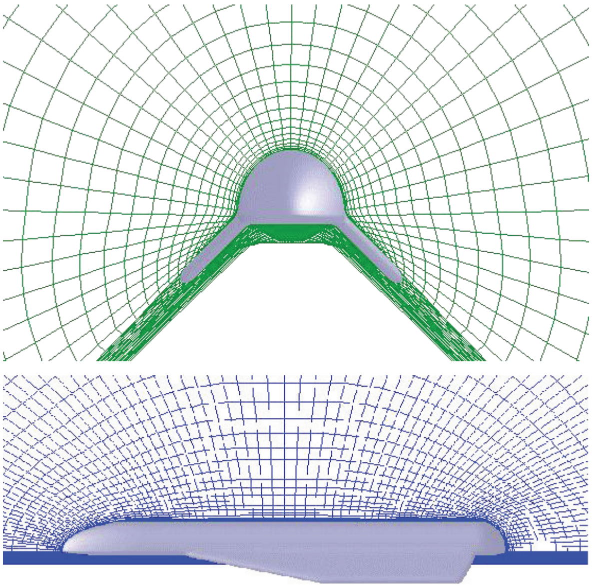
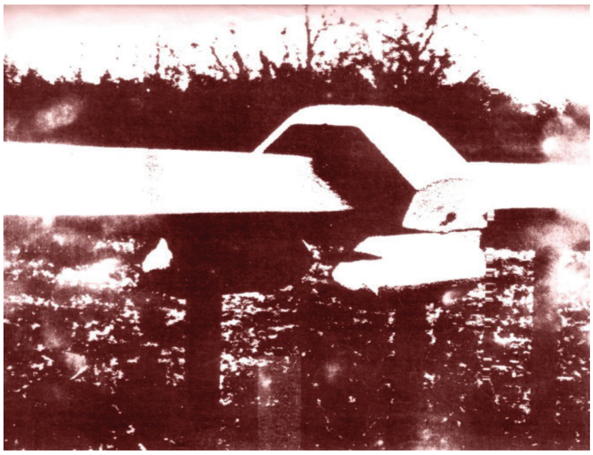
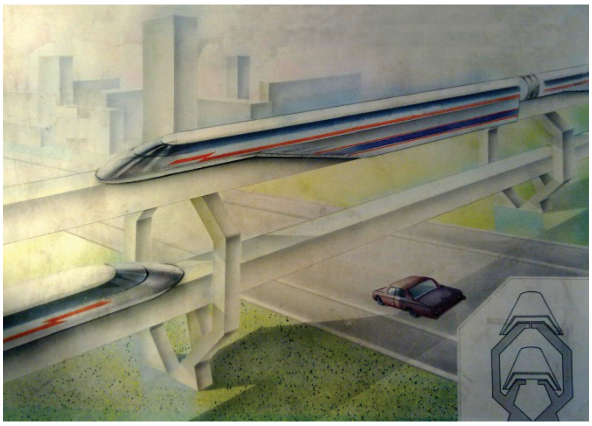
TRANSMAG is a Ukrainian Maglev system with aero-electrodynamic suspension, superconducting magnets and a long stator linear synchronous motor (Figure 2). It was developed at the Institute of Transport Systems and Technologies



(a) Aerodynamic suspension



(c) test line of aerodynamic suspension of the vehicle (Dnepropetrovsk city, Ukraine)



Specifications:
max. speed: 800 km/h;
section:
weight: 36 t, length: 40 m, height: 3 m,
wingspan: 6 m, width: 4 m;
passenger capacity: 120 person.

(b) Track-train structure

(d) Superconducting magnet

(e) Test track of aero-electrodynamic suspension of the vehicle (Dnepropetrovsk city, Ukraine)

Fig. 2. TRANSMAG Maglev system test vehicle and test trackline

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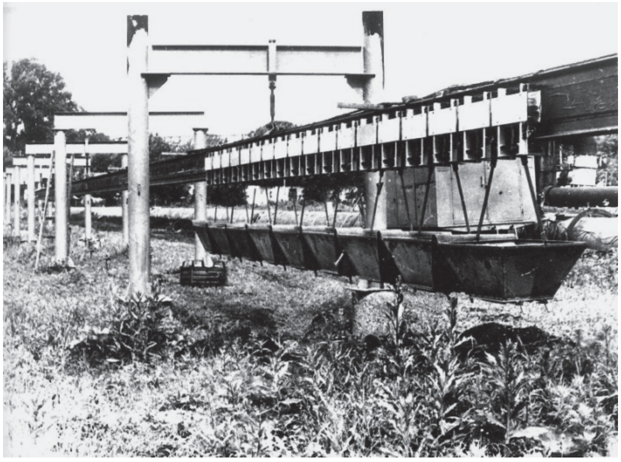
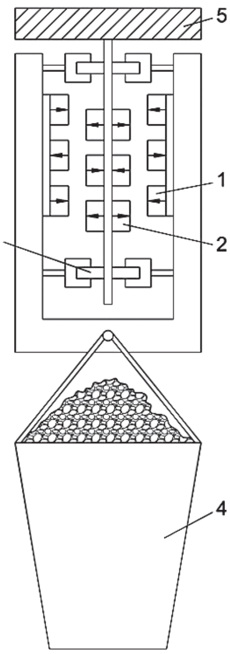
of National Academy of Sciences of Ukraine [2]. The economic component of the calculations of TRANSMAG was obtained in accordance with the internal market prices.

TRANSPROGRESS is the Russian Maglev system on permanent magnetic suspension of vertical type with a short stator linear asynchronous motor (developed in the design office “Transprogress” (Moscow) from 1986 to 1990), intended for transportation of friable goods in ore mining and metallurgical enterprises Fig. 3 [3].



(a) Test track (Orekhovo-Zuyevo, Moscow Region)



(b) Structure of a vertical magnetic suspension

1 – magnets of the vehicle
2 – magnets of the track structure
3 – stabilization rollers
4 – bodywork of the vehicle
5 – track structure

Specifications:
– length of test line: 250 m;
– speed: 11 km/h;
– weight of train: 6 t;
– specific payload: 500 kg per linear m;
– train resistance is 20 times < than at a railway system;
– specific energy consumption is 5 times < than at a railway system.

Fig. 3. TRANSPROGRESS Maglevsystem on test track

On the basis of an *abstract model for a generalized transport system* for each of these Maglev systems an algorithm was written. For TRANSRAPID and MLX01, the principle of combined optimization control was applied, and for TRANSMAG and TRANSPROGRESS the internal one was used.

Calculations of TRANSRAPID and MLX01 performed for the selected model lines and for lines in operation as described in Table 1.

For TRANSMAG and TRANSPROGRESS, calculations were carried out for an array of input data that characterize a set of model lines. For TRANSMAG, the length of line was taken in the range from 250 to 4 500 km, and traffic volumes varied from 1 to 25 million passengers per year. For TRANSPROGRESS, the line

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Table 1. Initial design data of various lines TRANSRAPID

Parameter	Project						
	Unit	METRO-RAPID	MÜNCHEN	SHANGHAI	SHANGHAI-HANGZHOU Maglev Line	HAMBURG-BERLIN	SIC!
Line	end stop-ping	Düsseldorf Hbf – Dortmund Hbf	München Hbf – München Flughafen	Longyang Road Station – Flughafen Pudong	Longyang Road Station – Hangzhou East Station	Hamburg Hbf – Berlin Lehrter Bf	Berlin Papestraße – Budapest
Length	km	79	37	30	163	292	884
Number of stations	stations	7	2	2	6	5	10
Average distance between stops	km	13.15	36.80	30.00	32.60	73.00	98.22
Maximum longitudinal slope	‰	30	80	19	40	100	100
Design slopes	‰	4 [a]	7 [a]	5	4 [a]	5 [a]	6
Relative length of bridges [b]	%	3.00	5.80	1.24	3.00	1.70 [c]	1.20
Relative length of tunnels	%	5.06	20.00	0.00	14.72[d]	0.62	0.80 [e]
Relative length of at grade guideway	%	72.46	47.00	1.24	30.00	32.77	65.20
Reltive length of guideway elevated	%	22.48	33.00	98.76	55.28	66.61	34.00
Annual volume of passenger traffic in both directions	mil. pass. per year	34.37	7.86	10.00	33.00	10.50	6.10
Annual growth of the volume of passenger traffic per year	%	4.5	3.5	4.3	6.2	3.2	1.6
The normative repayment of costs incurred (the validity period of the loan) [f]	years	20	20	27	31	20	50[g]
Annual percent of the credit	%	5.00 [h]	5.00 [h]	2.81	5.34	5.00 [h]	4.37 [i]

[a] Approximate data.
[b] Track structure on bridges laid on pillars.
[c] Total length of 4.7 km [4].
[d] 24 km tunnel under the Huangpu River on a 32 km part between the Longyang Road Station and the airport Hongqiao [5].
[e] Five tunnels with total length: 6.3 km [6].
[f] From the moment of putting of the line into operation.
[g] For the overall design life of the project 50 years (of which 10 years account for design and construction work and 40 years on the phase of operation) on total costs was not the returned [6].
[h] Equals to the average discount rate: ~ 5% [7].
[i] 3 % – discount factor + 1.37 % – internal revenue [6].

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lengths varied from 1 to 15 km with a slope from 0 to 40 ‰ and goods traffic from 0.1 to 0.9 mil. t/year were examined (Fig. 4).

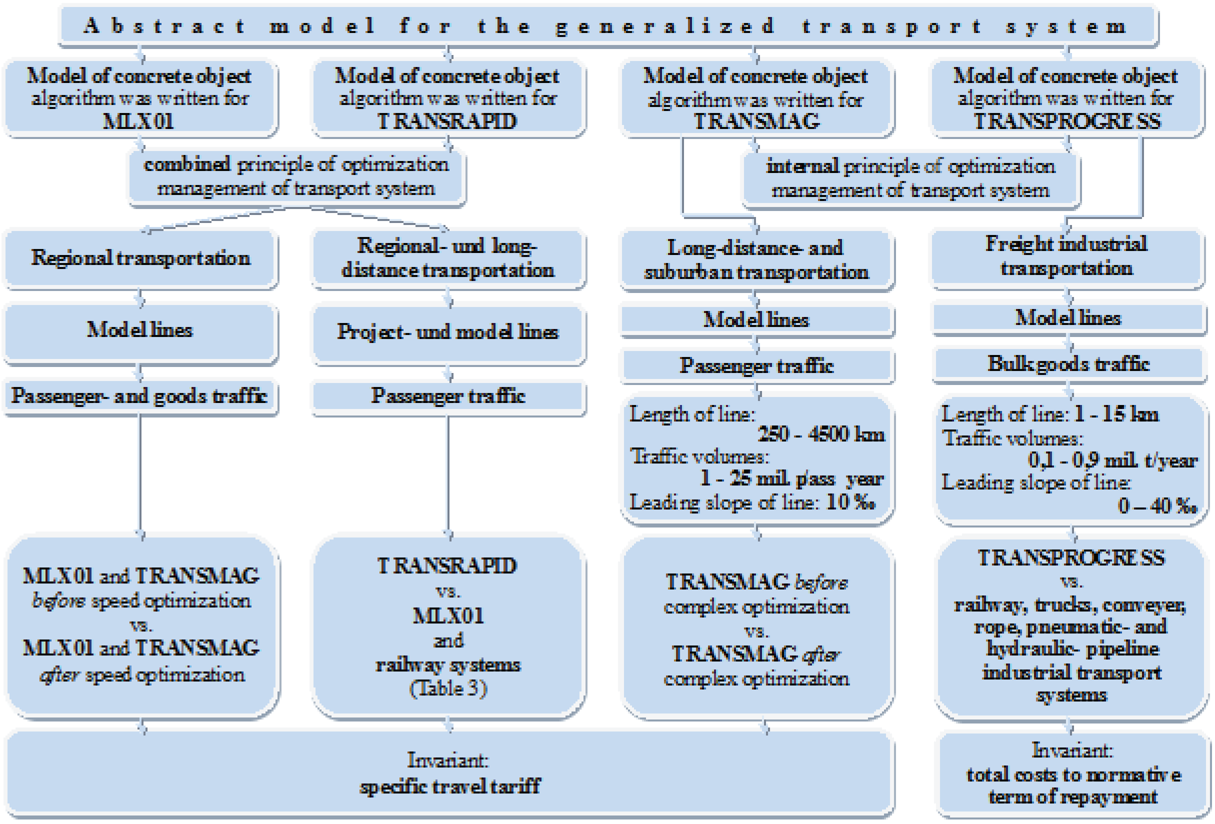

Fig. 4. Structure of the abstract model for the generalized transport system

For passenger transport, a comparison of Maglev system with conventional modes of transport the railway system was selected. These railway systems are operated or planned for the lines where in parallel concrete projects TRANSRAPID were investigated.

For goods traffic Maglev systems were compared with railway, trucks, conveyor, rope, pneumatic- and hydraulic- pipeline industrial transport systems.

In order to select the correct approaches for optimization of Maglev systems, the dependency of cost from the train maximum speed and the train configuration was studied

According to the results of the complex optimization, maglev-systems were evaluated by two criteria cost reduction and expansion of the application areas of Maglev systems compared to railway system (for passenger transport), as well as to other types of traditional transport (for freight industrial transport).

At the same time the limits of scopes of the application of TRANSRAPID and MLX01 were determined (Fig. 5).

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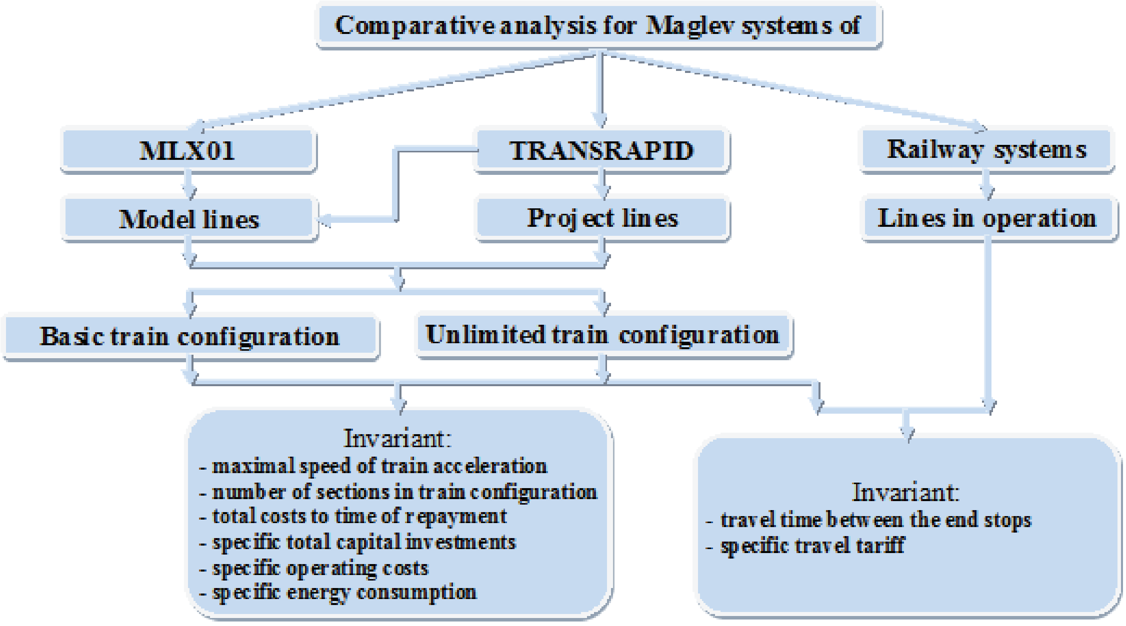

Fig. 5. Principles of the comparative analysis of Maglev systems

4. ANALYSIS AND ITS RESULTS

4.1 Analysis of complex optimization TRANSMAG

After conducting of the optimization of TRANSMAG [8] the value of the specific tariff was obtained for the transport of one passenger per one km, depending on traffic volume and line length (Fig. 6).

As a result of comparison of the tariffs of TRANSMAG before and after its complex optimization (Fig. 7) more than a double decline in the necessary traffic volume has been revealed at the fixed value of specific travel tariff 1,2 U.S. Cent per person*km (Table 2).

On this basis, it is necessary that at the fixed volume of annual traffic of 16 millions passengers per year, after complex optimization of TRANSMAG the size of travel tariff, after complex optimization of TRANSMAG, is approximately 2.11 times lower than the tariff before the system optimization (Table 3).

Thus, a 52.5 % decrease in the total expenses has been reached, decrease in capital investments and operational expenses defines economic efficiency of complex optimization of TRANSMAG.

More detailed structural analysis of expenses is presented in Table 4. It is showed, that the greatest part of their decrease constitutes of the operating costs.

The analysis shows a significant increase in efficiency of TRANSMAG as a result of its complex optimization [10].

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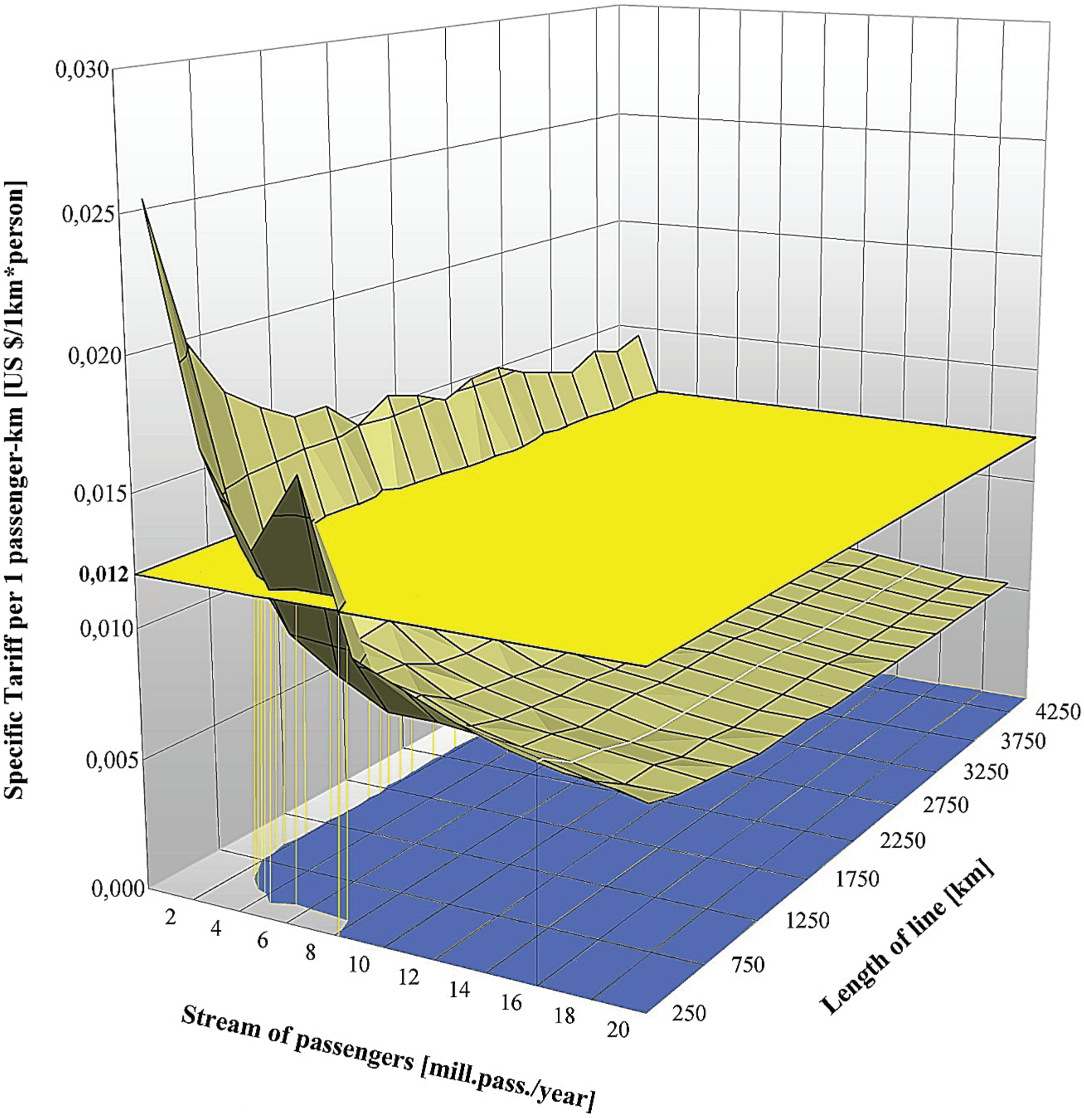

Fig. 6. Dependence of value of specific tariff of TRANSMAG on the traffic volume and line length, *after* the optimization

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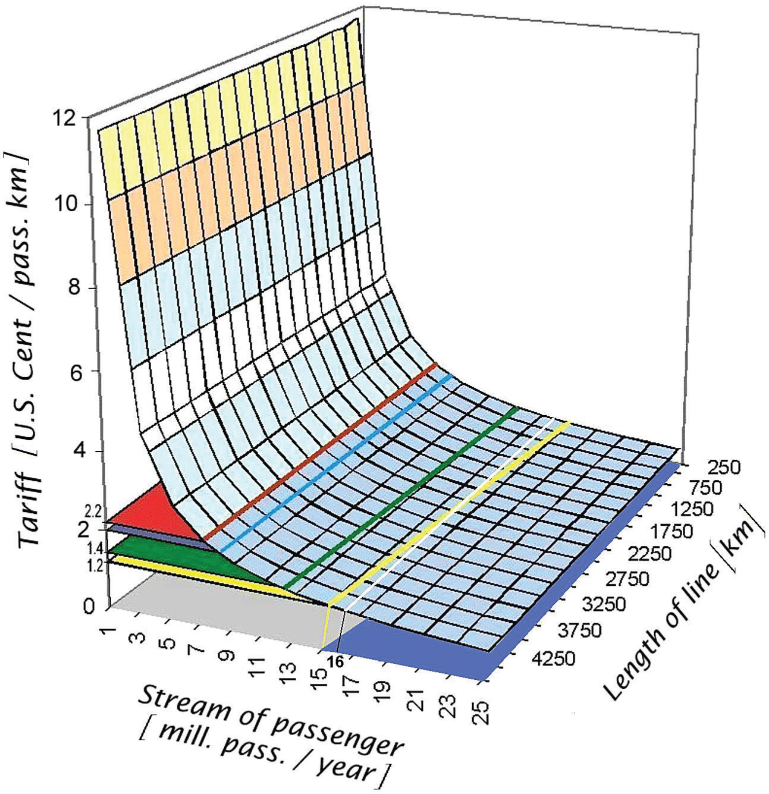

Fig. 7. Dependence of value of specific tariff of TRANSMAG on the traffic volume and line length, *before* the optimization [9]

Table 2. Determination of efficiency of complex optimization of TRANSMAG on the decline of traffic volume at the fixed value of travel tariff[a]

Parameter	Unit	Before optimazation	After optimazation
Specific travel tariff	U.S. Cent per person/ km	1.2	
Normative term of exploitation of line, to repayment of the expenses	Years	10	
Low range of traffic volume, depending on length of line	mill. pass. per year	from 15–17	from 3–9.5
Arithmetical mean value of low range of traffic volume in both ends	mill. pass. per year	from 16	from 6.25
Coefficient of decline of necessary minimum volume of annual traffic for providing of self-repayment of the born charges to the normative term of exploitation of line	x times	0	2.56

[a] Minimum necessary volume of annual traffic in both ends, for providing of self-repayment of the charges to the normative term of exploitation of line.

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Table 3. Determination of efficiency of complex optimization of TRANSMAG on the decline of value of the spared travel tariff at the fixed value of volume of annual traffic

Parameter	Unit	Before opti-mazation	After opti-mazation
Volume of traffic	mill. pass. per year	16	
Range of tariffs at the set volume of annual traffic depending on length of line	U.S. Cent per person×km	1.1–1.3	0.8–0.53
Arithmetical mean value of tariff	U.S. Cent per person×km	1.2	0.57
Coefficient of decline of value of tariff at the set volume of annual traffic	x times	0	2.11
Stake of the total resulted cost cutting to the normative term of exploitation of line	%	0	52.5
Stake of capital investments from the total brought charges over to the normative term of exploitation of line	%	27.48	47.39
Stake of total operating expenses from the total brought charges over to the normative term of exploitation of line	%	72.52	52.61

Table 4. Structural determination of economic efficiency of complex optimization of TRANSMAG

Parameter	Unit	Capital investments	Operating Costs
Reduction of costs at the expense of optimization	%	18	66
Reduction of the initial resulted costs	%	5	48
Reduction of the costs of the total economized sum	%	10	91
Reduction of the mean annual operating costs of the initial resulted expenses	%	missed	5
Reduction of the mean annual operating costs of the total economized sum	%	missed	9

4.2 Analysis of optimization MLX01 and TRANSRAPID

For the calculation of MLX01 and TRANSRAPID, the design data on the TRANSRAPID lines were used. Fig. 8–15 present the results of simulation of MLX01 and TRANSRAPID.

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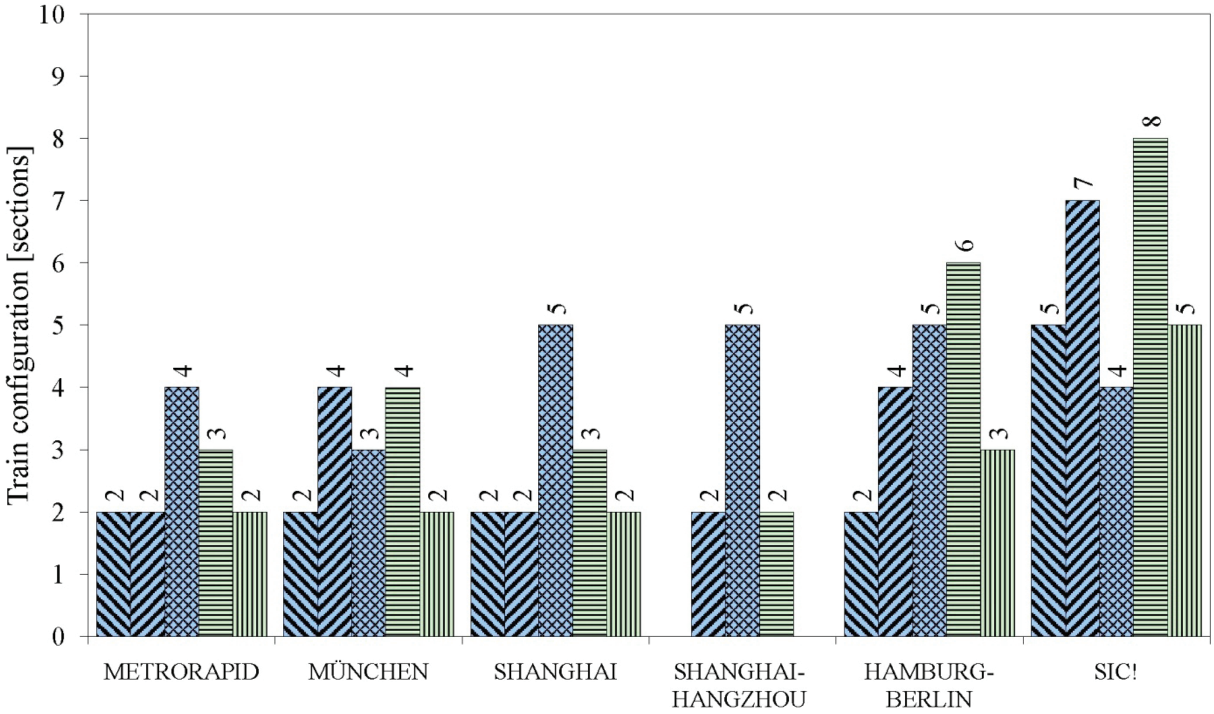
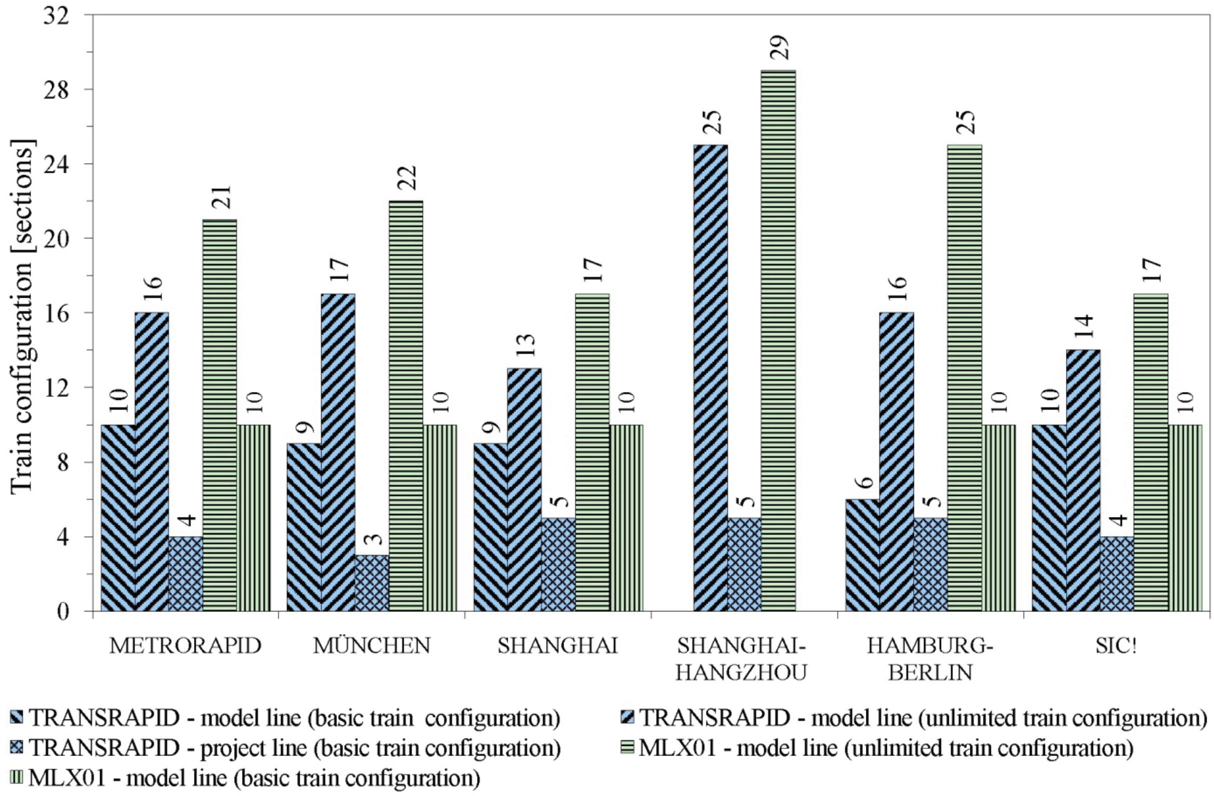


(a) In the first year of operation



(b) In 50th year of operation

Fig. 8. Number of sections in train configuration

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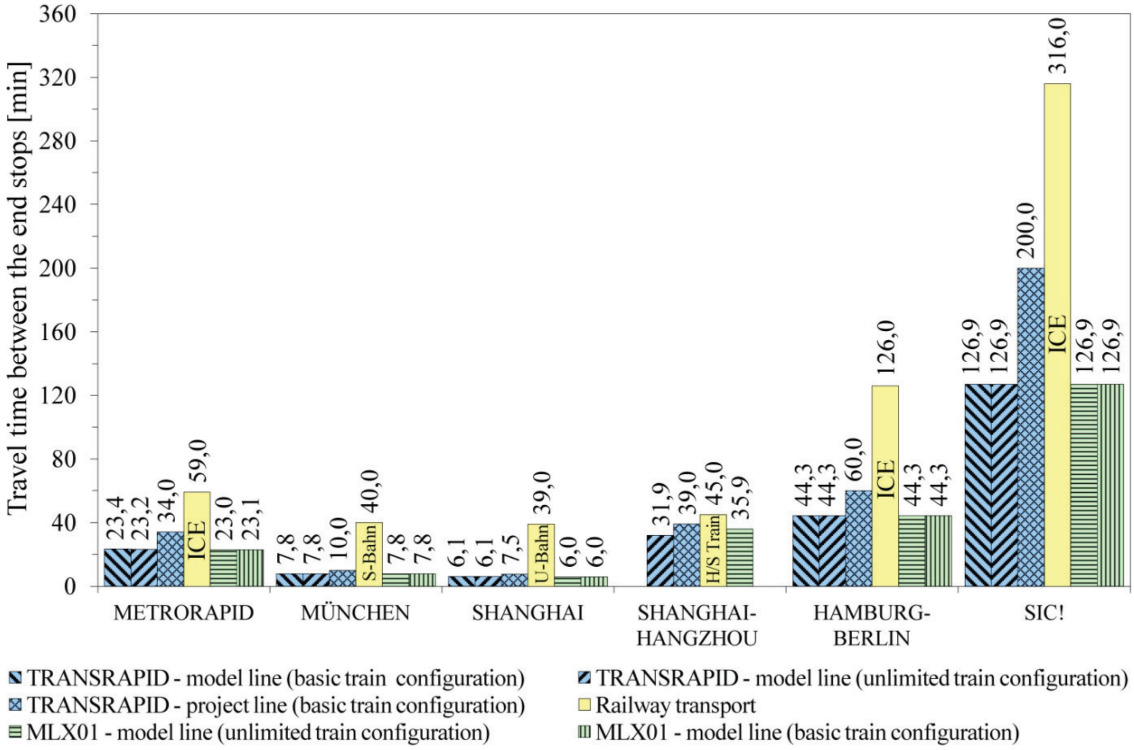

Fig. 9. Travel time between the end stops per line

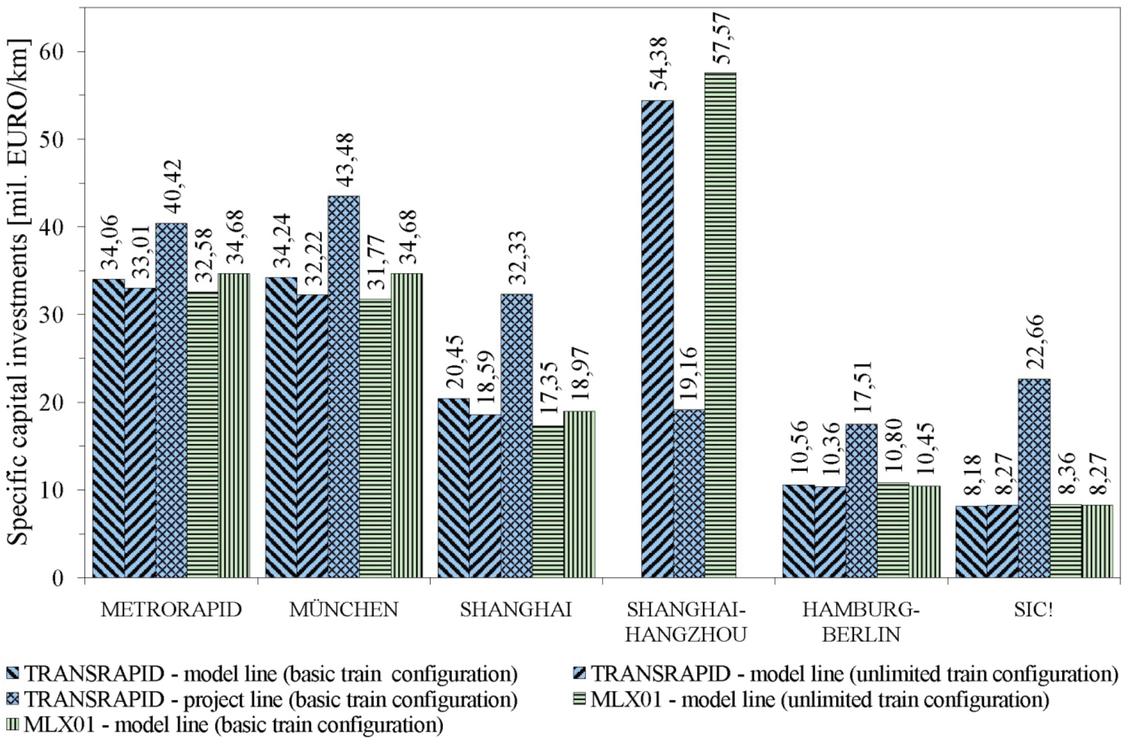

Fig. 10. Specific total capital investments per km length[1]

[1] Without capital expenditures for the acquisition of additional rolling stock in connection with the increase in the volume of annual traffic.

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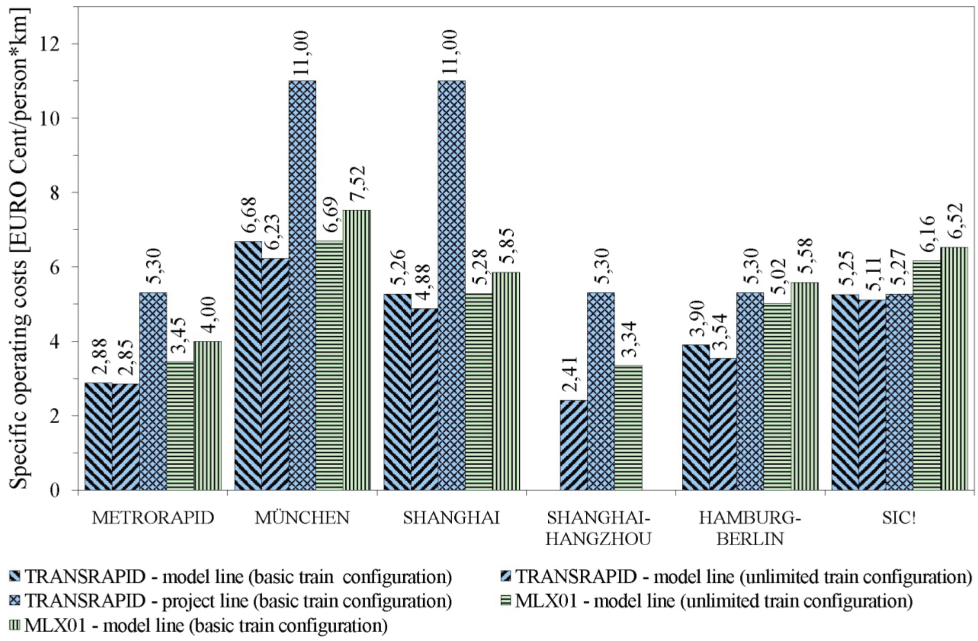

Fig. 11. Specific operating costs for one passenger and one 1 km length[1]

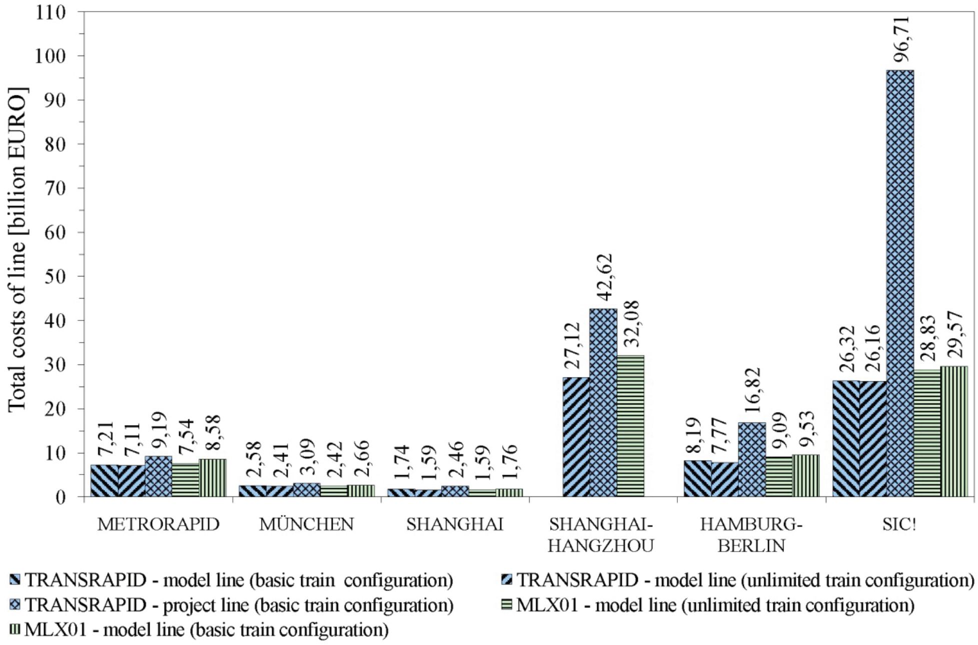

Fig. 12. Total costs to time of repayment (payment of the loan)[2]

[1] The model-project operating costs are variating. Operating costs vary depending on traffic volume and train configuration, consumed energy costs, the number of staff etc. Therefore the average value of operating costs is taken.

Also the calculation was performed according to the German projects from the condition of 0.053 EUR/person×km for regional and 0.11 EUR/person×km for the city-airport communications [11].

[2] Taking into account capital expenditure for the purchase of additional rolling stock, in connection with the increase in the volume of annual traffic.

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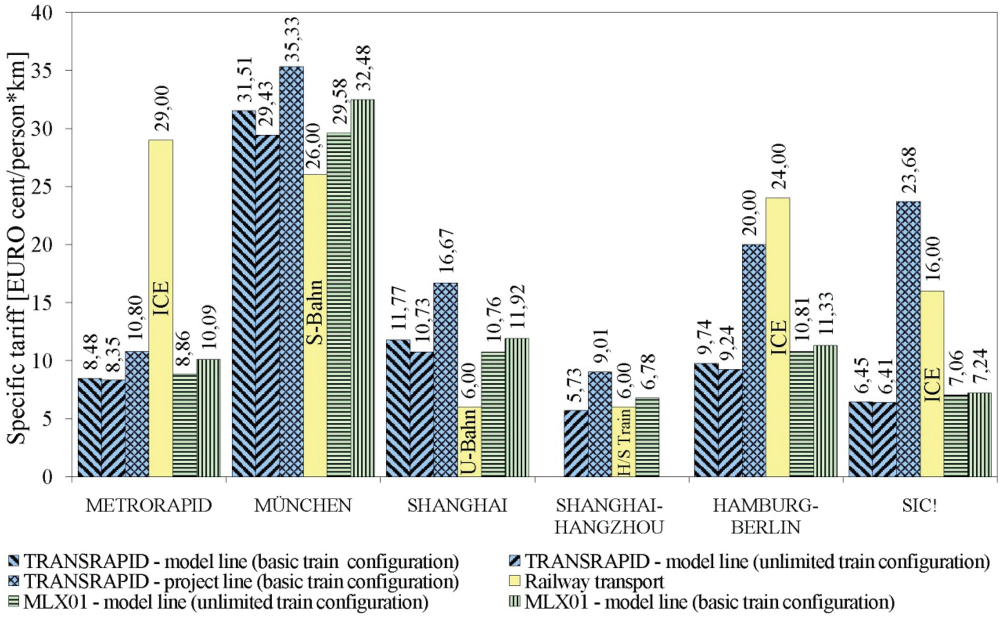

Fig. 13. Specific tariff for transportation of 1 passenger per 1 km (the car of 2nd class)[1]

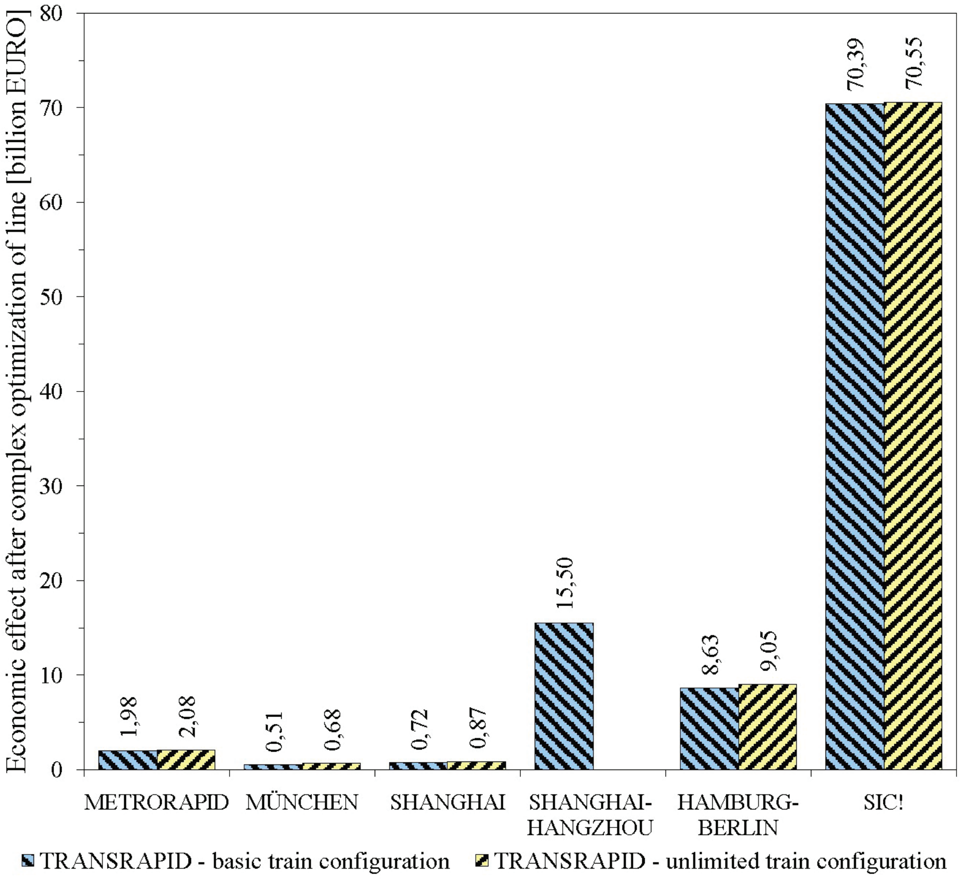

Fig. 14. Economic effect to time of repayment of the total costs (validity period of loan), of TRANSRAPID

[1] Travel tariff are calculated taking into account factors of: the development experience of operating the new lines, discounting (reduction of costs at different times) and additional profit.

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The optimization model showed that, in parallel with the increase in speed performance, economic efficiency of the TRANSRAPID has increased on one third compared to its design data (Fig. 14).

These results are quite analogous with the value of economic efficiency, obtained in the optimization of TRANSMAG (52.5 %). This testifies the reliability of the results.

It also demonstrates that the increase of maximal number of sections per train compared with the base configuration, results in an additional decline of expenses of Maglev-systems by 7 percent on average.

4.3 Determination of the Application scopes between TRANSMAG and railway System

The area, characterizes by the specific travel tariff of the Ukrainian high speed train (1/2 U.S. Cent per person×km), limits the scope of the effective application of TRANSMAG by the largest annual passenger traffic (Fig. 6, 7). By the optimization model of TRANSMAG, this low boundary moved up from 15–17 to 3–9.5 million passengers per year (Table 2) and thus *two and half* times enlarges the scope of its effective application.

4.4 Determination of the scope of TRANSPROGRESS in comparison with industrial bulk transport systems

For determination of the scope of effective application of the Maglev systems with traditional industrial transport systems for ore mining and metallurgical companies at transportation of friable loads, TRANSPROGRESS was chosen.

In this case the choice of the most effective transport system was carried out by minimum value of the total costs of line to the normative term of their repayment.

For TRANSPROGRESS, a *abstract model of a generalized transport system* was chosen. The method of calculation of the technical-economic indices [12] and preliminary optimization [13] were utilized. The technical-economic indices of other compared traditional industrial transport systems were executed via the methods of [14–15].

The scopes of effective application of the compared transport systems were determined in 3D co-ordinates, the axes of which correspond to the basic line parameters: length, size of leading slope and annual traffic of goods. Every point in the indicated co-ordinates system corresponds to most effective of compared transport systems.

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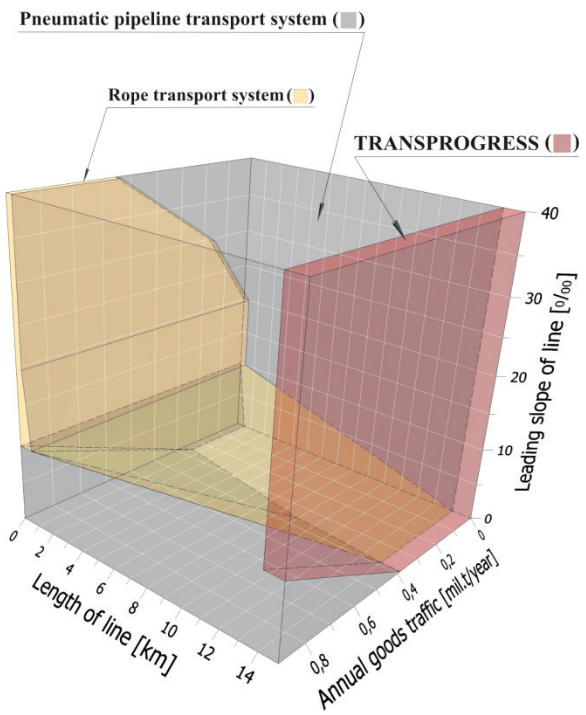
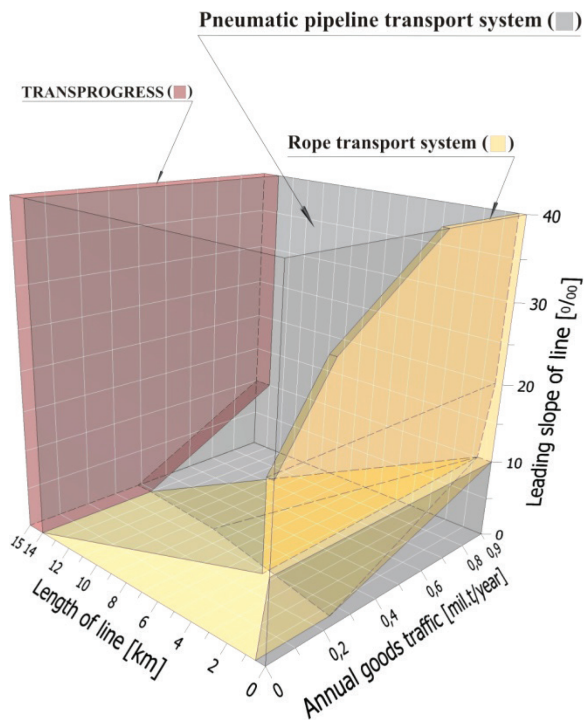
The results of calculations for seven conventional goods transport systems showed that the hydraulic pipeline appeared to be the most effective. After excluding from comparison the hydraulic pipeline transport system, the next effective systems are the TRANSPROGRESS, the rope transport system and the pneumatic-pipeline transport system (Fig. 15). In this case other belt systems appeared not competitive.

Further for the exposure of scopes of effective application of TRANSPROGRESS, the rope (Fig. 16), pneumatic pipeline (Fig. 17) and conveyor transport systems were consistently excluded from comparison.



(a) Right-side view



(b) Left-side view

~~hydraulic pipeline transport system~~; pneumatic pipeline transport system; conveyor transport system;
rope transport system; TRANSPROGRESS; trucks;
railway transport system.

Fig. 15. Comparison of TRANSPROGRESS with rope and pneumatic pipeline transport systems for transportation of bulk good in the conditions of ore mining and metallurgical companies

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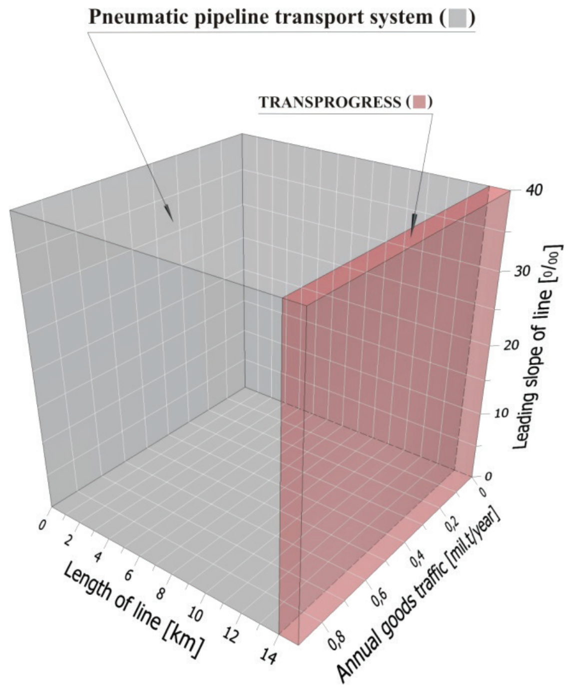
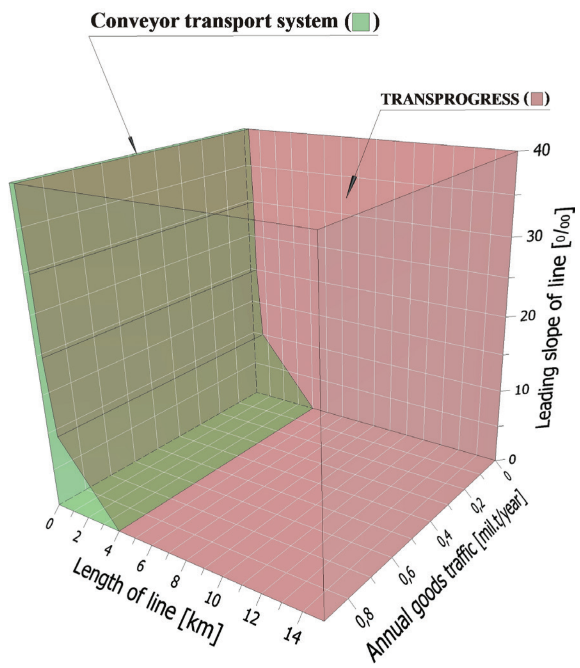


~~hydraulic pipeline transport system~~; pneumatic pipeline transport system; conveyor transport system;
~~rope transport system~~; TRANSPROGRESS; trucks;
railway transport system.

Fig. 16. Comparison of TRANSPROGRESS with pneumatic pipeline transport system for the transport for of ore mining and metallurgical companies



~~hydraulic pipeline transport system~~; ~~pneumatic pipeline transport system~~; conveyor transport system;
~~rope transport system~~; TRANSPROGRESS; trucks;
railway transport system.

Fig. 17. Comparison of TRANSPROGRESS with conveyor transport system for the transport for of ore mining and metallurgical companies

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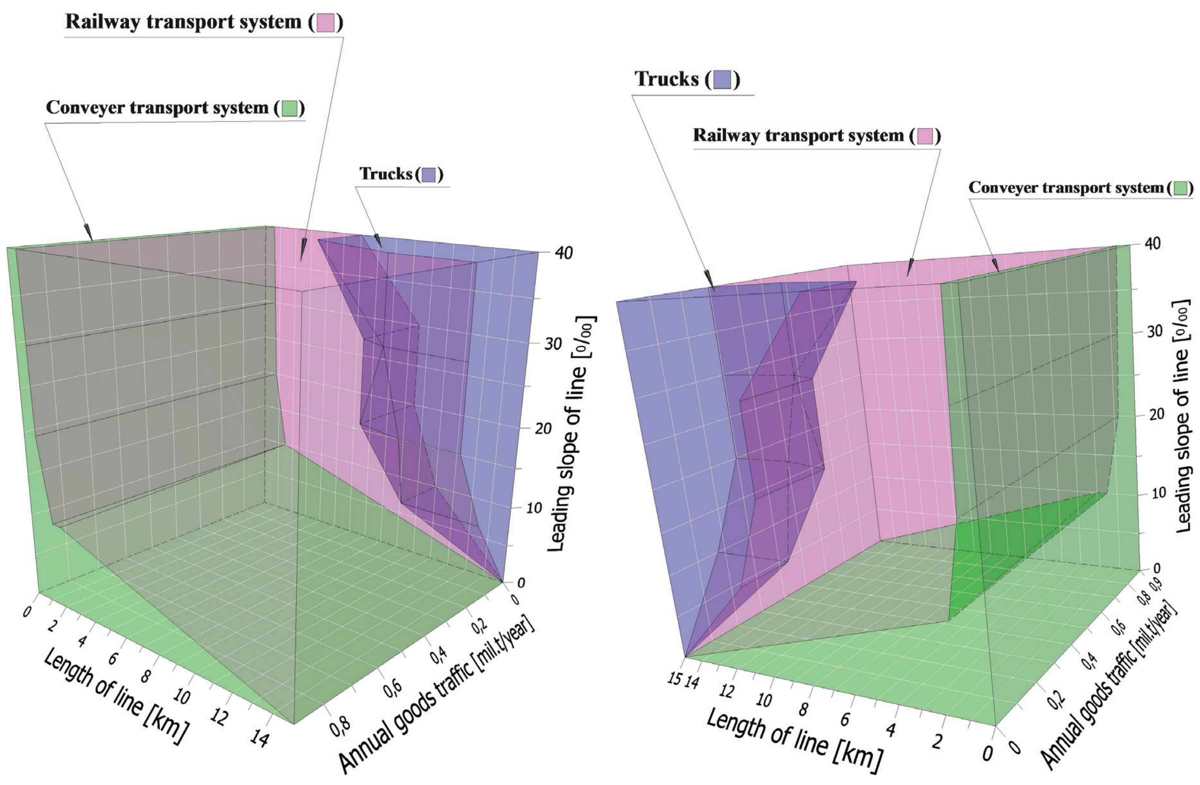
As it is seen, after exclusion from comparison of the conveyor transport system, the TRANSPROGRESS stay the most effective transport as compared to remaining railway and motor-car.

Thus, in all cases of application of TRANSPROGRESS, the most optimum for composition of its trains appeared configuration of continuous (closed) type that technically fully corresponds to the conditions of transport in ore mining and metallurgical enterprises.

Thus, on the example of complex optimization of TRANSPROGRESS, the competitiveness of application of the Maglev system in ore mining and metallurgical companies was grounded. Also possibility of determination of scopes of effective application of the compared traditional industrial transport systems was evidently presented (Fig. 18).



(a) Right-side view (b) Left-side view

~~hydraulic pipeline transport system~~; ~~pneumatic pipeline transport system~~; conveyor transport system;
~~rope transport system~~; ~~TRANSPROGRESS~~; trucks;
railway transport system.

Fig. 18. Comparison of a conveyor belt system with trucks and a railway transport systems for the transport for of ore mining and metallurgical companies

Received: 01.10.2018. Revised: 30.10.2018. Accepted: 17.11.2018.
Transportation Systems and Technology. 2018;4(3 suppl. 1):36-56

doi: 10.17816/transsyst201843s136-56

5. CONCLUSION

This study proved the validity of the *technology of complex optimization of transport* (for example Maglev systems). Its use will significantly reduce the cost of implementation of various transport systems and expand the scope of their effective application (Fig. 19).

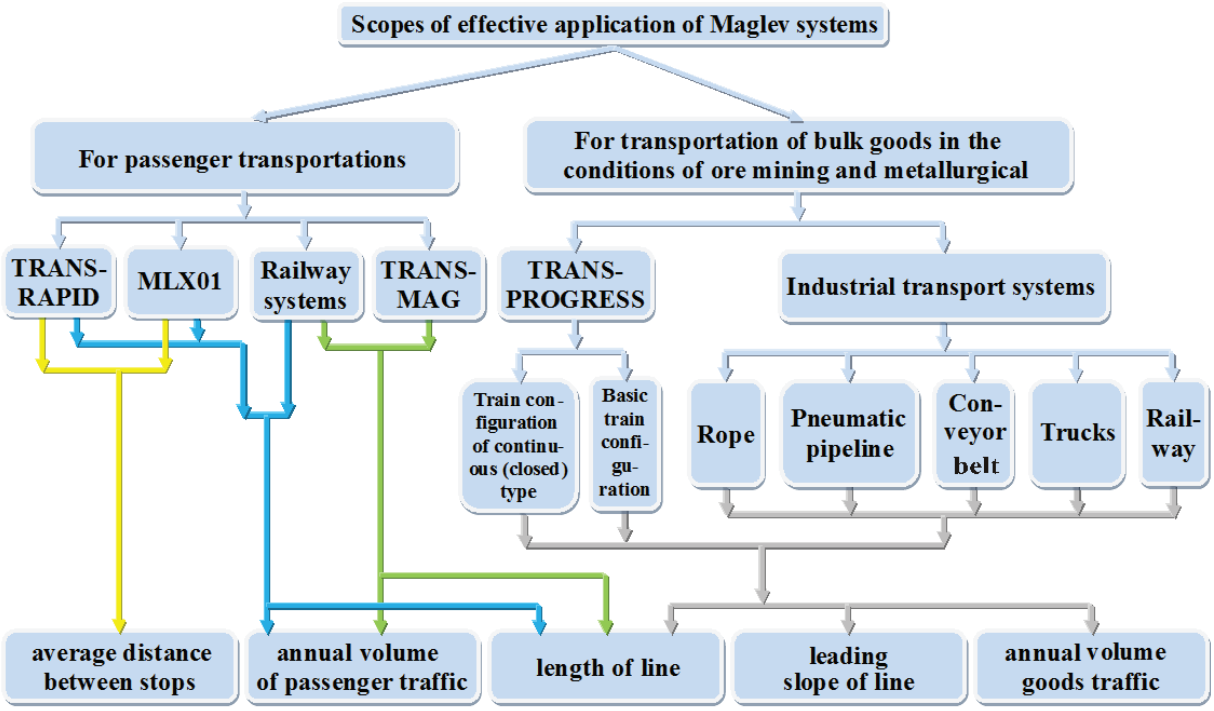


Fig. 19. Determination scheme of the scopes of effective application of Maglev systems

The results of theoretical researches presented in this work are intended above all for the exposure of basic directions of optimization of transport systems.

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Received: 01.10.2018. Revised: 30.10.2018. Accepted: 17.11.2018.
Transportation Systems and Technology. 2018;4(3 suppl. 1):36-56

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Received: 01.10.2018. Revised: 30.10.2018. Accepted: 17.11.2018.

doi: 10.17816/transsyst201843s136-56

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To cite this article:
Lascher A, Witt M, Frishman E, Umanov M. Results of the Complex Optimization of Maglev. *Transportation Systems and Technology.* 2018;4(3 suppl. 1):36-56. doi: 10.17816/transsyst 201843s136-56