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THEORETICAL BASE AND METHODS OF THE COMPLEX OPTIMIZATION OF MAGLEV

Background: In this study the feasibility of using Maglev transport through the determination of the limits of the effective application of the MLX01 and TRANSRAPID compared with railway systems was investigated.

Aim: Development of the technology of complex optimization of Maglev.

Methods: Resource-oriented optimization, system analysis, structured modeling, creation of the dynamic models, vector optimization, combined principle of optimization control, operation concept of the Maglev systems, economic aspects of the modeling, comparative analysis, determination of the borders of effective application of the compared transport technologies, research tools.

Results: Providing of maximum adapted configurations Maglev systems according to the conditions of their application. At the same time these configurations correspond to the state of the most stable equilibrium between all groups and the elements of the general optimization process.

Conclusion: This paper is scientifically justified work, which intended to accelerate the process of implementation Maglev technologies in the existing transport infrastructure.

Keywords: Maglev-system, optimization, system analysis.

1. INTRODUCTION

Currently, with the ever-growing competition in the world market of transport services and dynamically developing new transport technologies, will be able to compete only those maglev-systems that will use their technical and economic advantages. And if we take into account that modern maglev-systems are complex and high-tech multi-functional designs, which is constantly updated with new developments, then the existing evaluation methods were not always able to identify the maximum benefits of the aforesaid transport technologies.

Thus, a new tool has been proposed in this paper, which allows scientifically based methods to find the most optimal solution for maglev-system, depending on its application. This scientific instrument, as a full virtual model of the entire maglev-system, allows you to simulate any work processes of such a transport system, taking into account the introduction into it of new technical developments. As a result, at the lowest cost maglev-system ensures its maximum performance and the required traffic safety, which ultimately creates a good preconditions for considered maglev-system not only maintain a good position in the competition with other transport systems, but also to expand its scope of application.

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2. METHODS OF SOLUTION

2.1. Fundamental approaches

In order to improve the competitiveness of Maglev systems (Fig. 1) they were optimized by creating mathematical models based on the condition of maximum satisfaction of existing transport needs with minimum resource consumption.

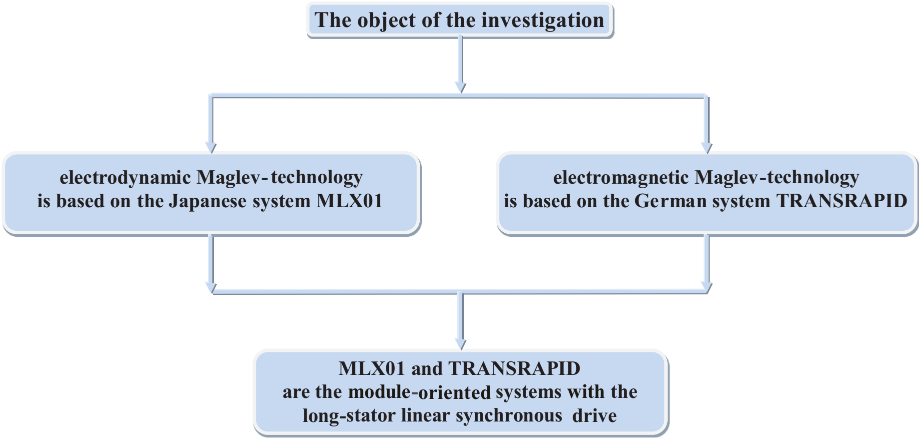

Fig. 1. The object of the study

For this purpose, according to the systems theory, in the basis for the creating of the models of MLX01 and TRANSRAPID the system analysis method was applied to correct reflection the main features of these Maglev systems, their structure and properties, acting in this systems interactions and regularities, causal relationships inside the systems and methods of influencing them (Fig. 2).

Also, for the analysis and description of the existing complex algebraic problems, there was used the principle of structured modeling, based on the research of the hierarchical structure MLX01/TRANSRAPID and qualitative/quantitative relationships between their elements, which have an impact on the economic parameters of considered Maglev systems.

Using graph theory the possibility of configuration of module-oriented multivariate technical execution structure was investigated for MLX01/TRANSRAPID, depending on their capacity to adapt to the conditions of application for selected case of the building of a new line in terms of dynamically changing during its operation, technical and economic characteristics of these Maglev systems.

2.2. Basic principles

To eliminate the imbalance in the whole Maglev systems as a result of striving to improve the technical characteristics of one of its components or

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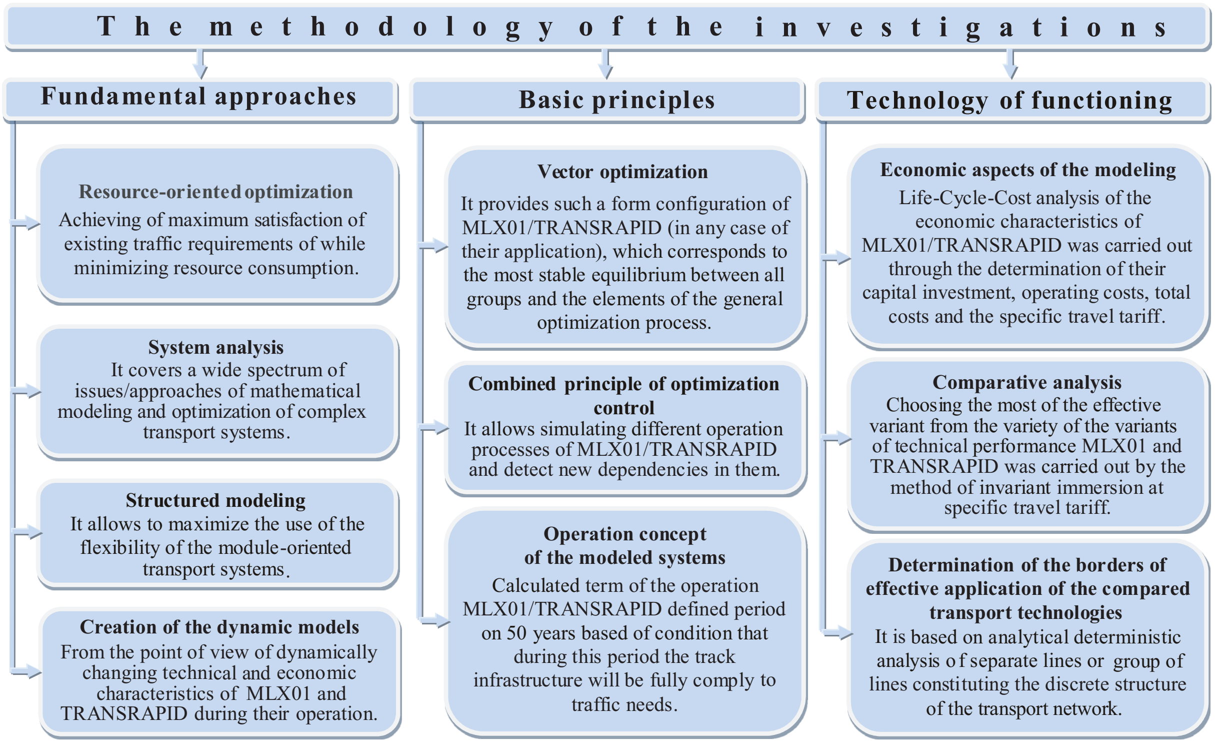

Fig. 2. Structure of the research methodology

groups thereof, which can lead to their dominance due to the deterioration of the values of other elements of the system, the choice of most of the equilibrium state MLX01/TRANSRAPID carried out according to the vector optimization for the selected criteria through a complete solution of system of equations describing the calculated parameters of their technical and economic structure and operation technology. As a result, all unnecessary costs were cut off to provide maximum adapted configurations investigated Maglev systems according to the conditions of their application. At the same time these configurations will correspond to the state of the most stable equilibrium between all groups and the elements of the general optimization process.

According to the control theory and in order to identify new dependencies in the time carrying out simulative calculation was applied the combined principle of control of the optimization in models MLX01/TRANSRAPID, where the values of some parameters of their configuration and exploitation (which are considered as external control parameters) entered manually, and the value of all the other calculated parameters investigated Maglev systems are defined according to conditions of their application automatically.

The operating concept of MLX01/TRANSRAPID, used in the modeling was calculated for a period of 50 years. This period is equal to the period of operation of the track infrastructure of the line until its overhaul, taking into account changes

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in the intensity of seasonal/daily traffic and the continued growth of their annual volume. In the same time this schedule of trains and their number during this period have not changed over the years. The number of sections in the train configuration was only increased. Based on the maximum load on the line, which falls on the "peak hour" of the last calculation year of its operation, have been identified: type of track structure (single-track, double-track and single-track with bilateral passing track), the number of bilateral passing track and the number of station tracks at halt.

2.3. Technology of functioning

Economic aspects of modeling MLX01/TRANSRAPID are based on Life-Cycle-Cost analysis, according to which there were identified sum total costs as well as the specific travel tariff (as the main evaluation criterion) which was received from the calculation of the payback of the total costs to the time of credit payment.

The selection of the most effective variant of configuration MLX01/TRANSRAPID from the multitude ways of their technical execution (due to database diversity), as well as the choice between the investigated Maglev technologies and railway systems for each specific case their application, were carried out by the method of comparative analysis on specific tariff.

Thus, a deterministic analysis of individual lines or groups of lines constituting the discrete structure of the transport network, with a selection of the most efficient system from comparable transportation systems, allows to identify (according to the set theory) limits of effective application Maglev transport for each concrete case of its use and determine preconditions for optimal development existing transport infrastructure.

3. RESEARCH TOOLS

As a tool to achieve of the above purposes by scientifically-based methods, on the grounds of the principles of building of mathematical computer models, was developed the calculated application program that allows carry out the necessary volume of experimental calculations based of apparatus of methods of the optimization and the simulation modeling (Fig. 3).

Therefore, according to the aforesaid methodology for the calculation of technical and economic parameters MLX01/TRANSRAPID provided of their complex

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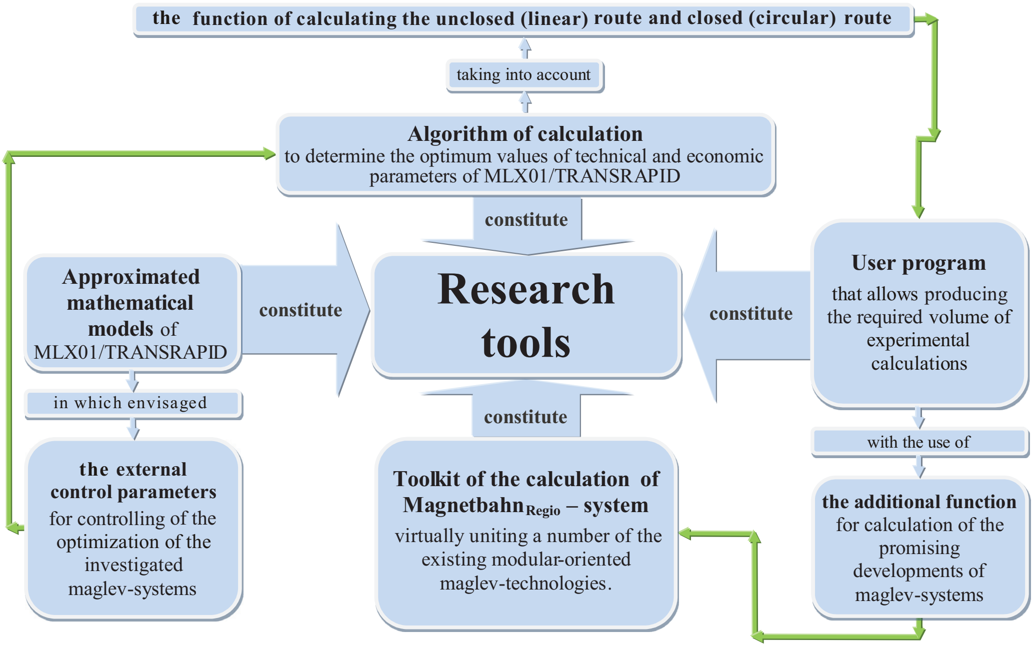

Fig. 3. Structure of the research tools

optimization, was written for each of these Maglev systems the separate algorithm for its mathematical model. For this the following data were used: test of model samples, experimental research and also theoretical research and design development.

However, due to deficit of information resources, caused by a strong structure considered Maglev systems and complicated functional connectivity in them, were used crude mathematical models MLX01/TRANSRAPID with limited modular execution (which takes into account the interaction only between their main components), for partial optimization these Maglev systems on average values of parameters condition of their application.

The principle of the combined method of control optimization MLX01/TRANSRAPID was implemented in algorithm of the calculated program through two external control parameters: the maximum speed of the trains between two stops and the number of sections per configuration.

Also a function for calculating the linear routes and the circular routes was provided in the program. Circular route allows instead of network radially arranged of linear routes to construct a closed route which will consistently link all the stops.

In addition, the flexibility of input program parameters allows calculations not only for already developed system design as is MLX01 and TRANSRAPID, but also for prospective directions of their development, including for other long stator linear motors and suspension on the electric or superconducting magnets.

Thus, the potential of the program algorithm ensured the holding of the calculation of number of the existing modularly oriented Maglev systems with the

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possibility of organization simultaneous studies of two under consideration Maglev technology under identical or different conditions of their application.

4. INPUT DATA

In this study were conducted the calculation for MLX01 and TRANSRAPID on the condition of combined of cargo and passenger traffic for two separately selected virtual lines and for passenger traffic for six model lines, including well known projects TRANSRAPID (Fig. 4).

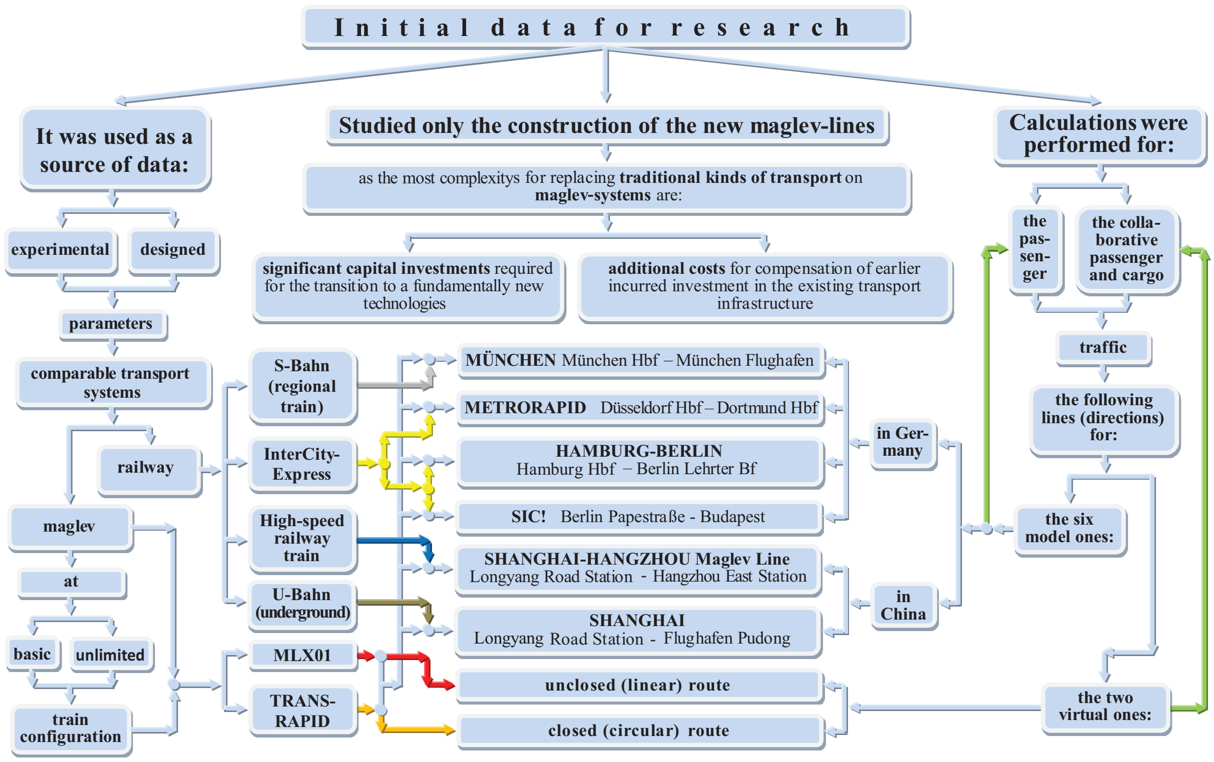

Fig. 4. Scheme of the baselines for the research

5. ANALYSIS AND ITS RESULTS

5.1. Results of the optimization TRANSRAPID

Eventually results of the optimization modeling TRANSRAPID showed one-third increase of the arithmetic average value of its economic efficiency (by reducing the total costs) compared with the previously calculated design data (according to standard methods) considered in the study of the lines (Fig. 5).

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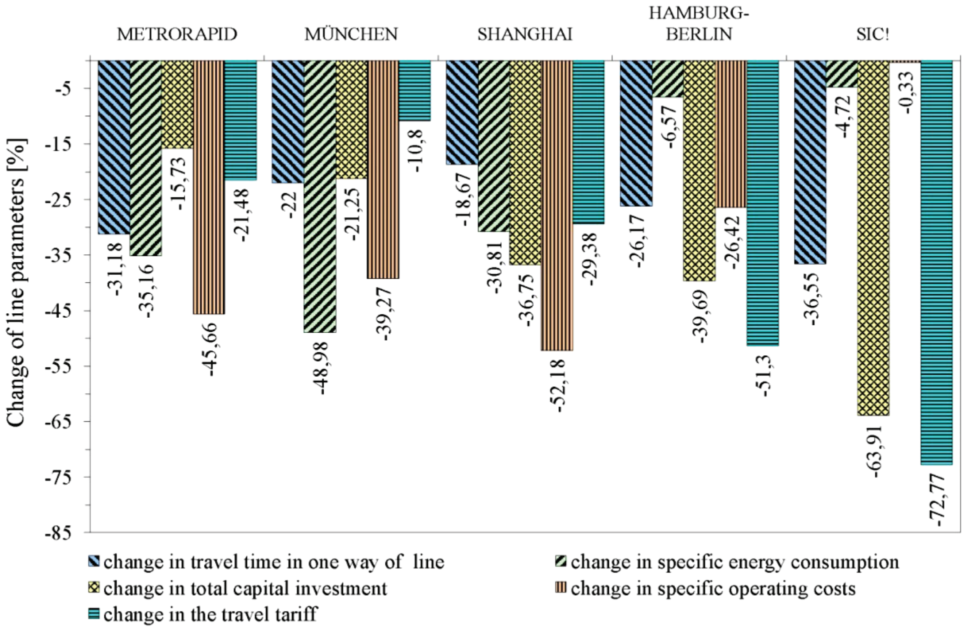
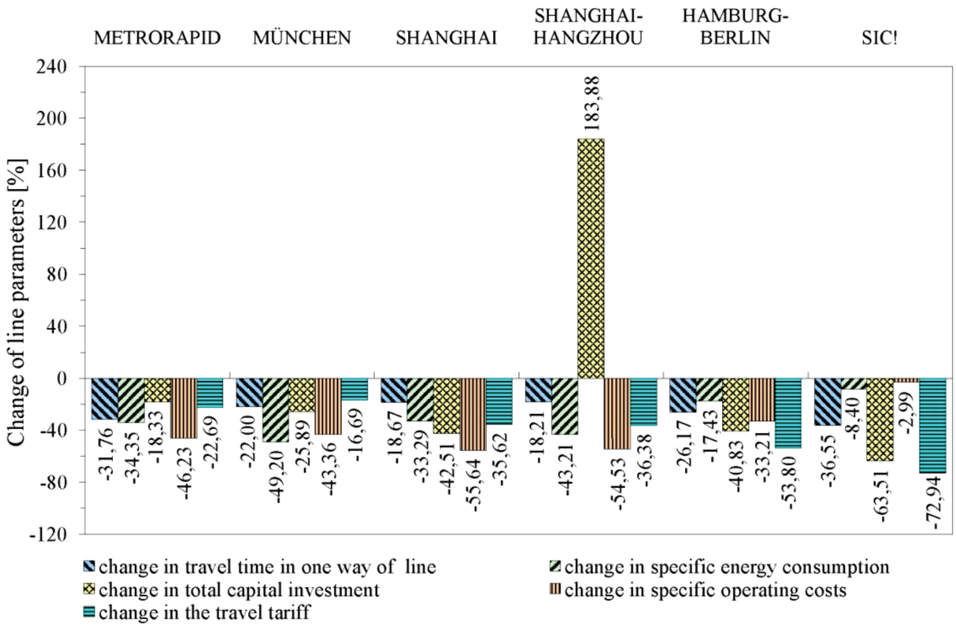


(a) At basic TRANSRAPID train configuration



(b) At unlimited TRANSRAPID train configuration

Fig. 5. A percent of change in line parameters on complex optimization of TRANSRAPID obtained by comparing of modeling results with the project data

5.2. Configuration of the track structure

So the optimization of the track structure by replacing a double-track by a single-track with bilateral passing tracks influenced on the decrease of costs

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of MLX01/TRANSRAPID and helped to identify perspective areas of their development such as further reduction of the minimal interval between traffic trains in the "peak hour" and design of turnouts for the operation of trains without reducing speed (Fig. 6).

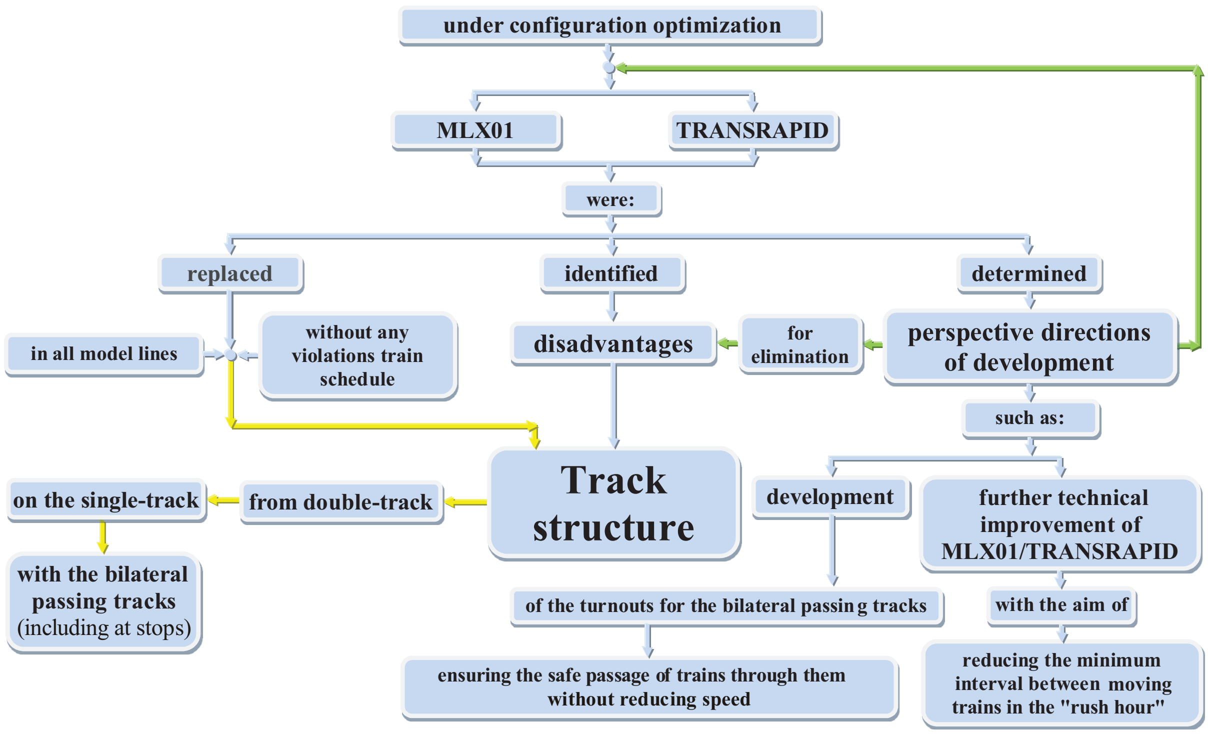

Fig. 6. Configuration of the track structure of MLX01 and TRANSRAPID

5.3. Train configuration

By a deterministic analysis the dependency of reduction of specific travel tariff from increasing of trains configuration MLX01/TRANSRAPID has been studied, according which the use of the long configuration Maglev trains proved optimal for all considered model lines (Fig. 7).

5.4. Optimal speed of train

By the method of the successive approximations the optimal speed for MLX01/TRANSRAPID on short distances between stops (typical of the regional traffic) was determined. It does not reaches its maximum of technical value, but in compared with the obtained economic effect leads only to a slight increase in travel time (Table 1).

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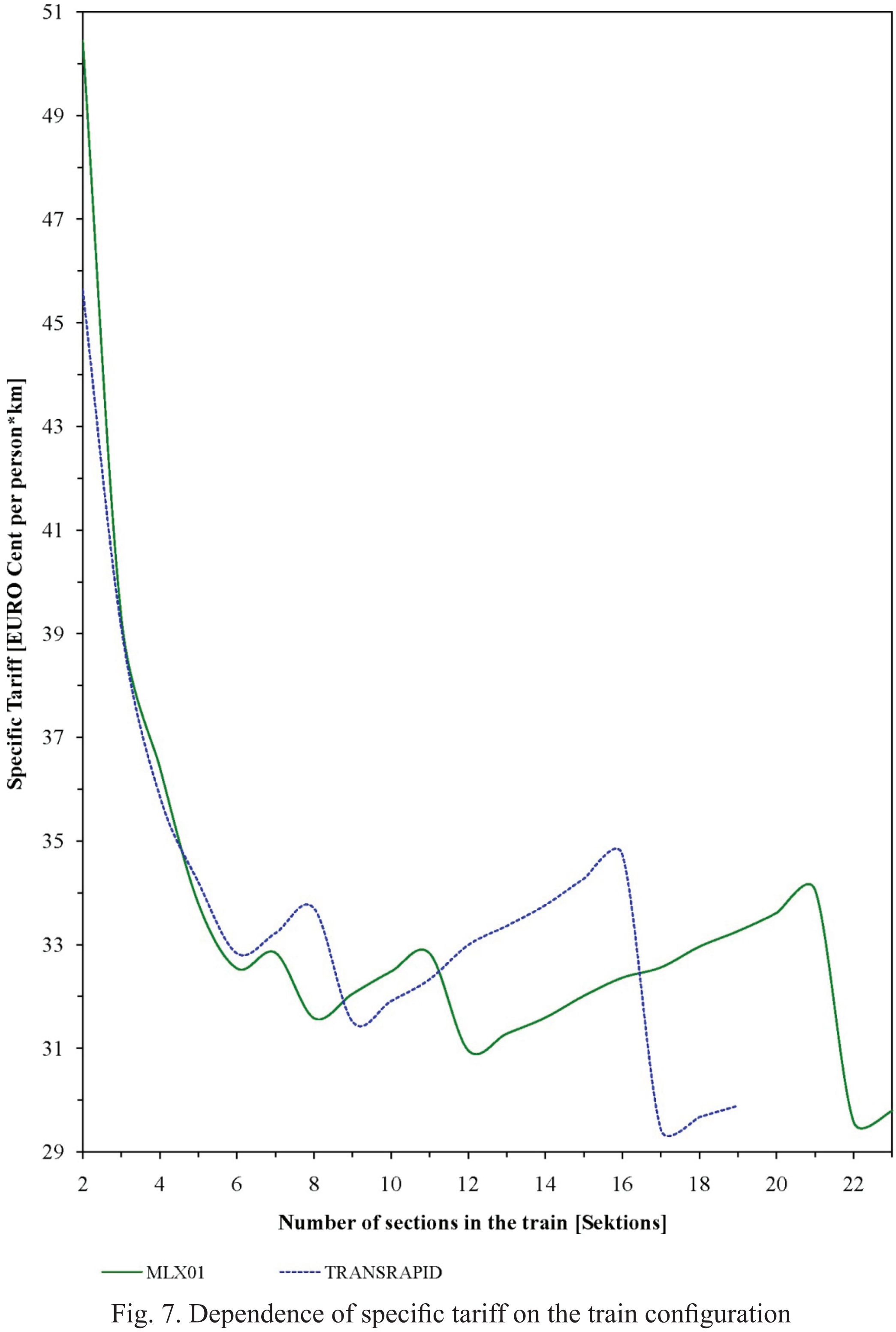

Fig. 7. Dependence of specific tariff on the train configuration

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Table 1. Parameters of MLX01 and TRANSRAPID, received by simulations

Parameter		Unit	MLX01		TRANRAPID	
			without the optimiza-tion of speed of the train	*with the optimiza-tion of speed of the train*	*without the opti-mization of speed of the train*	*with the optimiza-tion of speed of the train*
Maximum project speed of train		km/h	550	383	500	259
Maximum speed of train acceleration		km/h	412 [a]	383	388 [b]	259
Cruiser speed of train		km/h	162.8	161.6	161.6	134.6
Travel time between the end stops		min.	167.3	168.5	168.5	202.5
Travel time between the end stops		%	0.70		20.18	
Number of cars in the train	for the first year of line operation	sektions	4	4	2	2
	for the 50th year of line operation		10	10	6	6
Maximum capacity of the linear drive of train		MW	64.78	24.10	30.36	6.61
Specific energy consumption attributable to the transportation of 1 passenger per 1 km, taking into account energy recovery during braking train		Wh per person×km	72.5	70.4	53.5	36.2
Specific total capital investments per 1 km of line [c]		mil. EUR per km	35.62	23.70	27.65	14.98
Total costs at the time of repayment (the payment of the loan)[d]		billion EUR	52.84	43.09	37.41	25.50
Averaged operating costs for transportation of 1 passenger per 1 km		EURO Cent per person×km	4.67	4.36	3.16	2.51
Specific tariff for transportation of 1 ton of cargo per 1 km[e]		EURO Cent per t×km	83.96	68.47	56.13	38.26
Specific tariff for transportation of 1 passenger per 1 km[e]		EURO Cent per person×km	6.89	5.61	5.05	3.44
Economic effect after the optimization of the train speed		%	18.58		31.88	

[a] Power of the linear drive accelerates the train with a constant acceleration on 1 m/s^2.
[b] On increase in power of the linear drive, its maximum speed exceeds 420 km/h because of the short distances between stops. The original engine power will increase by 2,7 times (82,88 MW); specific tariff will rise to 5,20 EURO Cent per person*km; the total costs will increase given to the payback period for 1,09 billion EUR (up to 38,5 billion EUR). Transit time between the final stop will be reduced to 1,25 minute. In comparison with the version of the optimized speed of the train excess engine power reaches 12,5 times, the cost of travel to 1,5 times.
[c] Excluding capital expenditures for the acquisition of additional rolling stock in connection with the growth of annual shipments.
[d] Taking into account the capital investments to purchase additional rolling stock in connection with the increase in the volume of annual traffic.
[e] Travel tariff were calculated taking into account factors: of the development experience of operating of the new lines, discounting (reduction of costs at different times) and additional profit.

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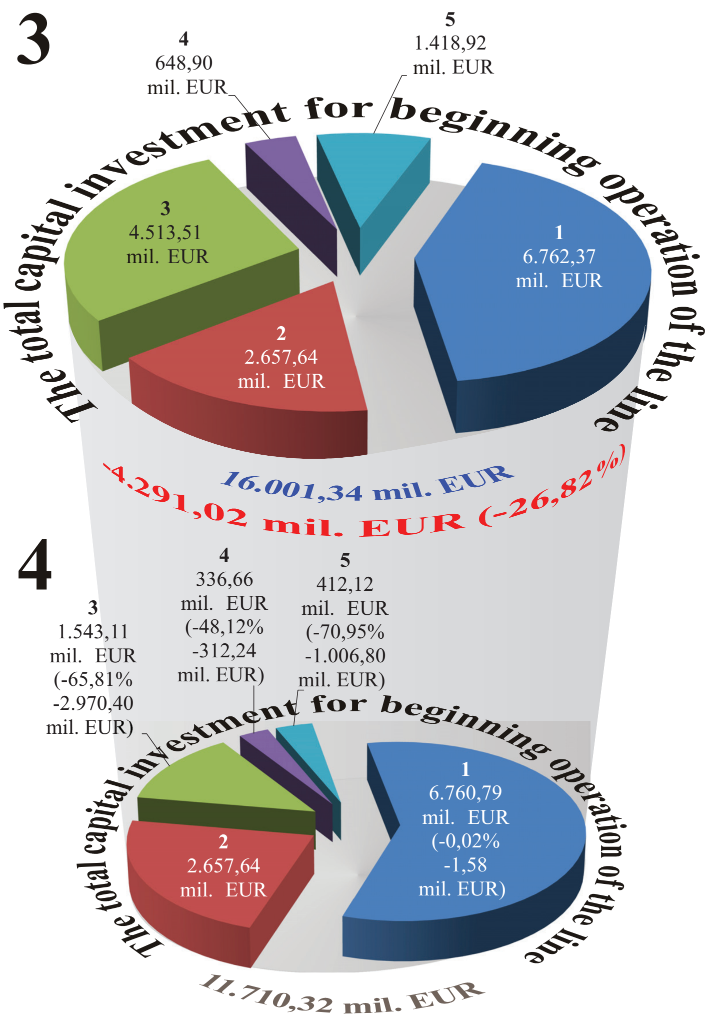
5.5. Application of the function of changing the unit costs from the volume of ordered quantity

Thus the correct calculation of economic values, expressed in application of the function of changing the unit costs from the volume of ordered quantity and using of the discount factor, led to an additional reduction in the cost of the investigated Maglev systems (Fig. 8, 9).



3 – total capital investment to the beginning of the line operation *before* the application a function of changing the unit costs from the volume of order quantity
4 – total capital investment to the beginning of the line operation *after* the application a function of changing the unit costs from the volume of order quantity
1 – costs for construction of the track of line and its infrastructure
2 – costs for acquisition of the plot of land for the construction of line
3 – costs for acquisition and installation of electrical equipment in the line track
4 – costs for acquisition of rolling stock line and the creation base of its service
5 – costs for creating of the line control system

Fig. 8. Structure of decline total capital investment of TRANSRAPID to the beginning of operation of the model line SIC!, after the application a function of changing the unit costs from the volume of order quantity

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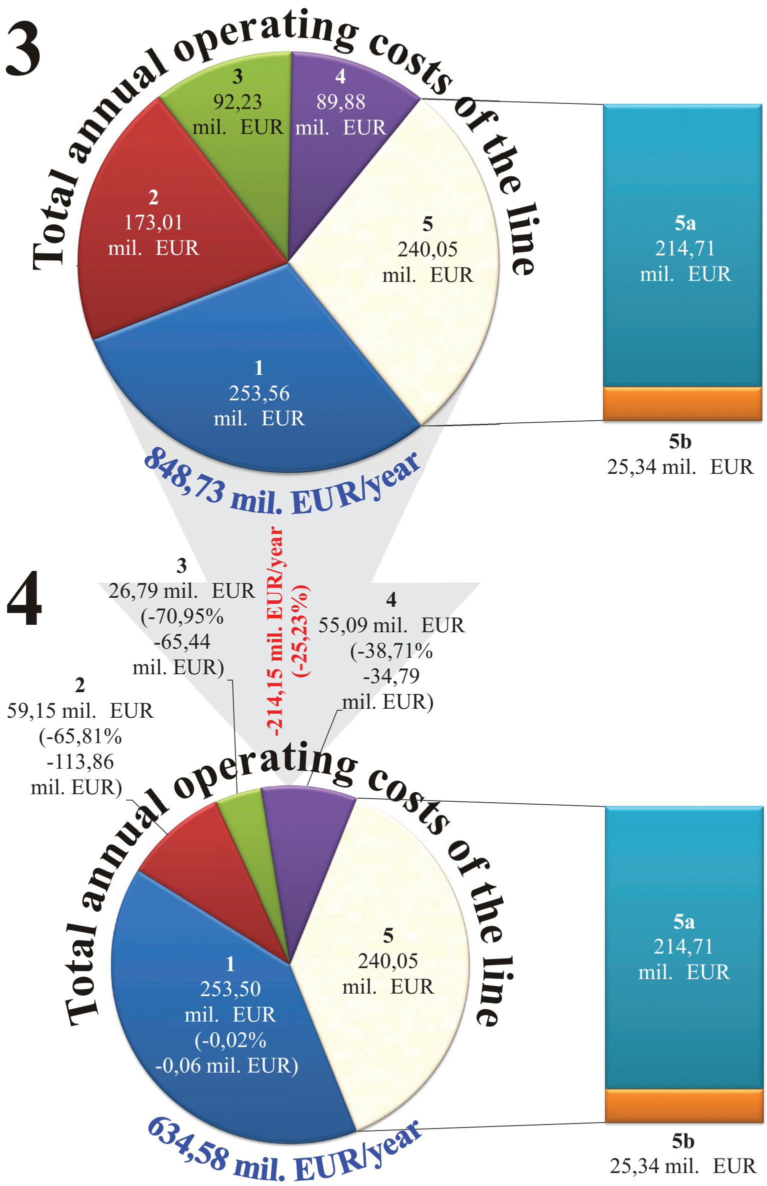

3 – the averaged total annual operating costs of the line *before* the application a function of changing the unit costs from the volume of order quantity
4 – the averaged total annual operating costs of the line *after* the application a function of changing the unit costs from the volume of order quantity
1 – the averaged annual costs for maintenance and repair of the track line in view of its infrastructure
2 – the averaged annual costs for maintenance, repair and renovation of electrical equipment of line
3 – the averaged annual costs for maintenance, repairs and renovation of the line control system
4 – the averaged annual costs for maintaining and repairing of rolling stock of line, including base his maintenance
5 – the averaged annual operating costs, which are not dependent on capital investments
5a – the averaged annual energy costs, that is consumed on the line
5b – the averaged annual costs for the payment of staff salaries of line

Fig. 9. The structure of the reduction of averaged total annual operating costs of TRANSRAPID for the model line SIC!, after the application a function of changing the unit costs from the volume of order quantity

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5.6. Control of quality calculations and determined the main factors/structure the costs reduction

In order to verify the results of the optimization (with a satisfactory result) a control of quality calculations was performed for the specific energy consumption of TRANSRAPID for model lines by comparing them with the experimental data of design lines (Fig. 10), and also were determined the main factors and the costs reduction structure for TRANSRAPID, critically were evaluated the accuracy of its economic calculations and the likelihood of the realization of the model project (Fig. 11–12).

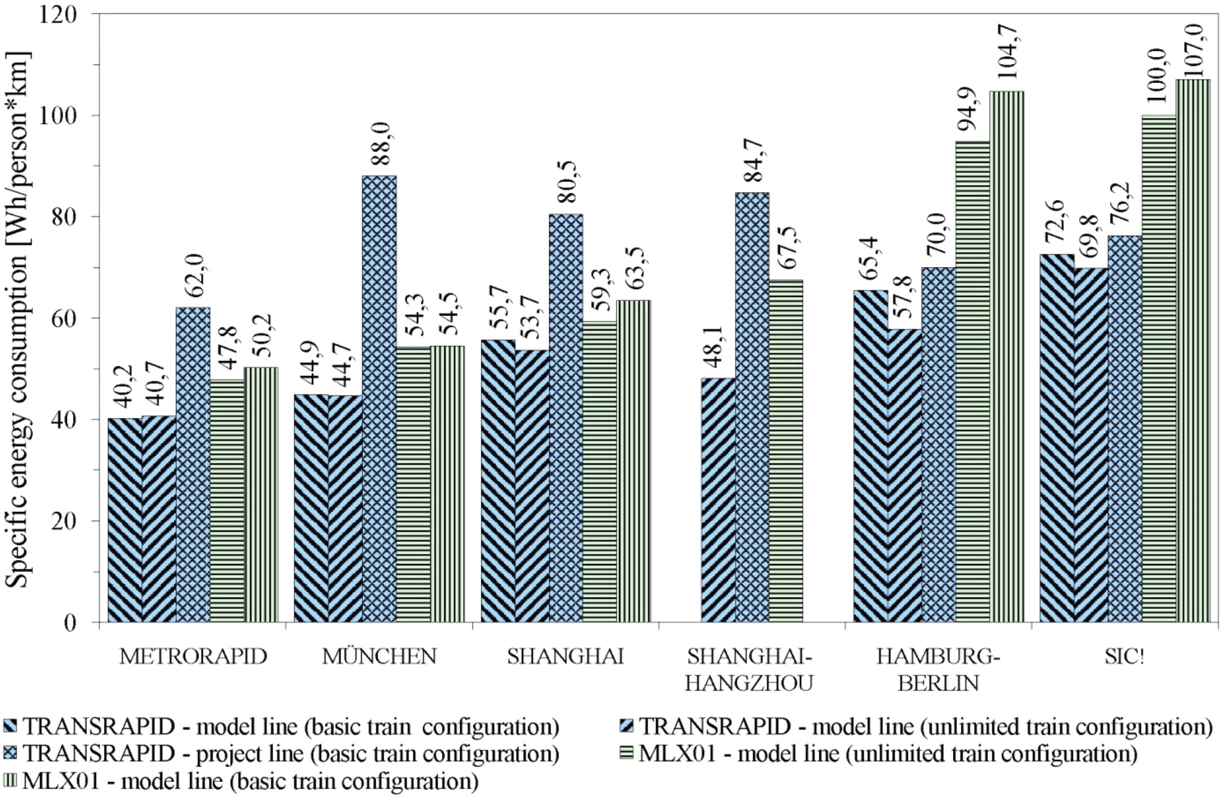

Fig. 10. Specific energy consumption attributable to the transportation of 1 passenger per 1 km, taking into account energy recovery during braking train

5.7. Determination of the limits of the effective application of TRANSRAPID and railway system

Since TRANSRAPID turned more effective than MLX01 for all model lines given in projects of traffic volumes, then at first was a comparative analysis of specific travel tariffs of railway system with project tariffs of TRANSRAPID, and

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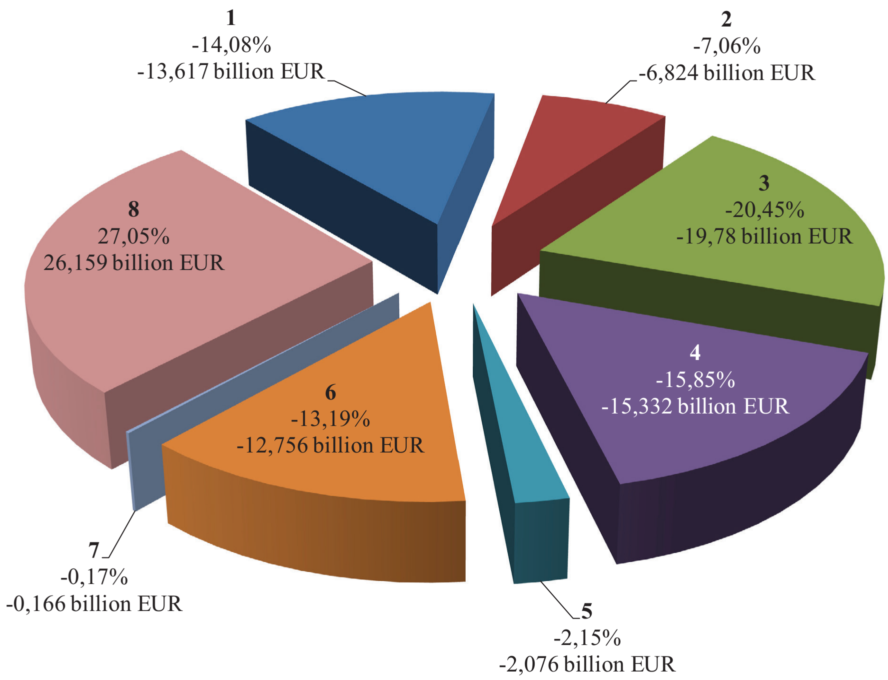

1– aggregate number of additional factors of optimization of the base variant of system execution of the model line (which is as close as possible to the initial design decision of the line), each of which separately has no significant impact on the reduction of its costs
2 – change of the basic train configuration from 4 to 10 sections
3 – application of functions of changing the price of piece goods of the volume of order quantity
4 – accounting of the discount factor
5 – phased acquisition of rolling stock of line during the whole period of its operation
6 – the use of single-track line with the bilateral passing tracks
7 – the use of single-track line with the bilateral passing tracks only on station tracks and change of the basic train configuration from 10 to 14 sections
8 – total costs of the optimized model line at the time of their recoupment

Fig. 11. The sequence of gradual reduction of total costs of TRANSRAPID in phasing out process of its optimization for the model line SIC!

then with the tariffs obtained as a result of its optimization, which led in 6 examined cases to a twofold the expansion of the limits of the effective application of Maglev transport: from 2 to 4 lines (Table 2).

5.8. Determination of the limits of the effective application of TRANSRAPID and MLX01

The limit of scopes of effective application between TRANSRAPID and MLX01 for a “city-airport” transport was determined over the maximum volume of the annual passengers’ flows, equal to 43,12 million passengers per year in both directions (Table 3).

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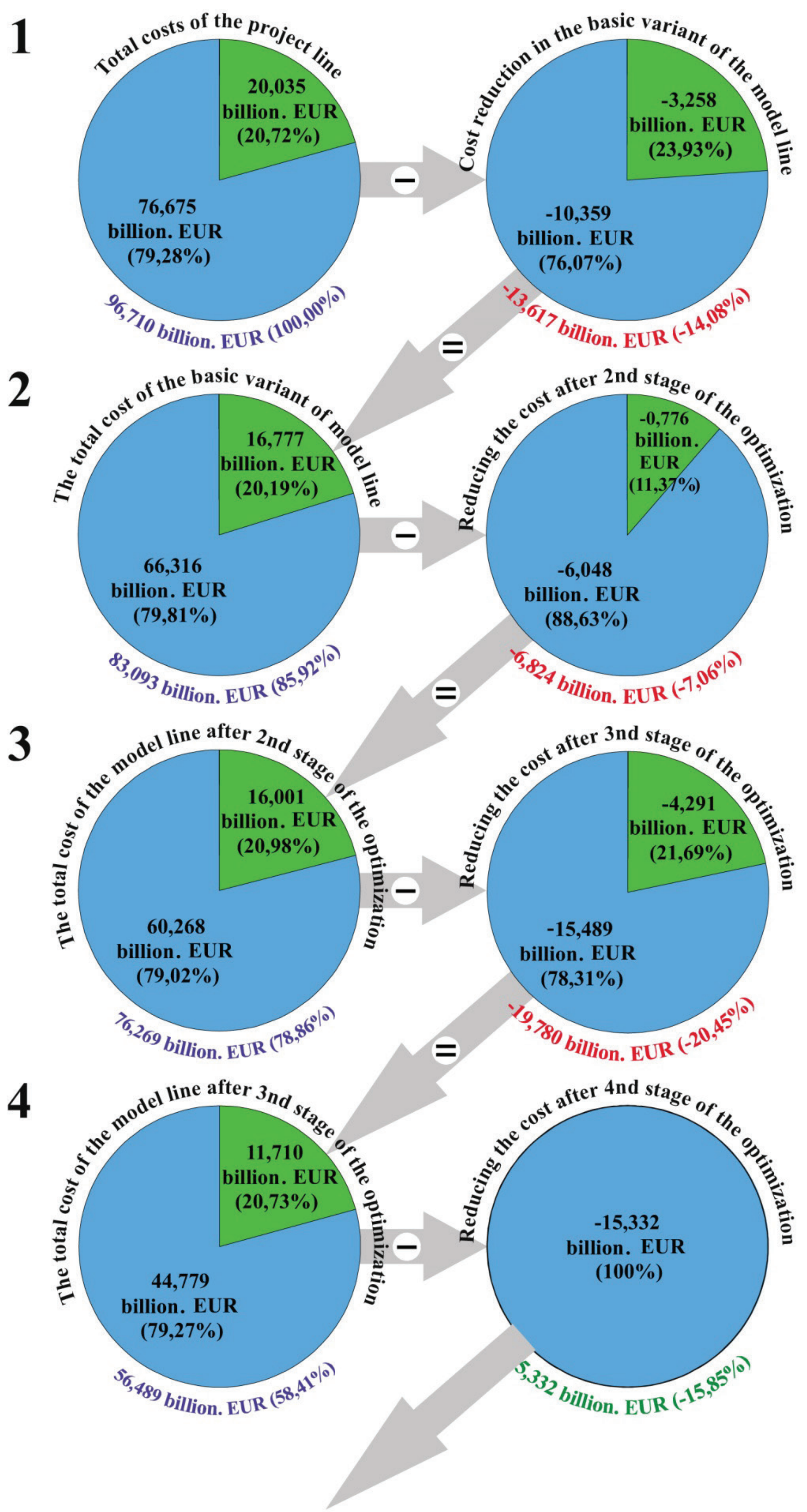

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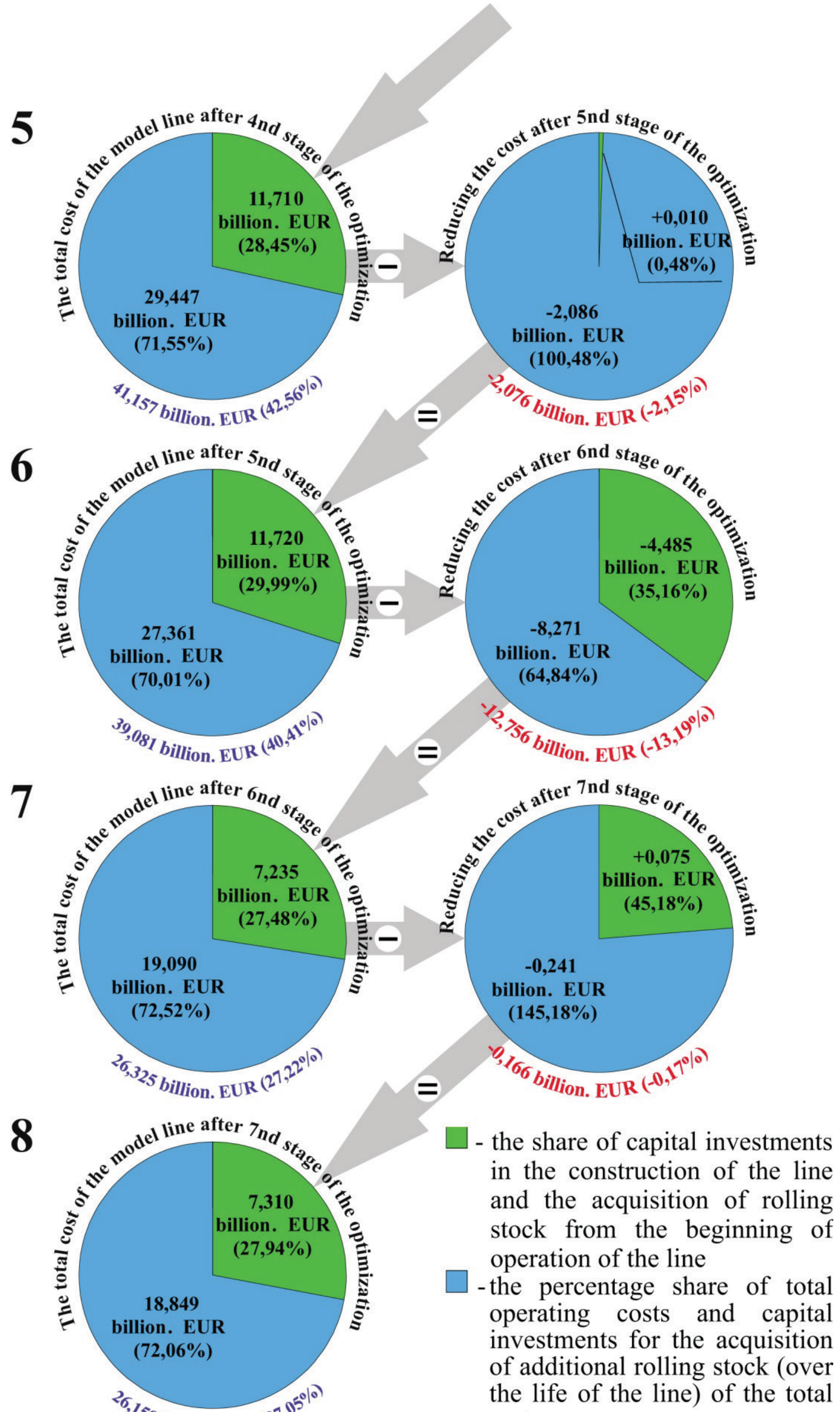

Fig. 12. Changing of the allocation of the proportion of capital investment and operating costs in the total costs structure of TRANSRAPID in phasing out process of its optimization for the model line SIC!

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Table 2. The boundary between areas of effective application of TRANSRAPID and railway system on value of specific tariff

Parameter	Unit	Project					
		METRO-RAPID	*MÜNCHEN*	*SHANGHAI*	*SHANGHAI-HANGZHOU Maglev Line*	*HAMBURG-BERLIN*	*SIC!*
At comparison with design data	transport system	TRANS-RAPID	S-Bahn	U-Bahn	H/S Train	TRANS-RAPID	ICE (Inter-City-Express)
At comparison with modeling data		TRANS-RAPID	S-Bahn	U-Bahn	TRANS-RAPID	TRANS-RAPID	TRANS-RAPID

Table 3. The boundary between areas of effective application of TRANSRAPID and MLX01

Parameter		Unit	Project					
			METRO-RAPID	*MÜNCHEN*	*SHANGHAI*	*SHANGHAI-HANGZHOU Maglev Line*	*HAMBURG-BERLIN*	*SIC!*
Limit annual passenger traffic in both directions in which the effectiveness of the changes in favor of MLX01	to first year of line operation	mil. pass. per year	no	7.99	10.30	no	no	no
	to 50th year of line operation		no	43.12	81.05	no	no	no
Specific tariff for transportation of 1 passenger per 1 km (the car of 2nd class)	TRANSRAPID	EURO Cent per person× km	missed	34.79	12.59	missed	missed	missed
	MLX01		missed	29.11	10.48	missed	missed	missed

5.9. Determination of the maximum allowable volume of traffic for transrapid and mlx01

In this case, in conformity with the maximum allowable volume of traffic (in terms of its satisfaction) was calculated threshold for the possible technical

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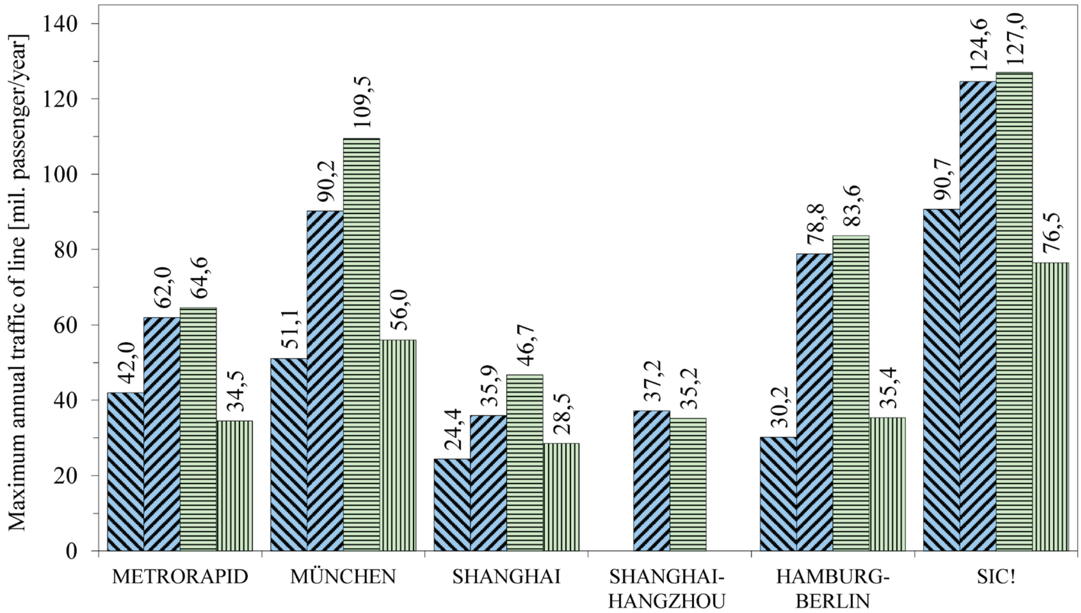
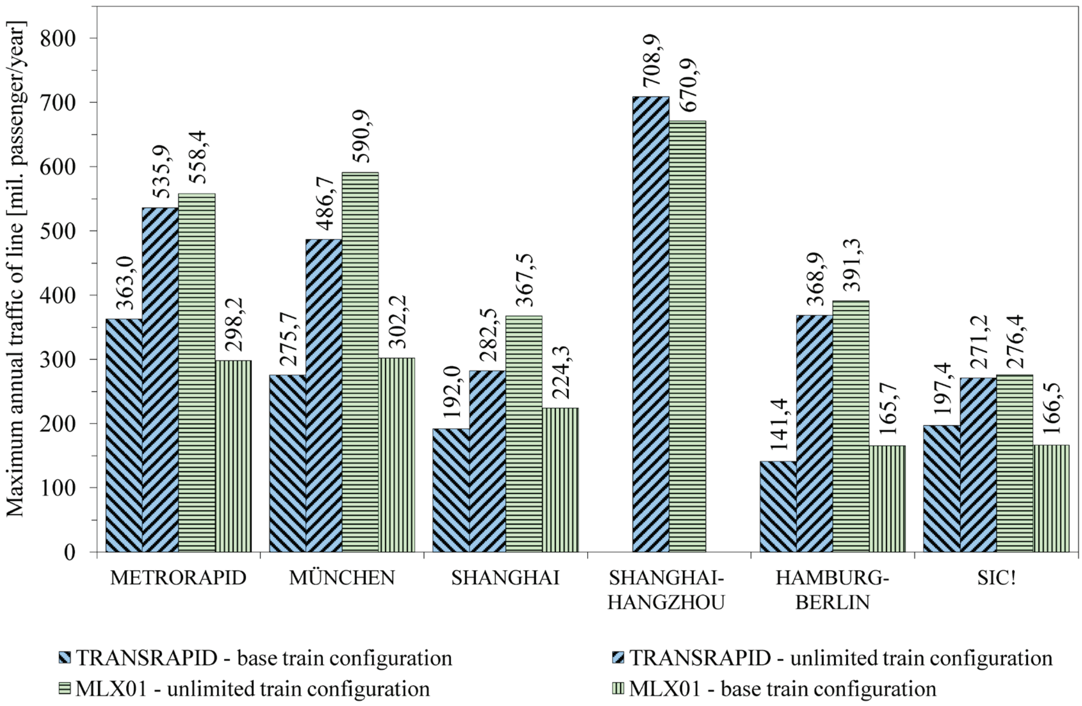
application of the provided in the project of configuration investigated Maglev systems. For TRANSRAPID it is from 271.2 to 708.9 million passengers per year, and for MLX01 it is from 276.4 to 670.9 million passengers per year (Fig. 13).



(a) To first year of line operation



(b) To 50th year of line operation

Fig. 13. Maximal annual passenger traffic in both directions provided the design configuration of the transport system

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5.10. Determination of the optimum distances between stops for MLX01 and TRANSRAPID

Besides, the optimum distances between stops for application of MLX01 and TRANSRAPID in a regional and suburban traffic were determined in the range of 10 to 15 km (Fig. 14).

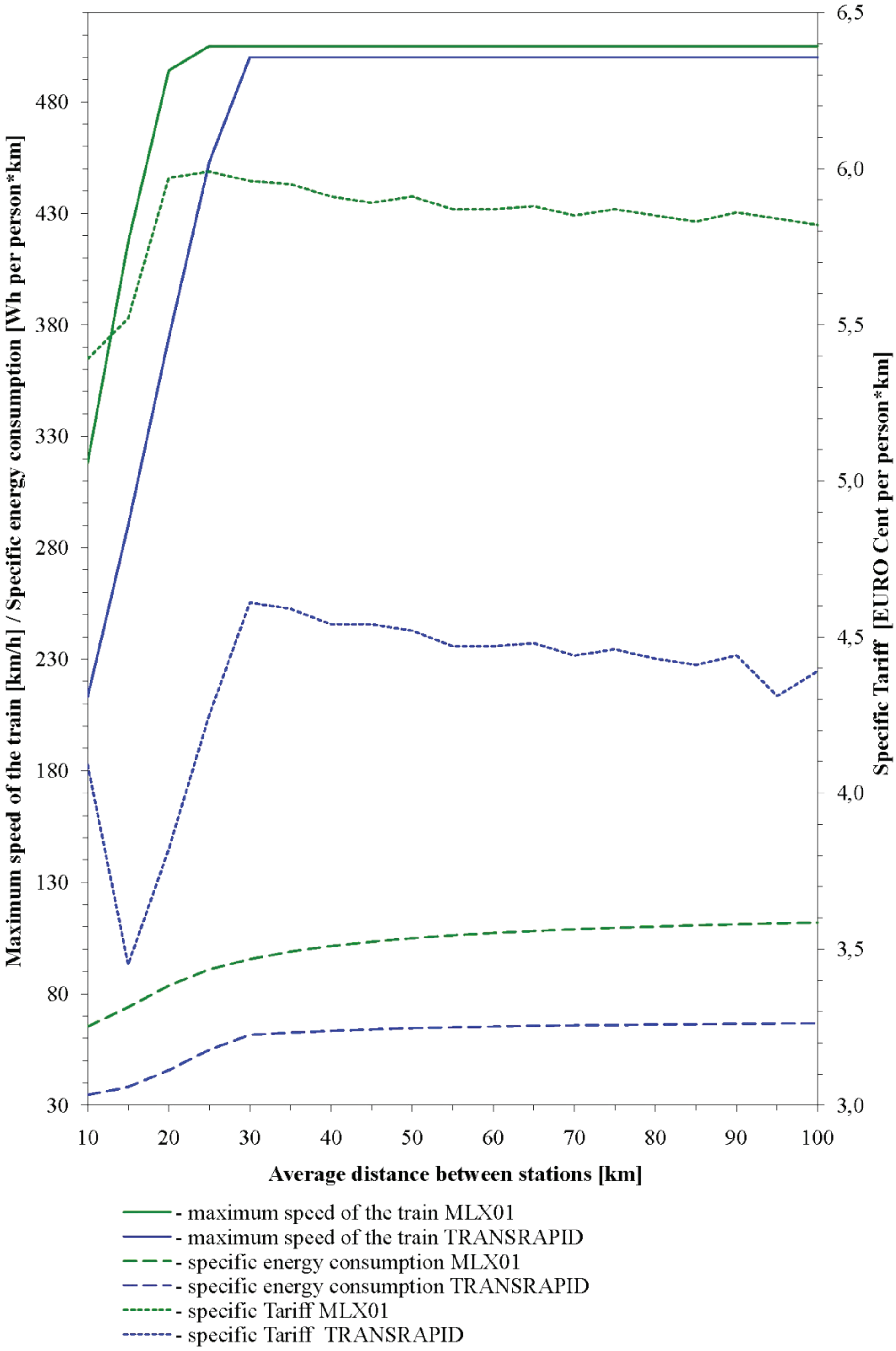

Fig. 14. Dependence of specific energy and specific tariff on the distance between stops

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5.11. Application of research results

The presented research results can be used for (Fig. 15):

- solving of technical and economic questions of vector optimization of Maglev systems, both in theoretical and in applied areas;
- studying of new economic processes/dependencies, occurring in Maglev systems in order of qualitative determination the directions of further perfection of the methods of their optimization;
- preliminary assessment of the effectiveness of introduction of innovation and the definition the most promising directions of the development of Maglev technologies with the aim of significant savings in time and resources to carry out further experiments, production of prototypes/experimental devices, and so on;
- carrying out a preliminary assessment of the feasibility of construction of the Maglev lines in a short time with the output the necessary design data;
- the correct determination of the limits of the effective application of Maglev systems in different conditions of their application, (that have multiparametric character), for compiling predictions to assess the development of transport networks and the development of clear practical recommendations for effective investment for the construction of Maglev lines.

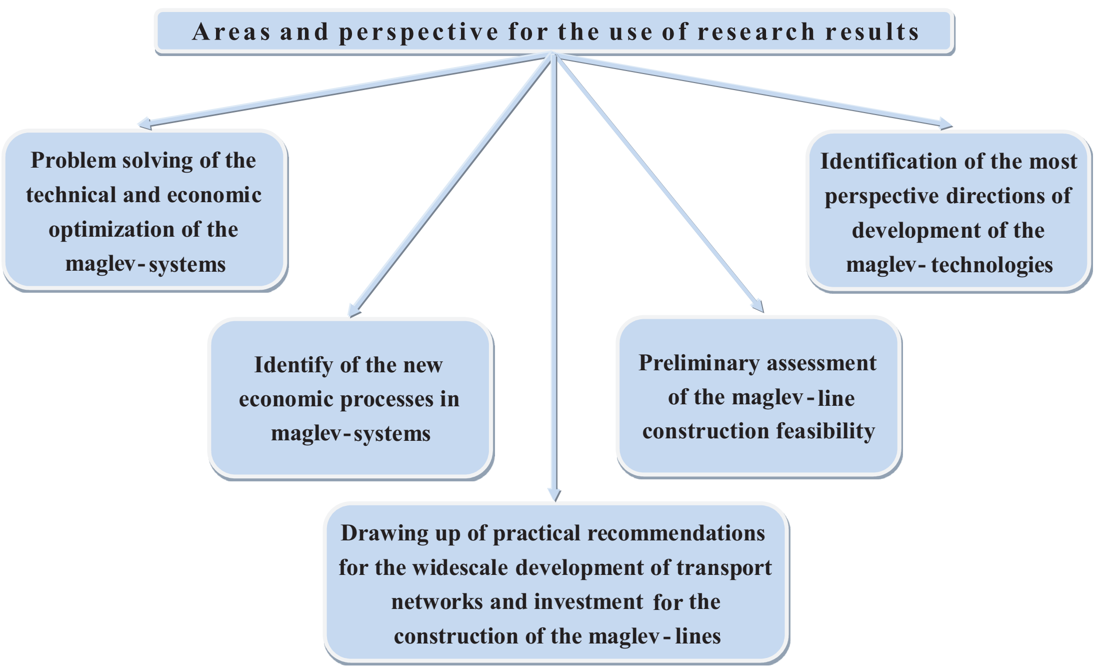

Fig. 15. The main aspects of the application of research results

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6. CONCLUSION

This study is scientifically justified work, which intended to accelerate the process of implementation Maglev technologies in the existing transport infrastructure, which will lead to further improvements in the transportation process and environmental conditions, and also will give new impetus for the stage of development of transport (Fig. 16).

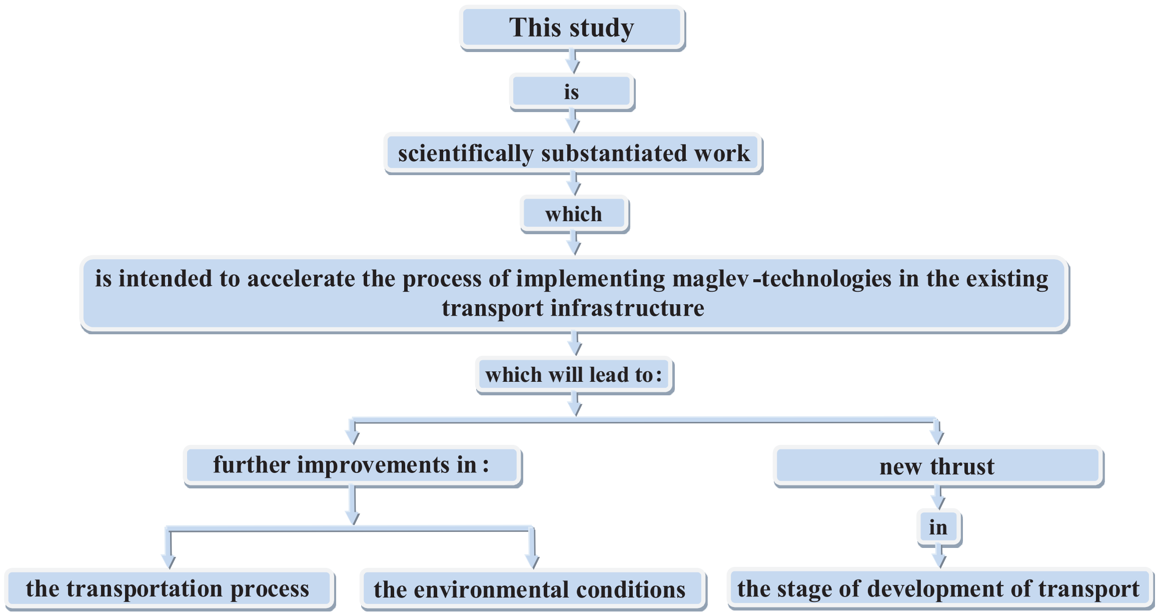

Fig. 16. Conclusion

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Lascher A. Theoretical Base and Methods of the Complex Optimization of Maglev. *Transportation Systems and Technology*. 2018;4(3 suppl. 1):173-194. doi: 10.17816/transsyst201843s1173-194Fig. 1. The last day of MagLev Conference in 2014

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