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Risk management model in road transport systems

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Abstract. The article presents the results of a study of road safety indicators that influence the development and operation of the transport system. Road safety is considered as a continuous process of risk management. Authors constructed a model that relates the social risks of a major road safety indicator - the level of motorization. The model gives a fairly accurate assessment of the level of social risk for any given level of motorization. Authors calculated the dependence of the level of socio-economic costs of accidents and injured people in them. The applicability of the concept of socio-economic damage is caused by the presence of a linear relationship between the natural and economic indicators damage from accidents. The optimization of social risk is reduced to finding the extremum of the objective function that characterizes the economic effect of the implementation of measures to improve safety. The calculations make it possible to maximize the net present value, depending on the costs of improving road safety, taking into account socio-economic damage caused by accidents. The proposed econometric models make it possible to quantify the efficiency of the transportation system, allow to simulate the change in road safety indicators.
Keywords: methods of mathematical modeling, motor roads, the risk assessment of the accident factors, the socio-economic damage, road safety performance management.

1. Introduction

The availability of reliable and efficient transport system is an important factor in the economic development of any country. Today transport is an important part of the global economy, as it is the material carrier between states. Area's well-developed transport system is one of the important factors to attract population and production and is an important advantage for the distribution of productive forces, which makes the integration effect.

The dominant type of transport in the world is an automobile that is growing rapidly every year. The importance of the road network is also reflected in the share of the total volume of passenger and cargo transportations by cars. Studies of foreign scientists have shown that road transport has one of the largest contributions to the budget revenues [1, 3]. For example, taxes and road user charges in the US totaled $78 billion in 1994 (6.2 percent of federal government revenue) and $33 billion in the UK in 1995-96 (of which only $10 billion was spent on the roads). The share of the transport system in the main production assets in Russia is 27%, and a significant share of transport services in GDP is 8%. Net financial flows from the road sector are generally positively correlated with economic development [8, 10].

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Efficient motor transportations are crucial to economic and social welfare of the country. However, in cities around the world, the existing transport network suffers from a policy of authorities responsible for traffic jams, unsafe conditions, high costs, pollution and poor service. As a result countries have huge economic losses, so the damage caused by congestion on the roads in European countries may be from 0.47% of GDP in Ireland to 2.95% in the Netherlands [1, 9]. In Russia, the loss caused by traffic congestion is 7-9% of GDP. A total annual loss from transport congestions in the US is estimated to be worth about $108 billion [4].

Therefore the question about the need to maintain and improve the existing road network and the construction of new infrastructure to increase the national wealth arises [11].

The economic losses of the country in which the third of major highways will work in overload mode, can reach tens of billions of rubles annually, and these costs will be included in the price of goods and services, which means the deterioration of living standards and reducing the competitiveness of the domestic economy, which in its turn, will reduce budget revenues [4, 6].

The researches of traffic flows that go through the Republic of Tatarstan have shown that they are growing faster than transport infrastructure develops. The need for roads is increasing annually, a large percentage of roads work in overload mode, and the entrances to major cities of the republic have become a permanent "bottleneck" in the movement of passengers and cargo. In this case, the increasing of the traffic, due to the steady growth of the number of cars, leads to the rapid destruction of road surfaces. Lag in the development of the roads limits population mobility, inhibits the development of the economy of the republic.

Inconsistency between the level of development of roads and the level of demand for road transport leads to unnecessarily huge budget expenditures. Thus, the annual damage from underdevelopment of the transport system of the Republic of Tatarstan is from 3.4 to 11.9 billion rubles, which corresponds to 1.2% and 4.1% of GRP. This compares with annual expenditure on transport that means the losses are equal or exceed the level of funding for the industry. From the point of view of the government (the ratio of "public investments" and return) the transport complex is very effective. Effectiveness of financing is 137%. This is one of the highest rates among the subjects of the Russian Federation [12].

The damage from undeveloped transport network occurs as a result of a combination of such factors as:

- Inefficient traffic management (social risk);
- Unrepaired road fund, failure of reserve maintenance periods of work on the roads (risk of severity of consequences);
- Existing traffic intensity exceeds the designed data of load on the road network of the Republic of Tatarstan, etc.

Setting of objectives for sustainable development of transport systems in terms of structural reforms of the economy should be carried out with the safety position. Achievement of road safety becomes the main organizational purpose of the functioning of the transport system and is considered as a continuous process of risk management.

In order to prevent road traffic accidents (RTA) it is necessary to evaluate the factors of accidents and manage road safety indicators. The possibilities of modeling help to understand better the mechanisms of accident, its development options and ways to prevent it. The present work is based on the main provisions of the theory of risk, analysis and assessment of the negative effects of an accident.

2. The impact of the transport complex on the economy

Due to its geographical position, a unique position for transport in the European part of Russia, the Republic of Tatarstan became one of the major economic regions of Russia. The Republic of Tatarstan is a competitive region, its competitive advantages is determined by its contribution to the Russian and global economy, comparative characteristics of socio-economic development, as well as the existing preconditions for sustainable growth of the Republican economic and social spheres [5].

One of the most important indicators of economic development of the Republic of Tatarstan is the gross regional product (GRP). GRP of the Republic of Tatarstan in 2014 was amounted to 1.631 trillion rubles; the growth rate was 1.3%. The growth of such indicator as the GRP and the development of the economy as a whole contribute to the fact that the republic steadily increases its macroeconomic indicators, which is important for investors.

The basic elements of the republic's economy are industry, construction, transport and communications, agriculture, wholesale and retail trade and other activities. The most important indicator of the importance of an industry to the economy and social sphere is the contribution of the sector to the formation of GRP.

Considering the basic spheres of the economy in the Republic of Tatarstan, we can say that transport is an essential part of the industrial and social infrastructure of the republic. The system of transport networks is a prerequisite for the region's territorial integrity and unity of its economic space. Transportation network connects the Republic of Tatarstan with other regions of Russia, with the international community, and appears as the base of the region's integration into the global economic system. Because of its geographical position, Tatarstan is one of the main transport arteries of the Russian Federation. In fact, the transport sector is the backbone sphere rather than simply serving infrastructure sector of the economy of the Republic of Tatarstan. The place and importance of transport is evidenced by its significant share in the basic production assets of the Republic of Tatarstan (13.2%) and significant share of transport services in the gross domestic product (6.2%), investments in the development of the sectors of the economy (10.1) and in the number of employed workers (6%) [12].

Among all types of transport the special role is played by automobile transport. Enterprises of the almost all industries give preference to it when shipping.

On average, the share of Tatarstan’s trucking expenses is 6.02% of the cost of material production, and rail and inland waterway transport’s shares are much less (0.63% and 0.35%, respectively). This clearly demonstrates the higher competitiveness of road transport. The percentage of cargo shipping provided by automobile transport in the Republic of Tatarstan is 60-70% of the total cargo traffic, and the percentage of passenger traffic is 50-60%.

Republic of Tatarstan is one of the leading regions in Russia in terms of the density of the road network - 406 kilometers per 1000 square kilometers (13th place of 83 subjects of the Russian Federation). For comparison, Moscow region has 695 kilometers per 1000 square kilometers (3rd place), Leningrad Oblast has 180 kilometers per 1000 square kilometers (42nd place) [12].

3. The theory of risks and assessment of socio-economic cost of road accidents

Indicators of safety in road transport should reflect the degree of safety of the transport system. They should take into account the impact of traffic safety on the timeliness and efficiency of road transport and allow to evaluate the effectiveness of road safety management.

For an integrated assessment of safety in road transport and the adoption of organizational and economic solutions for its improvement there can be used mathematical expectation of the socio-economic damage caused by the accident.

Applying the concept of socio-economic damage in this case is caused by the presence of a linear relationship between the natural (loss of life, loss of property) and economic (monetary) indicators of the damage caused by the accident.

Professor R. Smeed proposed a simple, but as shown by subsequent experience, a successful model that links social risks with the level of motorization. Based on the analysis of data on accidents of European twenty countries since 1938, he has developed a regression model (log-linear model) and set inversely proportional relationship between social risk (the number of deaths (injured) to the amount of the population) and the level of motorization (total fleet of vehicles to the amount of the population). This regression equation allows us to give a reasonably accurate assessment of the level of social risk for any given level of motorization [7].

In order to construct the model he used the heuristic considerations in the spirit of "the theory of dimension". In particular, he suggested that:

- the total number of road deaths (*D*) should be a power function from *P2 × N*, i.e. *D~(P2 × N) γ*;
- the specific number of people died in road accidents per unit of the car park (D / N) must be a power function of the level of motorization *(N / P)*, i.e. *D / N ~ (N / P) β*.

Calculations show that these assumptions imply that *2γ = -β, γ-1 = β* and, accordingly, *γ = 1/3, β = -2 / 3*.

From this we can get "Smeed formula" for transport risks:

$$\frac{D}{N} = \alpha \cdot \left(\frac{N}{P}\right)^{\frac{2}{3}}, \quad (1)$$

Its obvious consequences are the formulas for the social risks and the total number of fatalities in road accidents:

$$\frac{D}{P} = \alpha \cdot \left(\frac{N}{P}\right)^{\frac{1}{3}}, \quad (2)$$

$$D = \alpha \cdot N^{\frac{1}{3}} \cdot P^{\frac{2}{3}}, \quad (3)$$

The coefficient α is the only adjustable parameter, which was used by the author of the model. The value of α = 30 was calculated by twenty empirical points. Statistical tests showed a very high compliance of the model with the empirical data: the correlation coefficient r = 0.87 and $R2$> 0,7.

To determine the damage caused by social risk in the Republic of Tatarstan there was built Smeed model in "motorization - social risk" coordinates, Figure 1.

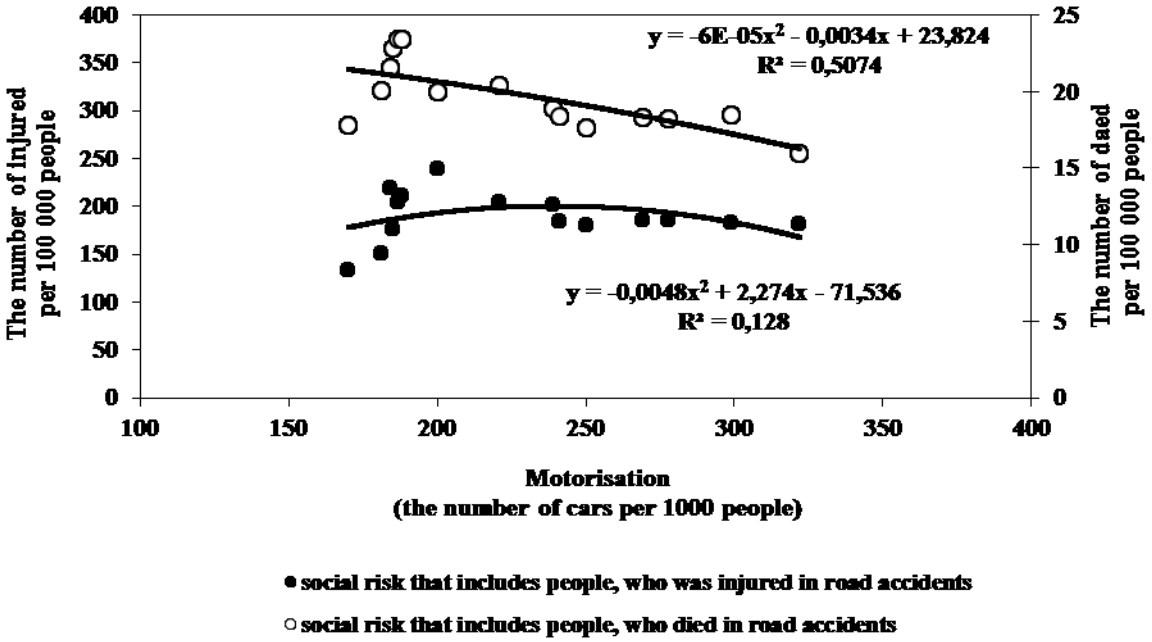

Figure 1. Smeed model in "motorization - social risk" coordinates of the Republic of Tatarstan in 2000-2014

The data presented in figure 1 shows that with the growth of car ownership in the country there is an increase in social risks, but after reaching a critical point (about 200 cars per 1,000 inhabitants) we

can see a decrease of social risks as the further growth of motorization. This change in social risks can be attributed to the fact that the level of development of highways does not match the growth of motorization and the demand for road transport and it is resulted in a reduction in the average speed of the vehicle, appearing of traffic jams and overloads on the transport network and rising of accidents number.

Economic losses due to death and injuries in road accidents include losses due to the disposal of man from the sphere of production. The method of total revenues is used to estimate the losses due to the disposal of man from the sphere of material production. The basis of this method is expressed in monetary terms of the economic benefits that the society will receive due to the preventing of the death or injury of a person in an accident. In this approach human consumption is considered as an integral part of the state profits from the production and socio-economic activities of individuals.

The assessment of the socio-economic damage caused by the death and injuries in road accidents in the Republic of Tatarstan was held under the simplified method technique R-03112199-0502-00 "Methods of assessing and calculation of norms of social and economic damage caused by road traffic accidents (RTA)." This technique allows you to make an exact calculation of losses value from accidents for each year, because the assessment depends on the size of the GRP as the main indicator of the economic potential of the Republic of Tatarstan.

Dynamics of damage from road accident victims in the Republic of Tatarstan is shown in Figure 2.

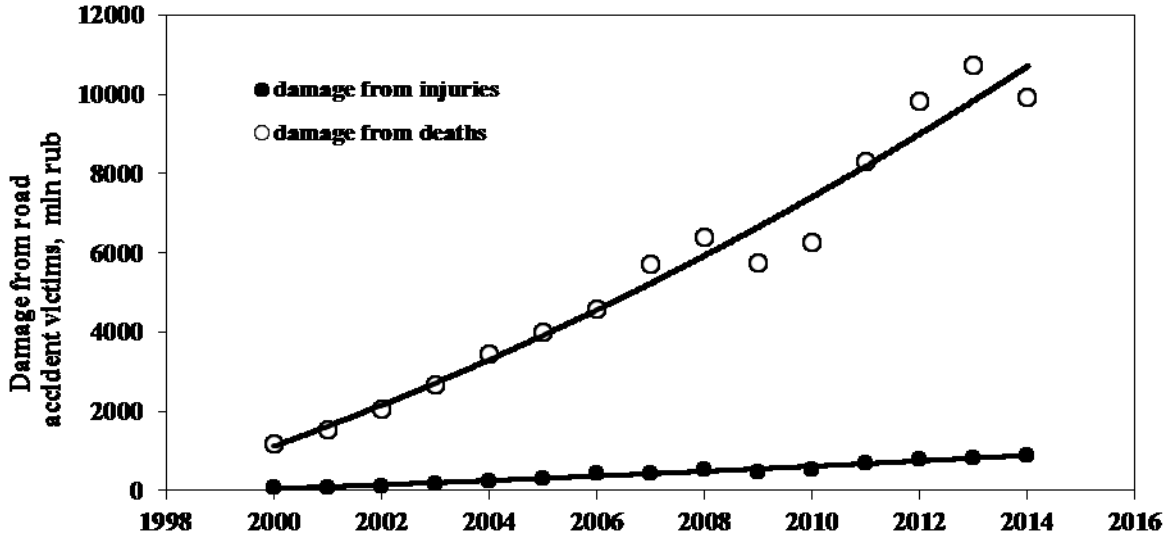

Figure 2. Dynamics of damage from road accident victims in the Republic of Tatarstan in 2000-2014

Calculations show that the damage from the people involved in road accidents in the Republic of Tatarstan increases every year, despite the fact of a decline in the accident rate in some years (the number of people affected in an accident). So, in 2014 the damage from the accident affected people in the Republic of Tatarstan was 0.65% of GRP or about 10.8 billion rubles, which could be used in the economy. If we consider that the social and economic damage is counted excluding damage from vehicles involved in an accident, without damage to the roads, this figure would be much higher.

Exploring this dependence we can assume that with a further increase of vehicles, number of people injured in road accidents will be reduced, but the damage will be bigger, while the growth of vehicles will increase other negative effects of growing motorization and the damage caused by the underdevelopment of the transport system will rise [10].

If we assume that the Z is a socio-economic damage (economic losses) from a traffic accident, P - probability of accident with victims (dead), then, according to the concept of $Z=\alpha \bullet P$, where the α is

coefficient of proportionality, or the price of risk measured in units of currency per one additional death (cost of losses to the state in connection with the loss of health).

The other indicators required to assess the safety level of traffic in road transport can be:

- the probability of at least one traffic accident within a certain time;
- expectation of passengers delivery time delay and cargo safety violations;
- expectation of costs of preventing and reducing accidents consequences.

The investigation of these indicators makes it possible to quantify the effectiveness of road transport safety management.

Besides the frequency, it's necessary to take into account the extent of adverse events. The consequences of an adverse event can be expressed in many different ways. The most common way of expressing the consequences of the accident is the death of a person. On this basis, for the mathematical formalization, the risk R is nothing else but a function of two variables. These are the frequency of accidents (β) and the amount of damage (Z), i.e. $P = f(\beta, Z)$.

Individual risk is the probability of damage to health and (or) property as a result of accident for one individual. This indicator can be used to assess the safety of road transport in a particular region and the comparison of regions for this indicator with each other.

It should be noted that the particular person is primarily interested in the extent of its own security. The level of personal safety is an individual risk (p_i), or the probability of death of a person (harm to his health or property) as a result of an accident during a certain time period:

$$p_i = \sum_{j=1}^{m} \beta_j \mu_{ij} z_{ij} \quad , \tag{4}$$

where β_j is the probability of occurrence of j-type; μ_{ij} is the probability that the i-th person is a party to the accident of j-type; z_{ij} is the probability that the i-th person in the accident of j-type die (get personal injury, property etc.).

Social risk determines the ratio between the probability of occurrence of damage and its size. This type of risk characterizes the severity of the consequences of the hazards associated with the occurrence of the accident.

Social or collective risk Po reflects the position of society and focused on the number of victims, which can be expected at this level of safety in road transport for a certain period of time. The value of social risk is determined by the statistics on accidents in road transport:

$$P_0 = \sum_{j=1}^{m} \beta_j G_j = \sum_{i=1}^{n} p_i \quad , \tag{5}$$

where G_j - the number of died in the accident of j-type.

As can be seen from the above formula, the social risk is the expectation value of damage equal to the sum of the individual risks.

This indicator is important for assessing the impact of traffic safety in road transport on the economic security of the state as a whole.

In contrast with collective risk, social risk Pe additionally takes into account the magnitude of the risks γ:

$$P_e = \sum_{j=1}^{m} \beta_j G_j \gamma_j \quad , \tag{6}$$

The inclusion of the scale factor γj in the calculations allows to assess accidents with a large number of victims.

For the public, as well as for the transport organization, collective risk is more significant. The probability of car accidents is small, so individual risks here are small and are characterized by a moderate value of the mathematical expectation of damage.

If the accident occurred and its consequences are huge, further work of transport organization may be associated with large losses due to the loss of competitive advantages. For the state the accident may

also have large and long-term economic consequences, even an increase in social tension. In this regard, the government is interested in reducing the number of accidents.

4. Socio-economic benefits from improved road conditions in the republic

Economic aspects of road transport security management on the basis of the theory of risks require solutions of three groups of interrelated tasks:

1. The economic evaluation of risk indicators and the damage caused by the accident;
2. The development of economic mechanisms of road transport security control;
3. Optimization of an acceptable level of risk of an accident and the choice of the most effective measures to improve traffic safety in road transport.

Management of the risk of dangerous situations in road transport can be carried out at the particular accident source level, local, regional and federal levels. At the same time economic and mathematical formulations of risk optimization problems will be similar. There can be a probability of a modification of the objective functions at different levels of governance.

In every case, an important part of the control and risk optimization of traffic safety is the social and economic damage. This optimization procedure will be to search for the extremum of the objective function that characterizes the economic effect of the implementation of measures to improve safety. The meaning of this optimization is to maximize net present income CF, depending on the cost of increasing the security C, taking into account the socio-economic damage Z, caused by an accident. This is equal to minimization the generalized reduced costs or expenses, including the cost of measures to improve road safety and the costs of compensation for damage (Figure 3).

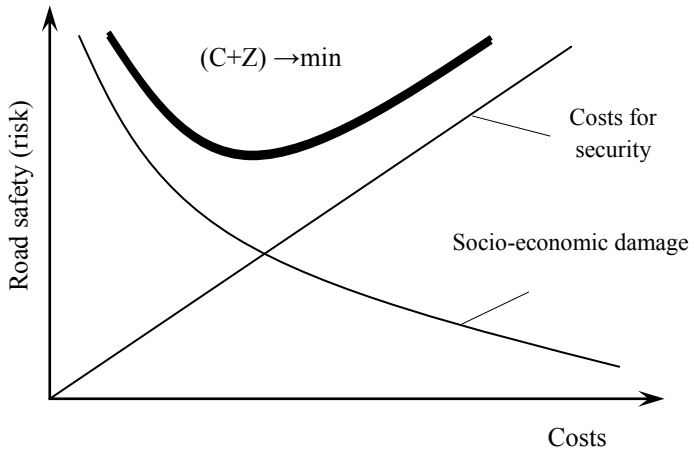

Figure 3. Dependence of the socio-economic costs of road accidents and the cost of measures to improve road safety

Optimality criterion of the cost of accident occurrence risk reduction with such an approach means that the limited economic costs of risk reduction must be equal to the unit cost of risk α:

$$MC = \frac{dC}{dP} = \alpha \ , \tag{7}$$

In this case, the level of economic costs must take into account which the maximum costs are allowed for the reduction of social risk, based on the death of one person. This is not the price of a human life, but rather the expenses which are society and the state ready to have to reduce the risk of fatalities on the roads.

In order to remedy this situation it is necessary to put Tatarstan roads in proper conditions. Currently part of the roads in the country is in a dangerous condition and requires a lot of money that would bring it into proper condition. The relevance of the question is caused by necessity of

improving road safety, particularly by ensuring the efficiency of budget expenditures allocated for this purpose. The mechanism of formation of the positive effect that will be applied on the economy of the Republic of Tatarstan by the improving of road conditions is shown in Figure 4 [11].

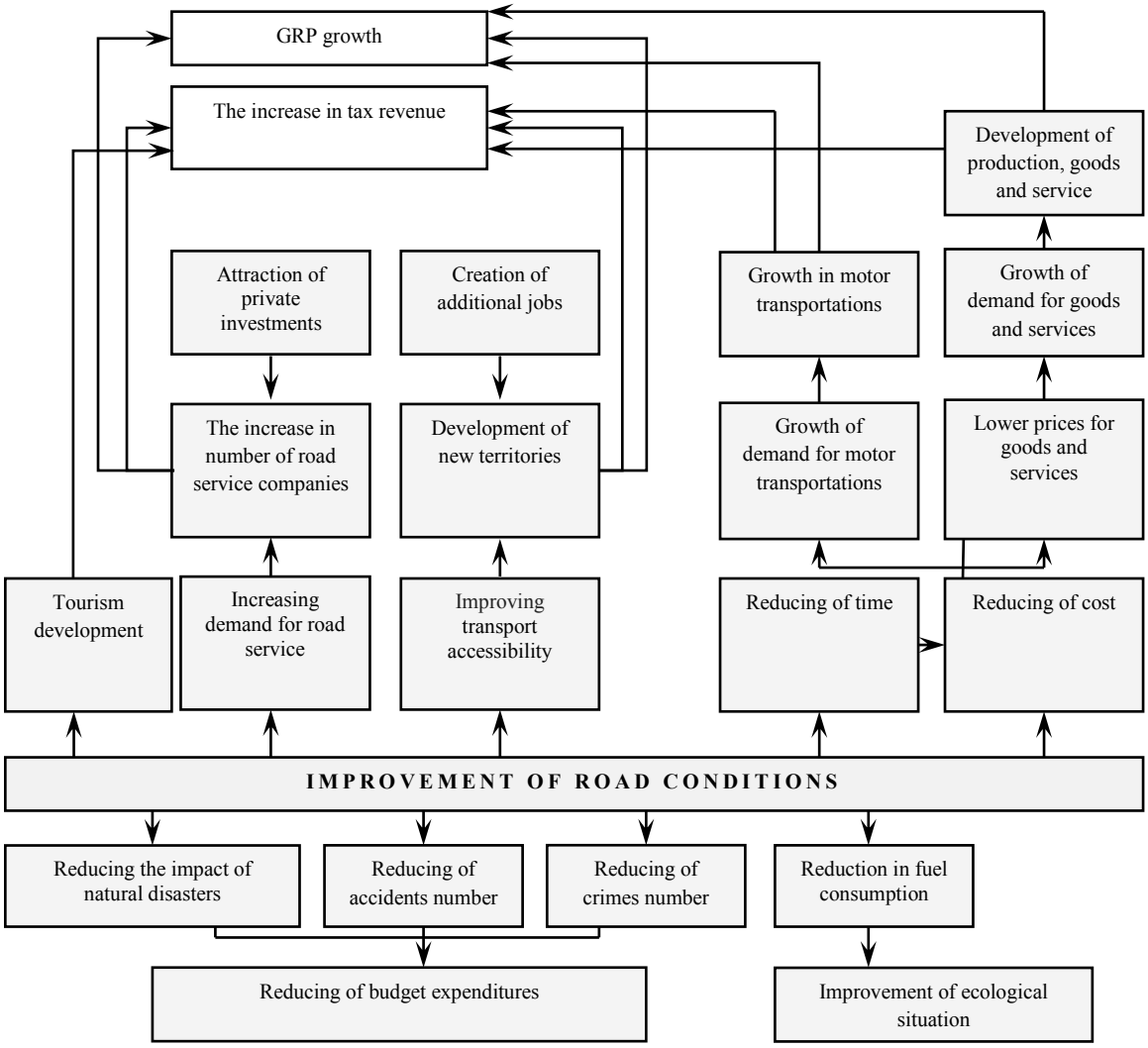

Figure 4. The impact of improved road conditions on the economy of the Republic of Tatarstan

Socio-economic benefits of improving the road conditions are determined by the influence of modernization and development of the road network on the costs of road transport and on the demand for road transport. Also there are the effects associated with increasing of vehicle speed and reliability of year-round connections across the network of roads [2].

Assessment of the socio-economic benefits from the implementation of measures for improvement the road conditions can be carried out in accordance with the Methodology for phasic improvement of transport and road performance, which is based on the principle of the calculation of the transport effects.

Transport effect is defined in terms of value on the basis of changes in the cost of passenger and cargo transport, the cost of road maintenance works, savings of costs of road traffic accidents and reduction of repair of vehicles:

$$E = C^{transport}_{pass.+cargo} + C_{\substack{road \\ main-ce}} - C_{lands} + C_{\substack{repair \\ sav.}} + C_{accidents}, \quad (8)$$

where:

$C^{transport}_{pass.+cargo}$ − savings from reducing the cost of passenger and cargo transport;

$C^{road}_{main-ce}$ − savings from reducing the cost of road maintenance works;

C_{lands} − the cost of lands for motorways;

$C_{\substack{repair \\ sav.}}$ − savings from reduced repair of vehicles;

$C_{accidents}$ − savings from the reduction of road accidents.

Reducing the costs of road transport makes it possible to decrease the tariffs for transportation of goods and passengers, which affects the cost of goods, works and services in the intermediate and final consumption and leads to lower production costs or reduces producer prices, which leads to an increase of the demand for manufactured goods and services. These factors lead to an increase in GRP of Republic of Tatarstan. The reduction of transport margins on manufactured goods and services leads to additional (beyond reduction in producer prices) decrease in purchase prices of goods and services (customer prices) that even more increases the demand for them and value of GRP republic.

Studies have shown that 1 ruble invested in the construction of roads will give 3 rubles after 5 years and 1 ruble invested in the repair and reconstruction of roads - 6 rubles. The most effective investments are those in measures to ensure road safety: signposting gives 27 rubles on 1 ruble, lighting sections of roads gives 12 rubles, installation of barrier fencing – 11 rubles etc. [11].

5. Conclusion

A variety of methods of modeling and forecasting are being used to prevent dangerous traffic situations using.

Mathematical methods help to simulate a situation, assess it, to find ways to reduce the number of accidents.

Created mathematical models help to plan the measures to improve road safety. Marginal economic costs include the ratio of security and the cost of its maintenance; they cannot be defined solely on the basis of objective criteria. It shall enter into force some subjective assessments. The definition of marginal costs in order to prevent an accident is the subject of numerous studies.

They boil down to two main conclusions:

- procedures for the selection of measures of road safety improvement always contain assumptions about the availability of their funding. A large cost variation is possible, which indicates volatility of assessments;
- there is no universal marginal costs value for all occasions. Determining the limits of risk price, we should take into account the risk category.

The marginal cost of safety improvement can be determined on the basis of empirical research, the study of similar systems and processes, based on expert assessments and other ways.

Establishing the cost of risk unit price will allow for an economic optimization analysis of measures to improve safety in road transport.

The use of the methods of mathematical modeling is the possibility to assess factors of accidents and management of road safety.

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