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Efficiency of Operation and Functioning of the System of an Indirect Transport Flow Regulation and Control

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Abstract

The article is devoted to a scientific substantiation of the optimum combination of equipment accuracy and principles of its placement on the highway-road network (urban transportation network) within the framework of indirect traffic flows control and regulation. Moreover, the minimum necessary accuracy of identification of the routes of vehicles (transport means) movement for the most efficient operation of the system of indirect traffic flows control and regulation is defined in the article. The major method of this research is the simulation modelling of traffic flow distribution, based on the recalculation of qualitative correspondence matrixes. The article describes the methodology of formation and redistribution of traffic flows, depicts street-road networks models (urban transportation network models), their main features and the results of the comparative analysis of the results of the experiments. The developed principle of adjusting and correcting the accuracy of qualitative correspondence matrixes allows us to reduce the minimum necessary accuracy of identification of routes of vehicles movement from 90% to 60% without significant losses in efficiency of indirect control and regulation of transport means.

Keywords: indirect management (control and regulation) of transport flows; intelligent transport systems; a qualitative correspondence matrix.

INTRODUCTION

The system of indirect traffic flows control and regulation (SITFR) is based on creating motivation techniques for selection of optimal direction in real conditions with the possibility of arriving at alternative solutions, concerning the traffic flow direction. The functioning and operation of the SITFR is based on the interests of road traffic participants (RTP), that coincide with the interests of the regional center, organizing road traffic according to the principle of increasing crossing of the street-road network (urban transportation network) parameters by means of optimization of traffic flows redistribution**.**

Scientific researches of many famous Russian and foreign scientists such as: S. Zhankaziev, A. Vorobyev and A. Tour, Li Yang, R. Hostettler, V. Bernhardsson, B. Johanson, C. Wang, and M. Simon [1-11] are devoted to the problems, related to the organization of SITFR operation. However, the problems of SITFR operation assessment in terms of optimal combination of accuracy indication equipment and principles of its placement on the street-road network (urban transportation network) have not been disclosed and thoroughly analyzed in their works yet.

The aim of this article is to develop an approach to identification of effectiveness of SITFR operation. It is necessary to tackle and accomplish the following tasks in order to achieve this goal, that is: to develop the structure of the experiment, with a help of which SITFR operation effectiveness indicators in simulation and imitation modelling programs can be identified; to create the models of traffic flows redistribution for different parameters of traffic flows and street-road network (urban transportation network); to identify the dependencies of the SITFR effectiveness on accuracy of qualitative correspondence matrixes in the conditions of their underestimation and overestimation; to determine the minimum necessary accuracy of identification of the routes of transport means movement.

METHODS AND MATERIALS

An identification and determination of the influence of qualitative correspondence matrix accuracy (QCM) underestimaton on the effectiveness of the system of indirect traffic flows control and regulation is based on establishing a basic simulation model, which would have all the necessary conditions for implementation of traffic flows (TF) redistribution (fig. 1). Calculation of SITFR efficiency coefficients is carried out in accordance with the output data of this model. More detailed and precise information about these coefficients can be found in S. Zhankaziev's scientific works and in ODM 218.9.011-2016, where the SITFR technological aspects are described in detail [1, 13].

The next step is to assign the QCM accuracy, depending on which adjustment and correction of matrix for third-party TF is carried out (performed), as a result, the difference between the actual and the estimated QCM accuracy is accepted as a third-party TF, aiming at making the output data of generated model of TF match the output data of the basic model.

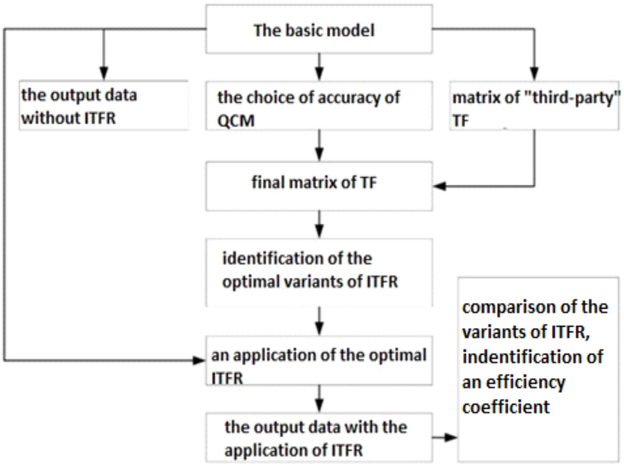

Figure 1. Scheme of carrying out the experiment with an underestimation of TF

The next step is to identify the best options for redistribution of TF for the models with a given (predetermined) QCM accuracy, taking into account the capacities of roads and junctions. The SITFR options, obtained experimentally, are applied directly in the basic model, the output data of base model are being collected in accordance with the SITFR. The identification of efficiency indicators of the SITFR is being implemented (performed) on the basis of these data and data of a basic model without taking SITFR into account.

Choice of QCM accuracy is carried out according to the following scheme:

(1) the best options for reallocation of TF for QCM, possessing 100% accuracy, are determined and defined;

(2) a new accuracy of QCM is appointed, with which the variants and options of distribution of TF, having been received for the previous QMC accuracy, have been undergoing procedures of checking, as well as search for other possible options is being made (Fig. 2);

(3) the most optimal redistribution options are identified among those, which were found and singled out, then next QCM accuracy is being chosen and assigned etc. This operation is being repeated until the only possible variant and option is left, which is equal to the maximum possible redistribution of TF.

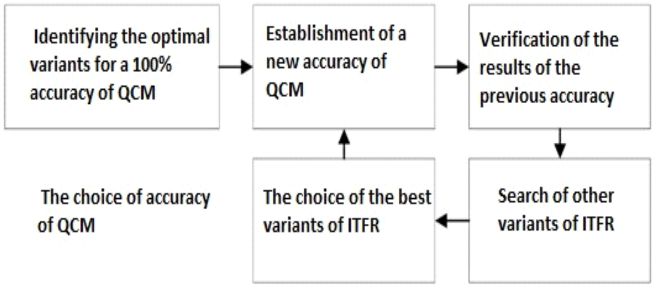

Figure 2. Scheme of QCM accuracy selection with underestimation of TF

The scheme of investigation of QCM overstatement differs from the scheme of investigation of QCM understatement in principle of the formation of matrixes of TF with a help of recalculation of QCM (Fig. 3). It should be pointed out, that the Identification Unit (IU) can create only the mistake of the first type (I), therefore, the use of IU as detectors of TF is undoubtedly an advantage and allows us to carry out proper assessment of QCM accuracy. Besides, the presence of only one type of error creates conditions for the correction and adjustment of the received data, i.e. in a recalculation of the QCM in a particular way, so that it could (would) meet the minimum system requirements of SITFR.

As (since) firstly the experiment of evaluation of the impact of underestimation of the TF was conducted and the analysis of its results revealed that the minimum acceptable QCM accuracy for maximum efficient SITFR is equal to 90%, so in cases where the estimated and calculated QCM accuracy turns out to be below this value, it is necessary to recalculate the QCM in order to reach the level of the minimum acceptable accuracy. This action (measure) made it possible to check the correctness of the work of the developed principle of correcting and adjusting the QCM simultaneously with the investigation.

In general, this methodology is identical to the previous one, except for one thing, i.e. recalculation, that allowed to get a minimum guaranteed accuracy equal to 90%, was being conducted after the selection of QCM accuracy.

In this situation two options of research are possible: a) all the routes of traffic of vehicles and transport means (TM) towards the objects of attraction (AO) have been defined; b) only the key traffic routes, that satisfy the conditions of SITFR, have been defined.

An opportunity to identify and define general factual QCM accuracy, but not accuracy of separate routes, is provided in the first case, as a result, it is possible to draw a conclusion about the value of possible error in the process of recalculation, if it is needed (recalculation is not necessary, when factual accuracy is not less than 90%). In the process of unfolding of events the mean (average) value of the factual QCM accuracy will become the worst variant, with which, for example, the accuracy of the identification of one route will turn out to be equal to the minimum computational accuracy, and the other will be equal to absolute. In the second case, it is impossible to find out the average factual QCM accuracy, so, in any case, one should recalculate accuracy, despite the fact that this may lead to a significant overestimation and extremely inefficient usage of SITFR.

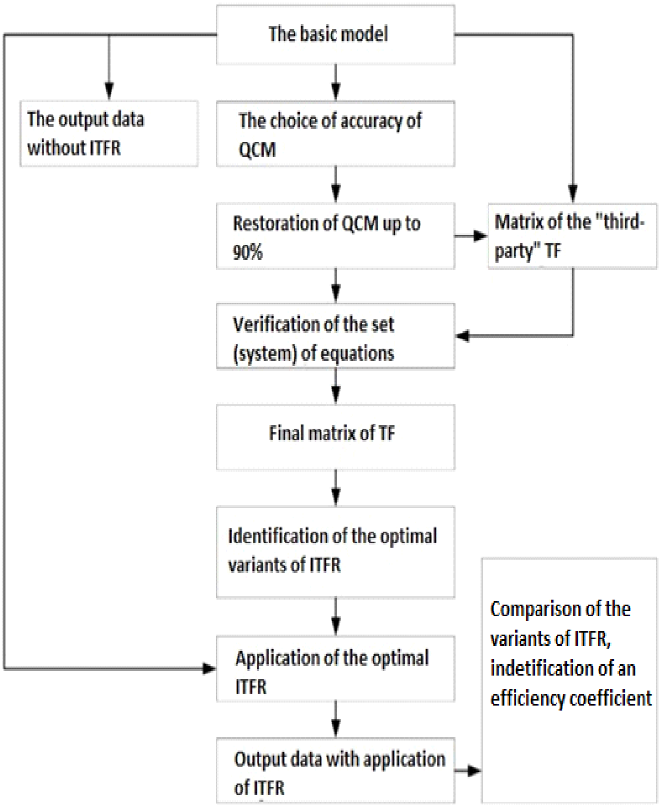

Figure 3. Scheme of the experiment during reassessing of TF

In the framework of the research, using a pseudorandom number generator, the factual accuracy of the identification of the routes of TM movement was assigned for each QCM accuracy in the range [*P*; 100], where *P* is the nominal minimum QCM accuracy. The upper limit is predetermined by peculiarity of identification, because it is impossible to identify more than 100% of TM. After that QCM was restored (recalculated) up to a minimum level of accuracy, reaching 90%. Thus, QCM, which accuracy did not exceed 90%, were considered. In order to compare the results of the experiments more correctly and thoroughly it was decided to take into consideration QCM of the same (equal) mean (average) accuracy for different simulation and imitation models. An application of a pseudorandom number generator resulted in achievement of more independent and reliable results. The use of pseudorandom numbers is wide-spread and applied, practically, in all programs of simulation and imitation modelling of transport flows, according to A. Sivakumar, I. Ryzhkov and others [2, 3].

In the process of QCM corrections and adjustments the following system of inequalities was taken into account in order to provide the simulation and imitation model with the characteristics similar to the basic model without applying of the SITFR:

$$\begin{cases} \sum N_{AO}^{QCM} \le N_{AO}^{gen}; \\ \sum N_{road}^{route} \le N_{road}^{gen}. \end{cases} \quad (1)$$

where $\sum N_{ao}^{qcm}$ – is the total, cumulative intensity of TF, taking and following the routes under consideration through the IU, installed on AO, in accordance with the recalculation results; N_{ao}^{gen} – denotes the total, cumulative intensity of all the TF, having moved through the IU on AO according to the indications of the detectors; N_{road}^{route} – denotes the total, cumulative intensity of TF on a stretch of the road, taking into consideration the recalculation results; N_{road}^{gen} – denotes the total intensity of all the TF, having moved through the IU on a stretch of the road according to the indications of the detectors.

Failure to comply with any of the requirements of the system of inequalities (1) signals an exceeded amount of TF, set in the basic model. In such cases, the neglecting of "third-party" (outer) TF, which cannot be influenced by the SITFC, is allowed (as far as it is possible) in order to get the model that reflects real traffic conditions more authentically and correctly (in a proper way). It is allowed to disregard (neglect) only those TF, which movement direction coincides with QMC on major roads and that have direct impact on the traffic jams (congestion). It should be mentioned that the application of such measures is permissible only when the phases of traffic light objects remain unchanged, otherwise, an incorrect traffic light regulation may occur (become possible) and, consequently, more serious traffic jams may appear.

Since the calculation of the indicators of the SITFR effectiveness and efficiency in simulation and imitation modelling programs is carried out in the average (mean) value (meaning) not only for the separate stretch of network of roads in general, but also for major roads in isolation (taken separately), so in order to obtain a more accurate result the experiment was carried out in three different simulation and imitation models:

a perfect (ideal) simulation and imitation model (it is the most preferable for the calculation of the average values of efficiency indicators);

simulation and imitation model № 1 is based on the ideal model and is close to real conditions (the topology of street-road network or urban transportation network (URN) is altered; the TF, which are not influenced by SITFR, are added);

simulation and imitation model № 2, which differs from the previous topologies of URN, is also close to real conditions.

Zhankaziev [1] highlights several key parameters, which the stretch of the road network must meet within the

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framework of introduction and implementation of systems of indirect control, management and regulation of traffic flows, in his scientific writings. And each of the models, described above, meets these requirements, such as: the availability of alternative routes; the presence of traffic jams; the presence of dominant AO; the length of the alternative routes does not exceed the length of the main routes more than two times.

Besides, it was decided to abandon the controlled and regulated intersections in favor of multi-level junctions in the first two models, because their use has no effect on the essence of the research. In order to make the model of TF more realistic, the following characteristics of roads and TM were set: the maximum permissible speed on the straight sections (stretches of the road) is equal to 60 km/h; the maximum permissible speed of movement on the exits (ramps) of junctions is equal to 20 km/h; the width of road stripe is equal to 3 meters; the length of TM is equal to 4 ± 0.5 m; the width of TM is equal to 2 m; the maximum acceleration (increase) of speed is equal to 3 m/s2; the nominal deceleration (decrease of speed) is equal to 4 m/s2; the maximum deceleration (decrease of speed) is equal to 6 m/s2; the minimum distance between the cars is equal to 1 m.

Similar parameters were also used in scientific works, written by Zhankaziev and Vorobyev, in the process of creation of the stretches of road network within the framework of simulation and imitation modelling of work of the systems of indirect traffic flow regulation [1, 4].

A) Ideal model

The peculiarity of this model of UTN is in the creation of the most favourable conditions for evaluation of the SITFR effectiveness and efficiency, such as:

- the absence of “third party” (outer) TF, i.e. in the models absolutely all TFs move in the direction of the main TF and all available for redistribution along UTN. As the third-party TF do not undergo influence of SITFR (redistribution along the UTN is impossible), so, they move only along the definite fixed routes and affect only the leftover traffic capacity of the roads and exits (ramps) of junctions. In addition, the "third-party" TF create additional errors in the output model;
- calculated average speed of TM on all routes is equal to 55 km/h;
- transit character of TM traffic was set, allowing to assign main and alternative routes in such a way that their length was approximately the same, which was important in order to obtain more accurate average values of efficiency indicators (see Fig. 4).

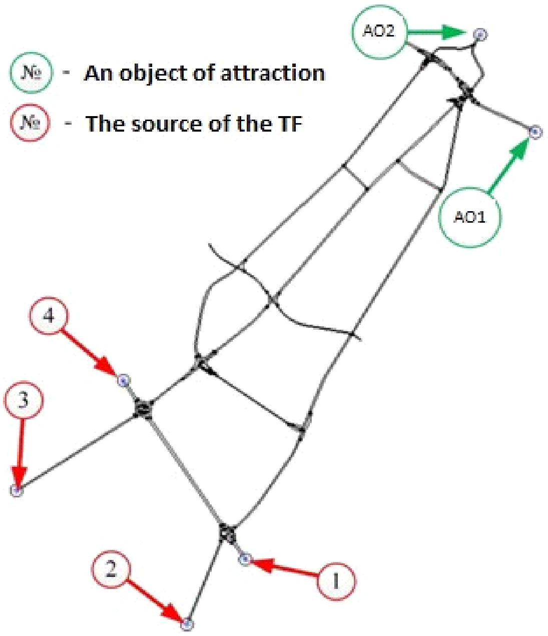

Figure 4. The general image of the ideal model

B) Simulation and imitation model № 1

The model of UTN, which is close to real conditions, was created in order to satisfy the needs of further research (Fig. 5). UTN of an ideal model was considered to be the foundation and base. It has undergone several changes, such as:

- additional origins (sources) of TF and AO have been created;
- geometry of road No. 1 was changed and altered, which made it possible to increase the length of the alternative routes and have a significant impact upon the result of the experiment;
- the scheme of organization of road traffic (ORT) was changed. Some exits (ramps) of junctions have undergone changes (possibility of driving from road No. 2 to road No. 1 was excluded), a new turnoff to the alternative road was added, which became the only turnoff to the alternatives from road No. 2.
- in accordance with the changes in the ORT the alternative routes of movement of TM have been changed;
- third-party TF, which are not influenced by SITFR were introduced. Third-party routes of TF lie on the same sections and stretches of the roads, where the main TM move, thus increasing the sensitivity of the model to the redistribution of TF.

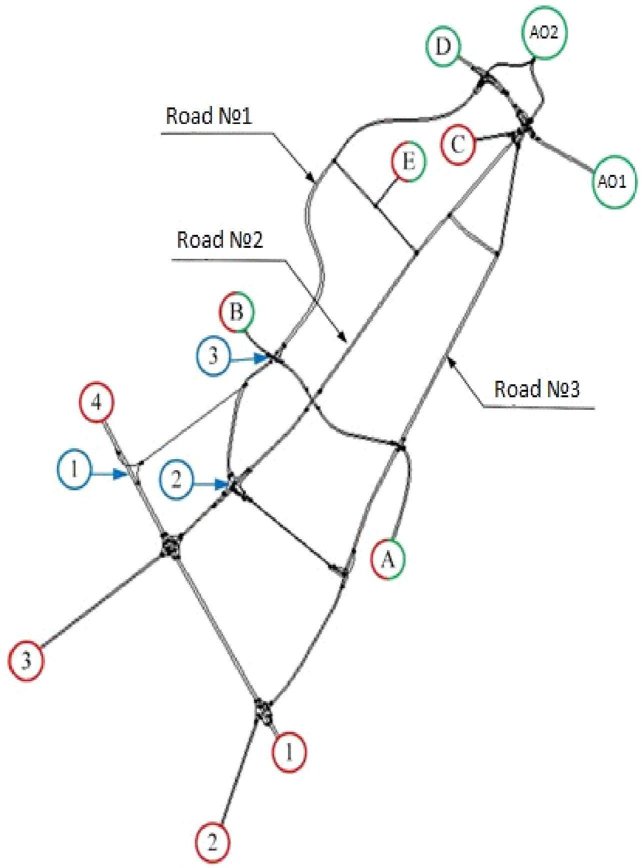

Figure 5. The general image of imitation and simulation model №1

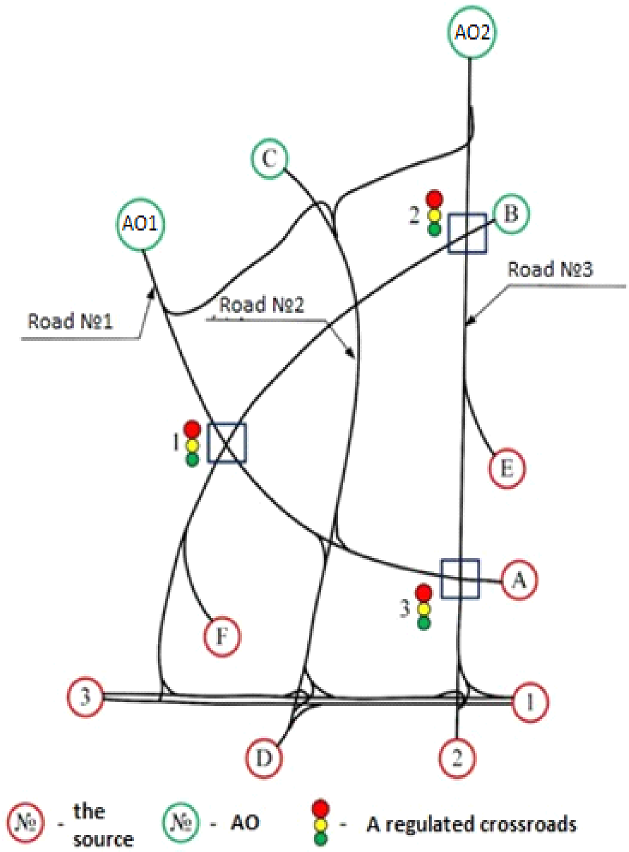

Figure 6. The general image of simulation and imitation model № 2

C) Simulation and imitation model № 2

This model of UTN, as well as the previous models, satisfy all the necessary requirements for SITFC and is characterized by presence of controlled and regulated interjections, traffic jams on the main roads before interjections №1 and №2. Moreover, this model has a number of significant limitations for implementing of SITFR, such as:

- the only turnoff for all the routes of TM to the alternative road;
- the big difference of length and stretch values of the major routes;
- high variation of relationships of stretching of alternative routes to the stretching of the relevant major routes. As the research covers only the SITFR, so the phases of traffic lights objects were considered to be a constant value (Fig. 6).

RESULTS

Let's consider in more detail the results of the experiments within the framework of ideal simulation model.

1. *The results of the experiments of investigation of the consequences of errors I sort (underestimation of the SITFC accuracy).*

According to earlier data the chart (graph) of dependence of efficiency coefficient of SITFC on QCM accuracy (Fig. 7) was created, which can be divided into two intervals: the QCM accuracy is not less than 90%; and, the QCM accuracy is below 90%.

The main difference between these given intervals is in the fact that if the QCM possesses accuracy, which value is more than 90%, so SITFR efficiency is not only stable, but also reaches the greatest values. Decrease of QCM accuracy, reaching the level, which is below 90%, leads to severe drop of the SITFR efficiency and effectiveness, moreover, this interval of QCM accuracy is characterized by unpredictable level of SITFR efficiency and effectiveness.

More detailed analysis of the results of the experiments has revealed that the diagram (chart) of dependency of SITFR efficiency and effectiveness on the QCM accuracy can be divided into several specific areas [17]:

Zone I* (QCM accuracy is less than 50%). The only possible variant of SITFR, equal to the maximum redistribution of TF, existed on the given interval of QCM accuracies, therefore, consideration and description of this zone does not represent any value for this research;

Zone I (QCM accuracy ranges from 50% to 70%) – it is considered to be the zone of inefficient SITFR. It is characterized not only by the lowest values of the coefficient of effectiveness of SITFR, but also by an enormous irregularity and uneven loading of the main roads;

Zone II (QCM accuracy ranges from 70% to 90%) – it is risk zone of ITFR. It is characterized by unpredictable ITFR efficiency; with equally successful results of model experiments within the framework of the selected QCM accuracy the found variants of ITFR give completely different results in basic model, concerning not only the value of the coefficients of ITFR effectiveness, but also loading of the main roads;

Zone III (QMC accuracy exceeds 90%) – it is the zone of effective and efficient ITFR. It is characterized by the most effective ITFR and balanced loading of UTN.

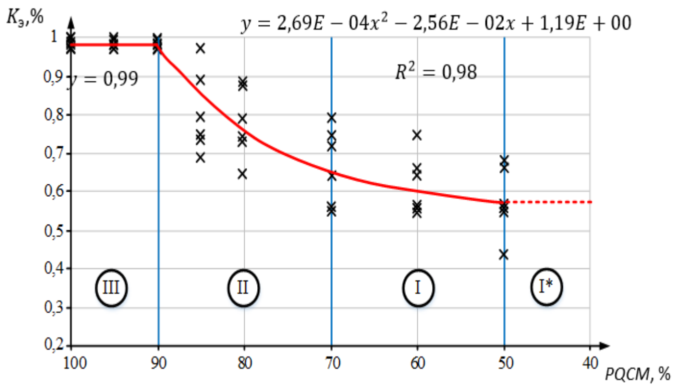

Figure 7. The chart of dependence of efficiency and effectiveness of SITFR on the QCM accuracy when it is underestimated

We can come to the conclusion, that the minimum allowable QCM accuracy in case of its underestimation is equal to 90%, if we consider calculated efficiency and effectiveness indicators to be basic. Application of QCM with lower accuracy leads to a sharp increase in uneven loading of the UTN, with which overload of alternative routes and unloading of major routes take place. Thus, TF is redirected from freer roads to traffic jams, which inevitably will have a negative impact on the level of tolerance and trust of users and participants of road traffic to ITFR systems, especially if the users and participants of road traffic have access to services, informing them about current traffic conditions.

2. *The results of the experiments of study of the effects and consequences of errors of the (II) type (reassessment of QCM accuracy).*

According to the data, the diagram (chart) of the dependences of coefficient of ITFR efficiency and effectiveness from the QCM accuracy has been constructed (Fig. 8).

Analysis of experiment results allowed us to determine and find out that the diagram of dependence of ITFR efficiency on the QCM accuracy can be divided into several specific areas, as in the previous case:

Zone I* (QCM accuracy is not less than 50%). On this interval the value of QCMs accuracy, acquired with a help of recalculation, exceeds significantly the value of the basic QCMs. The situation on the road differs from the initially pre-set in such a way that traffic jams can be spread on the whole territory of UTN and identification of the ITFR options becomes impossible. Thus, this zone is not valuable and representative for this study;

Zone I (QCM accuracy ranges from 50% to 60%) – it is characterized by a significant mismatch of recalculated and basic QCM, resulting in an understatement of the possible ITFR effectiveness;

Zone II (QCM accuracy ranges from 60% to 80%) – it is characterized by small and medium-sized excess of recalculated (clearing) QCM of the basic matrix, which also reduces (lessens) the ITFR effectiveness a little bit;

Zone III (QCM accuracy exceeds 80%) – it is the zone of efficient and effective ITFR. It is characterized by the highly effective (the most efficient) ITFR, balanced UTN loading and deviations of applied QCM from the basic QCM.

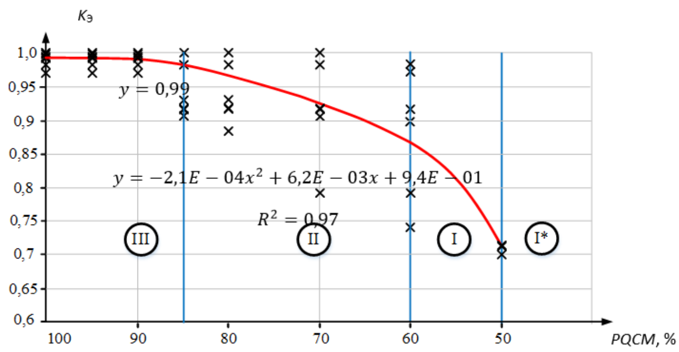

Figure 8. The diagram (chart), representing dependence of the ITFR efficiency on the QCM accuracy, when it is reassessed

Taking into consideration the calculated efficiency indicators, we can come to the conclusion that the minimum allowable QCM accuracy, when it is underestimated, reaches 60%. Reduction of the ITFR effectiveness does not have a negative impact on the trust level of the road users in the ITFR systems; therefore, after the evaluation of the results of systems functioning, the correction of the TFR scenarios becomes possible in the process of striving for maximum efficiency.

Similar studies were conducted for other simulation and imitation models, the detailed and thorough description of which is inappropriate and not necessary, because of their identity. We consider it to be more practical and appropriate to compare the results of the experiments.

DISCUSSION

The general graphs were constructed, where the ITFR efficiency coefficient was plotted (was shown) against (versus) QCM accuracy, when it is underestimated and overestimated, in order to make the process of comparison of the results of different models more convenient (fig. 9 and 10). This graph shows the similarity of results of the experiments having been conducted in various simulation and imitation models. Especially visible is identity of the results, when the QCM accuracy is equal to the value, exceeding 90% (ITFR efficiency is the maximum with the given QCM accuracy).

The graph, where the ITFR efficiency is plotted (was shown) against (versus) QCM accuracy, when it is underestimated, shows and signals abrupt decrease and reduction of the ITFR efficiency while QCM accuracy is being reduced and falls below 90%, besides, demand and need for traffic capacity of the alternative road, caused by redistribution of TF, exceeds traffic capacity of the alternative itself, and the lower QCM accuracy is, the larger is excess. As the level of trust of drivers within the framework of the experiment has a constant value, so TM were moving according to the given plan of redistribution of TF, despite the fact that traffic jam had been formed on the alternative road.

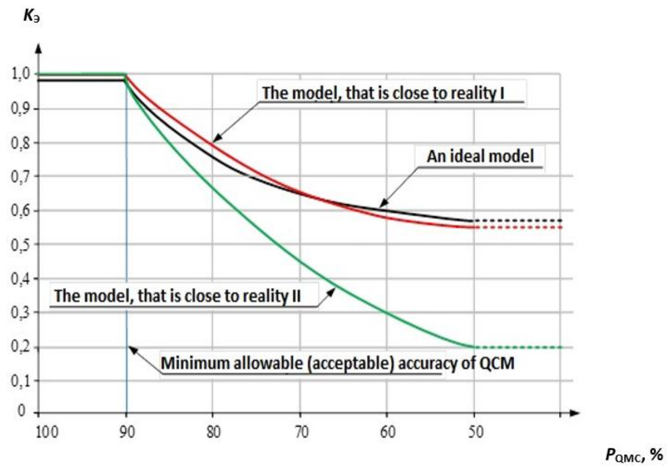

Figure 9. Comparison of charts (graphs) of ITFR efficiency against (versus) QCM accuracy, when it is underestimated

In reality such traffic situation on the road would have caused a dramatic negative impact on the trust level of the road users in the ITFR, which inevitably would have led to a further decrease of the efficiency coefficient. In addition, BSM and the ITFR scripts (scenarios) are being developed on the basis of the level of trust in the system [14, 15]

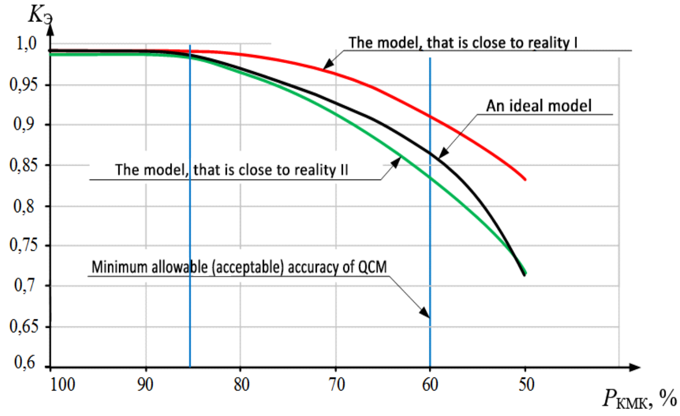

Figure 10. Comparison of graphs of the ITFR efficiency against (versus) QCM accuracy, when it is overestimated

Since the results of studies of the graphs, where the ITFR efficiency coefficient was plotted (was shown) against (versus) QCM accuracy during its underestimation, were obtained before conducting further research, it was decided to continue further work on the basis of data, which made it possible to perform two tasks simultaneously and save time resources (to combine the study of the impact of the overestimation of the QCM on the effectiveness of the ITFR systems and the application of the principle of recalculation QCM).

It should be mentioned, that if we take into consideration the results of recalculation of QCM, so the highest level of efficiency and effectiveness of the ITFR systems is achieved, when QCM accuracy is not lower than 85%. After the mark of 85% for all simulation models a decrease of the coefficient of efficiency of the ITFR can be observed, which is connected with increasing error (overestimation) of QCM. This is due to the incomplete implementation of possibilities of alternative routes, i.e. the road capacity of alternative routes exceeds demand for the road capacity, which is formed with a help of the redistribution of TF. Such situation does not have a negative impact on the trust level of the road users and participants of road traffic in the ITFR systems, that is why further reduction of the effectiveness of the ITFR systems is not foreseen and expected (in contrast to the situation with underestimation of QCM), on the contrary, after implementing of the ITFR the possibility of taking measures, aimed at enhancing the effectiveness of the ITFR (e.g. correction of the content of BSM and/or the scenarios of the ITFR [18]), is created and provided. Despite the fact that the value of the minimum allowed QCM accuracy can not be found and identified unambiguously on the graph, comparison of the characteristics of the level of service allowed us to come to the conclusion that the investigated value under consideration is equal to 60%.

CONCLUSION

An application of the developed principle of correction of the accuracy of QCM allowed us to reduce the values of minimum necessary accuracy of identification of traffic movement routes of TM from 90% to the level of 60% without any significant loss in efficiency of indirect regulation of transport means. Thus, the results of the study allow getting real correspondence matrixes of traffic flows without the use of different models at the present stage of development of road infrastructure, which will allow us to avoid or minimize the amount of errors, which are inevitable due to the inaccuracy of the models. Features of some models of creation of correspondence matrixes are described in the scientific works of such outstanding scientists as Xinwei W, Ning Z., Zhou X., Mahmassani H., Lo H., Zhang N., Lam W. [4, 5, 6]. If we take into consideration these studies, we can conclude that there are many algorithms of generation of the matrixes of traffic flows nowadays. However, they have a number of conventions, which are valid within the design of the automated traffic control and regulation systems, but within the framework of functioning of the systems of indirect traffic flow regulation these data errors can lead to extremely negative consequences [1, 15, 16]. Besides, the use and application of real correspondence matrixes will provide us with an opportunity of an accurate and up-to-date assessment of the implemented scenarios of regulation and control of transport flows and, consequently, will allow us to correct these data scenarios faster and more rapidly.

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