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Definition of Accuracy of Qualitative Correspondence Matrixes for Indirect Traffic Flow Control and Regulation

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Abstract

The notion of qualitative correspondence matrixes is defined and revealed in this article. They are considered to be one of the key elements of the technology of indirect traffic (transportation) flows control and regulation and provide the basic source data not only on the level of designing and constructing the systems of indirect control and regulation of transport (traffic) flows, but also at the stage of their operation and functioning. This article also identified dependency of reliability of qualitative correspondence matrixes on the accuracy on the accuracy of the equipment and the method of its placement on the street-road (highway-road) network and the areas of application of the obtained relationships (dependencies) were identified. The aim of the research is to develop the method of defining accuracy of qualitative correspondence matrixes for an indirect control and regulation of traffic flows within the framework of an indirect control and regulation of traffic flows. Aiming at identification of transport means, the method of graphic recognition of state registration plates (signs) with a help of the road infrastructure was used, by doing so, accuracy of identifying the route of transport means (vehicles) can be found and identified with a help of Bernoulli’s formula. The obtained results can be used for feasibility (techno-economic) study of introduction of the systems of indirect traffic flows regulation during performing of the tasks of design and assessment of the effectiveness and efficiency of system operation and functioning.

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

INTRODUCTION

The subsystem of control and regulation of transport flows is one of the most common and wide-spread subsystems of intelligent transport systems. It is divided into two types according to the principle of functioning and operation, such as: a policy control and regulation of transport flows (PTFR); an indirect transport flows regulation (ITFR).

The essence of PTFR principle is in non-alternative restrictions on traffic flow by means of traffic lights, signs, and road traffic rules (RTR), etc. Operation and functioning of ITFR is performed by motivation and stimulation techniques for choosing the most effective directions in current circumstances and conditions, with the possibility of adopting alternative solutions, concerning the direction of traffic. In the framework of the ITFR system the interests of road users and road traffic participants (RTP), connected with the reduction of time passage through a given stretch of road traffic, coincide with the interests of the region, organizing movement (traffic), based on the objectives of improving the road crossing parameters with a help of optimization of redistribution of traffic flow on the highway-road network (street and road network, urban transportation network) (UTN). [1]

The process of developing the system of ITFR is a rigorous sequence of global challenges and tasks, such as:

(1) an identification of a location of a stretch (part of the road) of UTN;

(2) ITFR technology development;

(3) a preliminary identification of the location of dynamic bulletin board installation (DBB);

(4) development of technical requirements for the DBB;

(5) the final definition of the area of installation of the DBB;

(6) the calculation of the indicators of ITFR system functioning efficiency;

(7) the correction of the technology (with unsatisfactory indices of efficiency indicators) (Figure 1).

The scientific works and researches of such well-known scientists as: S. Zhankaziev, A. Vorobyev and Tour are dedicated to the descriptions of the solutions to the problems, connected with ITFR system design. The scientific papers of the authors, mentioned above, reveal key aspects of an indirect control and regulation, such as: physical and functional architecture and structure of the system, instruments and tools of identification of the most rational areas of informing the participants of traffic and the most appropriate parameters of the means of providing them with necessary information, based on psychophysiological aspects of drivers [1-4]. However, an important part of the technological component, relating to information, concerning the routes of movement of various transport means (vehicles), has not been thoroughly described and analyzed in these works yet.

In the world practice the majority of the solutions of ITFR are arrived at and checked with a help of simple correspondence matrixes of transport flow (TF), obtained either by means of different mathematical models on the basis of data about the intensity and the redistribution of TF at the intersections (junctions) of the stretch of UTN, or with a help of social surveys. This is reflected in detail in the scientific works of such scientists as: Li Yang, Roland Hostettler, Viktor Bernhardsson, Björn Johanson, Wang C. (Carter Robert Ren-Deh), Mathilde Simon [5-10]. TF intensity and the parameters of TF redistribution serve as the criteria for the assessment of the accuracy of these models, however, this approach has a significant drawback, that is its inability of defining and identifying the routes of movement of vehicles, i.e. transport means (TM), if there is at least one border crossing to the main road and at least one exit (ramp) after this border crossing. In some cases this shortcoming will not matter: presence of one object of attraction (AO); presence of no more than one alternative route; presence of multiple AO with a united alternate route.

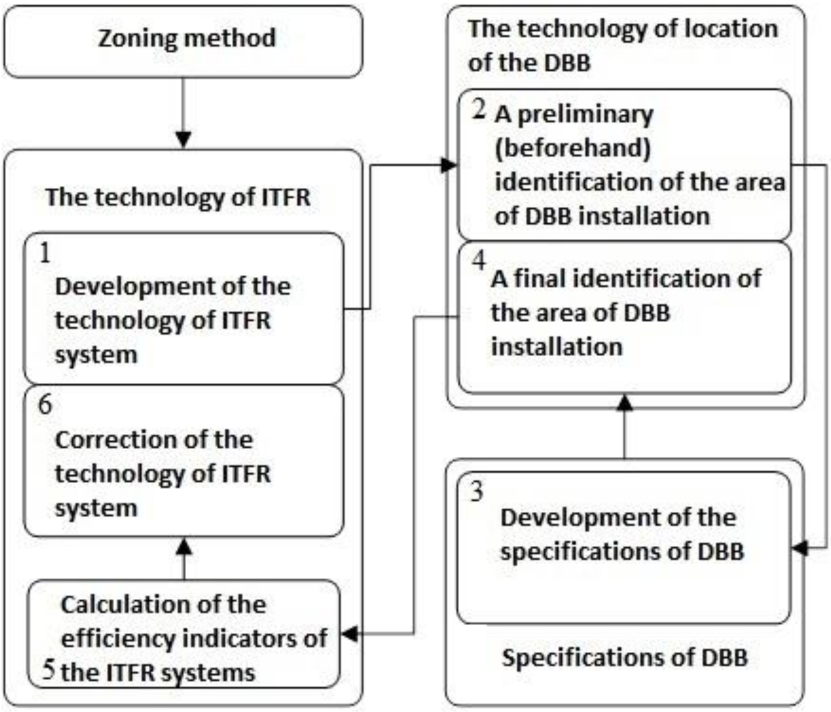

Figure 1. Process of ITFR system development

Information, concerning the routes of TM movement, as a part of the technological component of the ITFR system, is called a qualitative correspondence matrix (QCM) (Figure 2) [10]. The main difference of the QCM from simple correspondence matrixes is that it contains information not only about the origins, as well as, about AO and the TF parameters, connected with them, but also provides us with information about the main routes of TM movement and quantitative characteristics of TM, which use these routes. Consequently, the aim of this scientific article is to develop the method of identification of accuracy of qualitative correspondence matrix for the indirect transport flow regulation and control.

MATERIALS AND METHODS

The following operations are carried out with a help of QCM:

1) development of an exact matrix of objects attraction (MOA) - an array of lists of the main objects of attraction of transport flows (run-offs), situated within

the borders of the area of dissemination of an ITFR system, indicating their lifetime, value and nature (outbound or transit) of traffic flow;

2) establishment of the bank of standard messages (BSM), which is a hierarchical list of standard message templates, updated for disseminating (zones) of the ITFR system and places of providing information about UTN.

3) preliminary identification of locations of informing of the UTN.

Thus, QCM turns out to be one of the key aspects of the technological component of the ITFR system.

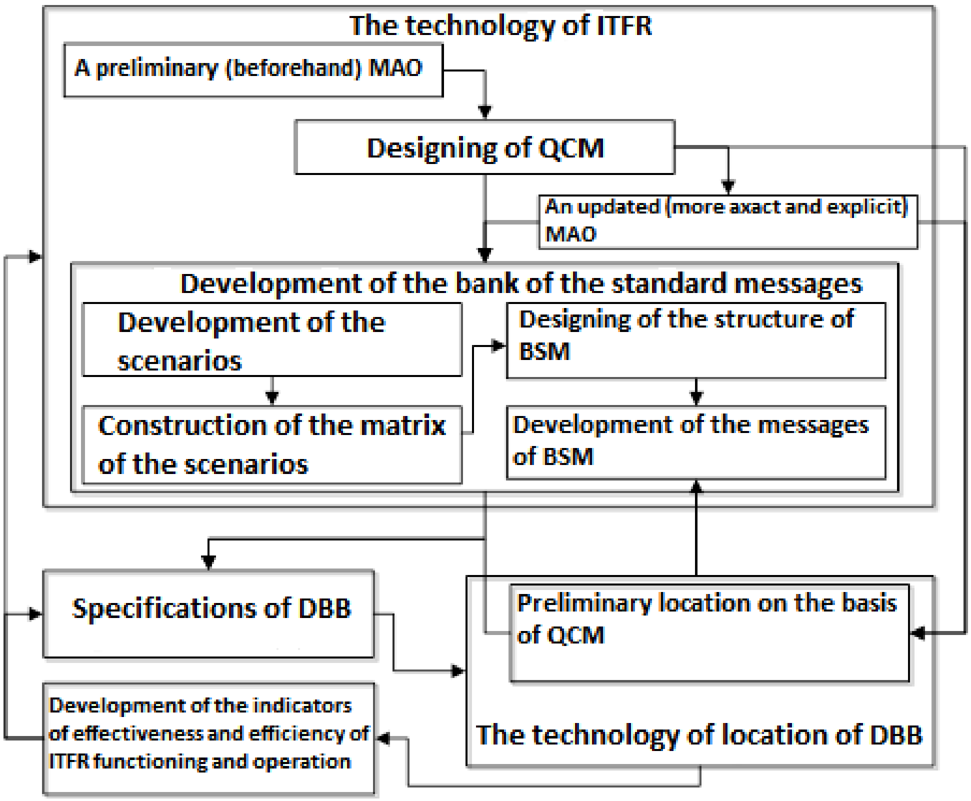

Figure 2. The scheme of the process of ITFR system design [4]

Nowadays the graphical recognition of state registration plates (SRP) with a help of road infrastructure is considered to be the most available method of TM identification.

A TM identification by means of the road infrastructure is a random independent testing, and in this case a successful TM identification is considered to be an event, which probability is equal to accuracy of the equipment. Independence of testing is determined by the fact that the result of TM identification on the same road stretch (part) has no impact on the likelihood of a successful TM identification at other parts of the road [11, 12].

RESULTS

Bernoulli's formula should be chosen as the basis for the calculation of the minimum accuracy of the routes of TM movement:

$$P_n(i) = C_n^i \cdot p_{bl}^i \cdot q_{\mathrm{bl}}^{n-i}, k = 0 \dots n, \quad (1)$$

where n – denotes a total number of identification units (IU), located on the route; (i) – denotes the number of IU, where a TM was identified; $P_n(k)$ – a probability of detection of any IU of n on k; $C_n^i = \frac{n!}{(n-i)!\cdot i!}$ – is a number of combinations of i recognitions out of n IU; p_{bl} – denotes IU accuracy; q_{bl} – denotes an IU error; $q_{bl} = 1 - p_{\mathrm{bl}}$.

Moreover, the rule of a full and complete group is usually observed for each route, i.e. the sum of all possible combinations of successful TM identifications are equal to 1:

$$P_n(0) + P_n(1) + P_n(2) + P_n(3) + \dots + P_n(k) = 1. \quad (2)$$

It should be noted that Bernoulli's formula can be applied only if the accuracy of TM identification on each IU is identical. At the stage of operation of ITFR system fulfilment of the condition of equal accuracy of TM identifications on all IU is next to impossible and highly improbable, at all, so, the current minimum QCM accuracy should be identified by means of the theorem of multiplication of probabilities, as well as the rule of a full (complete) group within the borders of the routes of TM movement:

$$P_n(0) + P_n(1) + P_n(2) + \ldots + P_n(n) = 1; \quad (3)$$

$$P_n(0) = q_1 \cdot q_2 \cdot \ldots \cdot q_n; \quad (4)$$

$$P_n(1) = p_1 \cdot q_2 \cdot q_3 \ldots \cdot q_n + q_1 \cdot p_2 \cdot q_3 \cdot \ldots \cdot q_4 + \ldots + q_1 \cdot q_2 \cdot q_3 \cdot \ldots \cdot p_n; \quad (5)$$

$$\ldots$$

$$P_n(n) = p_1 \cdot p_2 \cdot \ldots \cdot p_n. \quad (6)$$

An unsuccessful identification at least on one IU is the cause of impossibility of constructing a complete route of TM movement, and accuracy of the route of TM movement is calculated due to the identification and definition of the probability of successful identification on all IU, where TM were moving:

$$P_{м} = P_n(n) = p_{bl}^n. \quad (7)$$

When a TM identification is faulty and unsuccessful, in some cases there is the possibility of partial building of the routes:

A) if the TM could not bypass the section of the road, on which it has not been identified (Figure 3A). In this case the value of accuracy is equal to the probability of the unsuccessful identification only on the IU under consideration. In this case the accuracy of identification of the route can be defined in the following way:

$$P = p_{\text{bl}}^3 + q_{bl} \cdot p_{\text{bl}}^2, \quad (8)$$

where $q_{bl} \cdot p_{bl}^2$ – denotes the probability of the unsuccessful identification only on the marked IU.

B) if one or more IUs is also located (Figure 3B) on the detour (circuit, rounabout way) of the road stretch (section), where the TM identification has not taken place and neither of them has had a successful identification of the TM under consideration. In this case, the value of accuracy is equal to the product of the probability of the successful identification of IU, installed on detour, into the probability of the unsuccessful identification only on the IU under consideration. In this case the accuracy of identification of the TM route can be defined in the following way:

$$P = p_{bl}^3 + p_{bl} \cdot q_{\text{bl}} \cdot p_{bl}^2. \quad (9)$$

C) if an unsuccessful identification cannot affect the process of route identification, i.e. the route of TM movement will be obvious (Figure 3B). In this case, the accuracy, as well as in the first case, is equal to the probability of the unsuccessful identification only on the IU under consideration:

$$P = p_{bl}^4 + 2 \cdot q_{bl} \cdot p_{\text{bl}}^3, \quad (10)$$

where $q_{\text{bl}} \cdot p_{\text{bl}}^3$ – is the probability of the unsuccessful identification only on the marked IU; 2 – is the coefficient that determines the number of cases that might take place in the framework of the route under consideration.

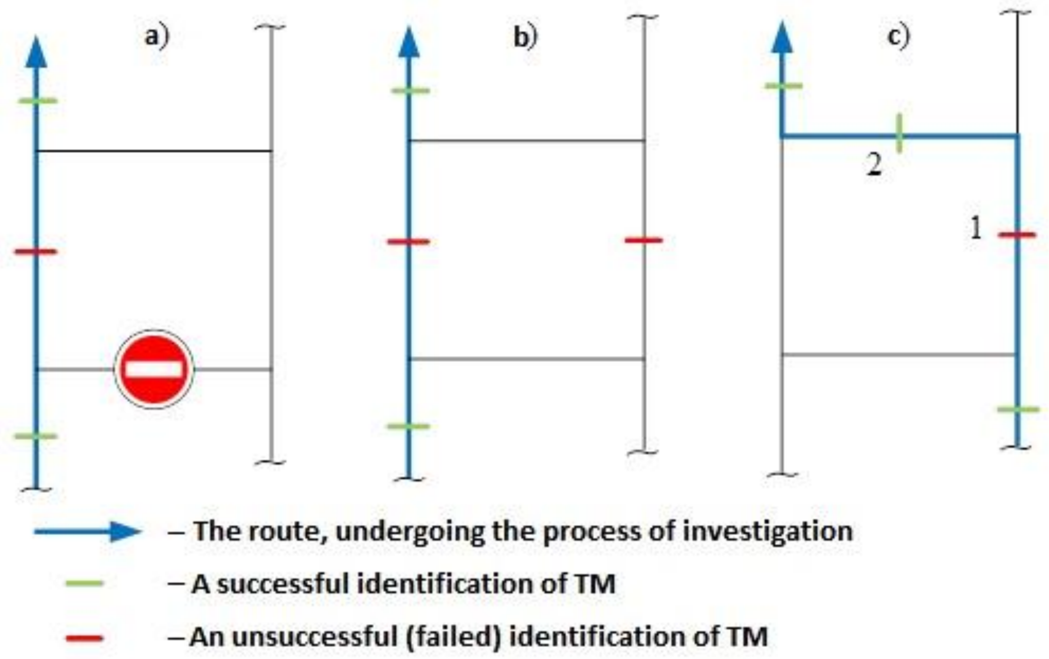

Figure 3. Examples of identification of the routes

The described variants of route identification obey one law:

$$P = p_{\text{bl}}^{n} + \alpha \cdot k \cdot q_{\text{bl}} \cdot p_{\text{bl}}^{n-1}, \quad (11)$$

where α – is a share of TF, which can be identified and which is equal to the probability of a successful recognition of the TM at least on one IU, located at the detour (if there are several variants of the detour, we take into consideration the one, where the smallest number of IU is located); k – is the coefficient, that indicates the number of possible identical cases; $q_{\text{bl}} \cdot p_{\text{bl}}^{n-1}$ – denotes probability of failure (unsuccessful, faulty) identification only on one IU.

An unsuccessful identification may not be fulfilled on the stretches and sections of the roads, where AO and the source of TF are situated and leads to the inability to build a complete route, thus increase of accuracy on such stretches of the roads depends only on the technical characteristics of the identification equipment, and it matters, how it is set (errors of graphic recognition, connected with vertical and horizontal angles of inclination, as well as the angle of a heel (a careen)).

Thus, the minimum guaranteed accuracy of the route is as follows:

$$P_{\text{м}} = P_n(n) + \alpha_1 \cdot k_1 \cdot P_n(n-1) + \alpha_2 \cdot k_2 \cdot P_n(n-2) + \cdots + \alpha_m \cdot k_m \cdot P_n(n-j). \quad (12)$$

For each section of the road there might be various conditions of identification on the detours (circuits, roundabout ways) (a different quantity of IU and, consequently, different values of α and (k)), in this case the dependence has the following form:

$$P_{\text{м}} = P_n(n) + \alpha_1 \cdot k_1 \cdot P_n(n-1) + \alpha_2 \cdot k_2 \cdot P_n(n-1) + \ldots + \alpha_m \cdot k_m \cdot P_n(n-1) + \alpha_1 \cdot k_1 \cdot P_n(n-2) + \alpha_2 \cdot k_2 \cdot P_n(n-2) + \ldots + \alpha_m \cdot k_m \cdot P_n(n-j) + \alpha_1 \cdot k_1 \cdot P_n(n-j) + \alpha_2 \cdot k_2 \cdot P_n(n-j) + \ldots + \alpha_m \cdot k_m \cdot P_n(n-j) = P_n(n) + \sum_{j=1}^{n}(\alpha_1 \cdot k_1 \cdot P_n(n-j) + \alpha_2 \cdot k_2 \cdot P_n(n-j) + \ldots + \alpha_m \cdot k_m \cdot P_n(n-j)) \quad (13)$$

It is possible to identify some regularities and laws in this dependence, which gives the opportunity to write it in the following way:

$$P_{\text{м}} = P_n(n) + \sum_{j=1}^{n}(P_n(n-j) \cdot \sum_{m=1}^{n}(\alpha_m \cdot k_m)) \quad (14)$$

where m – is the quantity of IU, located on the detour; $\alpha m = 1 - qm$ – is the likelihood (probability) of a successful identification at least on one of m IU; $Pn(n-j)$ – denotes probability of a failed, unsuccessful identification simultaneously on j IU only for one combination of j of IU of n; km is a coefficient, denoting the number of combinations of considered αm and $Pn(n-j)$.

DISCUSSION

The dependence, which was found in the process of our research, includes three parameters: the accuracy of route identification (Pn); the accuracy of the IU (p_{bl}); the way of arrangement of IU. Therefore, provided that the minimum allowable accuracy of identification of the routes of TM movement is known, it becomes possible to solve the following tasks:

– identification of minimum accuracy and options of location ща the IU on the section (stretch) of UTN under consideration, aiming at achievement of the minimum necessary accuracy of the QCM. This problem occurs in the process of designing of new systems, when only the required accuracy of the QCM is set.

– identification of minimum guaranteed accuracy of the QCM, which can provide the IU, installed on UTN. It is used for an identification of possible implementation of ITFR on the basis of QCM, derived from installed equipment. The challenge arises during the implementation of the ITFR system on the section and stretch of UTN, where the identification of the TM is conducted, for example, the systems of photo and video-fixation of violations of laws and rules of urban road traffic and transportation systems are installed (the accuracy of the IU and their placement on the UTN are known);

– identification of minimum accuracy of IU with given (preset) possible locations of their setting and installation. The challenge occurs in the conditions of limited possibilities of location of IU on the UTN (for example, the prohibition on IU installation and placing, initiated by the federal security services), provided the minimum allowable QCM accuracy and allowed locations of installation and placing of IU are known;

– identification of the most optimal variant of installation and placement of IU on UTN for achievement of specified QCM accuracy with the specified accuracy of IU. The challenge occurs in case of the restriction, imposed on the choice of IU, for example, the conditions of the contract.

CONCLUSION

Therefore, the obtained results possess the following field of application: (1) technical and economic explanation and justification of the implementation of the system of ITFR during the design phase; (2) estimation of efficiency of functioning of the ITFR system during its exploitation [16]. The accuracy of operation and functioning of the ITFR system is directly related to the trust of the users in the system, which in turn directly influences the effectiveness of the functioning of the ITFR system. If you increase the accuracy of the ITFR system up to 30% [13-15], compared to the current level, so, almost triple increase in the efficiency of the operation and functioning can be achieved.

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