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A DYNAMIC MANAGEMENT OF A PUBLIC TRANSPORTATION FLEET

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ABSTRACT. Background: The present paper deals with the problems of a public transportation fleet management in public transportation operators. A management concept is proposed based on a real-time acquisition of parameters of public transportation passenger exchange.

Methods: The relevant research utilised video materials documenting the processes of passenger exchange in public transportation. The proposed methodology is based on a dynamic real-time measurement of passenger streams. A characteristic feature of the measurement methodology applied is that the data is collected outside the vehicles, with a CCTV camera used per access point. Demand for the public transportation service are calculated using the image processing.

Results: The derived demand characteristics allow not only an estimation of the magnitude of traffic streams in public transportation but also their qualitative description. Such an approach permits a flexible design of the transportation offer to adapt to the demand. This allows matching the timetables to the density functions describing the demand for public transportation within the space of transportation networks. In addition, based on the results of this type of research, a public transportation operator may despatch the vehicle base in a flexible way. For each run of a bus or tram fleet, basing on the registered passenger traffic streams, it is possible to rationally despatch the vehicles with suitable capacity.

Conclusions: A system of this type is capable of determining the quality of work of the public transportation. With the ITS systems being introduced still more widely, the proposed methodology allows the design and implementation of dynamic timetables.

Key words: Public transportation, PuT Management, Image Recognition, CCTV.

INTRODUCTION

Despite the fact that the sustainable development of transportation has been a policy promoted since almost 30 years, the public transportation itself is still in recession [Our Common Future. Report of the World Commission on Environment and Development 1987], [White Paper 2001], [White Paper 2011], [Sierpiński 2012]. The results of the studies of the modal split in transportation indicate a slow but steady increase in the number of trips carried out by individual transportation [Karoń et al. 2009]. According to these authors, a fundamental problem in this context is the increase of the gap between the supply of services offered by the public transportation operators and the demand for these services. The gap exists both in the qualitative and the quantitative domain. A number of factors affecting this situation exist. One of the key ones is the increase in the mobility dynamics of the contemporary societies. On one hand, an allocation of traffic generators and absorbers within the urbanised areas has been noted (due to the socio-economic changes). On the other hand these changes are accompanied by the significant changes to the individual and group transportation-related behaviours of the population (working time, number of places of

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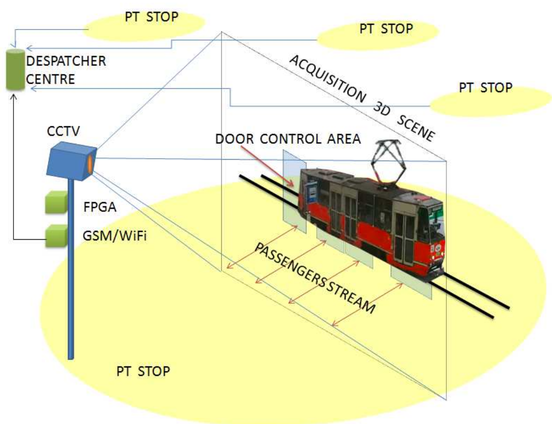
employment, forms of recreational activities, the suburbanisation processes, etc.) [Celiński and Sierpiński 2012]. Their negative effect (from the point of view of the bodies responsible for traffic management in transportation networks) is the resultant drastic increase in the time and spatial non-homogeneity of traffic streams (taking place in Poland since 1989). A non-flexible supply of the public transportation based on the timetables planned for months in advance caused the increase of dichotomy of the characteristics of the supply and demand processes in public transportation. Such a situation causes the clients of the public transportation to be 'pushed away' i.e. driven towards the purchase and use of the means of individual transportation. Such a scenario has realised itself in the US in 1950s and 1960s and the results of that are still observed in the American society [Klein 2008]. According to these authors reasonable tools exist allowing a harmonisation of the supply and demand in public transportation. The goal of the balancing of transportation should be a harmonisation of the transportation offer with the associated demand achieved through the available technical means (such as telecommunication systems, ITS, etc.). The alternatives, in the forms of soft and hard instruments of transportation policies are often too costly or misaligned with the subjective interests of specific social groups. The present paper covers the topic of a construction of a system allowing the public transportation fleet management aimed at a harmonisation of the supply and demand in public transportation. The goal of the construction of such a system is increasing the share of the public transportation in the modal split (the distribution of the transportational tasks). This goal is to be achieved by maximising the match (harmonisation) of the characteristics of passenger stream requests (raised to the service streams) at the public transportation stops (PT stops).

A MEASUREMENT SYSTEM AND THE PROJECT METHODOLOGY

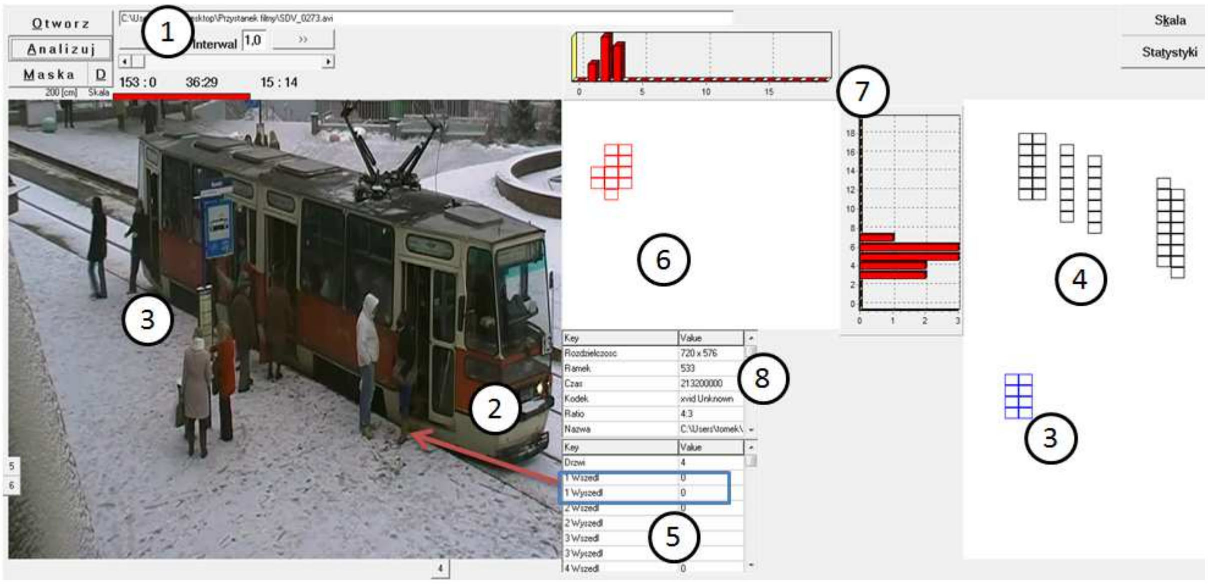
A system balancing the supply and demand sides of a public transportation system should in principle be provided with two kinds of functionalities. The first one is a large flexibility in measuring the characteristics of the request streams. The other is the ability to operate in real time. An important feature of the system should be its portability and the function of wireless communication with the public transportation operator's control and despatch centre. Existing measurement systems, counting the numbers of passengers either inside the means of public transportation or at the entries of the mass service channels (such as tunnels, stations or PT stops) do not meet the above criteria (are not flexible as far as the measured characteristics are concerned, both in the qualitative and the quantitative aspect). For this reason it is proposed that a system balancing the supply and demand sides of the public transportation should be based on CCTV. As an assumption, such a system should handle the measurement of the process of passenger exchange in the means of public transportation using one or two CCTV cameras per PT vehicle. A diagram of the relevant measurement system at a single access point of a public transportation line has been shown in Figure 1.



Source: Own research

Fig. 1. Measurement system diagram
Rys. 1. Schemat systemu pomiarowego

The system as presented in Figure 1 contains a set of CCTV camera (1 or 2 per one direction/platform edges) - FPGA module (in destination systems) - GSM (WiFi) module at each access point of the public transportation network. FPGA module (Field Programmable Gate Array) is responsible for the processing of the image acquired in real time. The GSM (WiFi) module is responsible for transmitting the processed data in the form of the acquired characteristic of passenger exchange. In practice, the volume of transmitted data is minimal and may well be transmitted as an SMS message. For the basic functionality of the system and for a single service request of a means of public transportation at a service point, the data format may, for example, take the following form: date, time, point_no, relation (direction), vehicle_no, door_no (in/out), exchange_time (as sum of: clearance time, alighting time and boarding time). In practice, as it will be shown further, much more advanced characteristics of passenger exchange may be gathered and transmitted. Within the remit of the present research, due to budgetary limitations, only a stationary system for passenger exchange measurement was used. Instead of using an FPGA and a GSM module, the data was post processed (stationary processing) in a computer application. The main window of the programme is presented in Figure 2. In case of an industrial application, the programme is to be substituted by a fully-fledged FPGA module connected with an MS (GPS) unit.



Source: Own research

Fig. 2. Passenger exchange analysis software
Rys. 2. Program do analizy wymiany podróżnych

The principle of operation of the application is based on the detection of mobile objects (passengers) within a video image recorded in real time. Field 1 (number in circle on Figure 1) allows a selection and download of a file containing the video material recorded at a public transportation service point (Field 8 contains the data on the video material itself: its format, video codec name, scene size, aspect ratio, etc.) By definition, the PT vehicle in such a system stops at the service point at a marker line (in practice, these authors were positioning the cameras). Such an approach allows an automatic selection of a programme mask for the zones in which the passenger exchange takes place (the masks are shown in Field 4 in Figure 2). Any movement is detected in the image and displayed in field 6 (any movement is detected, including that in the background of the PT scene). For the purpose of the analysis of the passenger exchange parameters (in order to limit the volume of the data) traffic is only analysed in the areas (zones) defined by the "door" masks. In this way it is only the traffic in the area of the doors of a public transportation vehicle that is analysed (Field 3). Fields 3 (in fact: 2 fields) presented in Figure 2 in the scene image and in the mask image (scale 1:2) correspond to each other (the mask field is a superposition of the scene). The so-called Block 8 of blue squares (Field 3 on the right hand side of Figure 2) corresponds to a passenger leaving through the back door of the vehicle within the scene (left side of the image - real image). The passenger exchange is registered in Field 5 with the assignment to the specific door and to the movement direction (in/out). A case with a larger number of data will be discussed further on. Based on the identified parameters of the moving objects registered in the "door" mask areas and on the results of additional statistical analyses (Field 7) the numbers of passengers getting in and out are counted and assigned to the appropriate doors of the means of transportation (Field 5). A description of the algorithms detecting the passenger exchange goes beyond the scope of the present paper. Based on the known dimensions of the objects on the scene (the height of a passenger, of the door, road sign, a shelter etc.) a user may define a scale for the registered passenger exchange scene. Applying such a procedure in the research process allows investigating the kind-related structure of passenger streams as well as more characteristics. It needs to be mentioned that the proposed system permits an investigation of a kind-related structure with the accuracy corresponding to the measurement scale accepted (e.g. taking into consideration the passenger height and taking into account the perspective-related contraction in individual exchange zones). As a result, the resultant information may be presented as shown in Table 1.

Table 1. The data obtained from the analysis of the passenger exchange scene image analysis (in the transmitted format and in a tabular format).
Tabela 1. Dane otrzymane w wyniku analizy pomiaru zmian pasażerów na obrazach (w formie transmitowanej i tabularycznej)

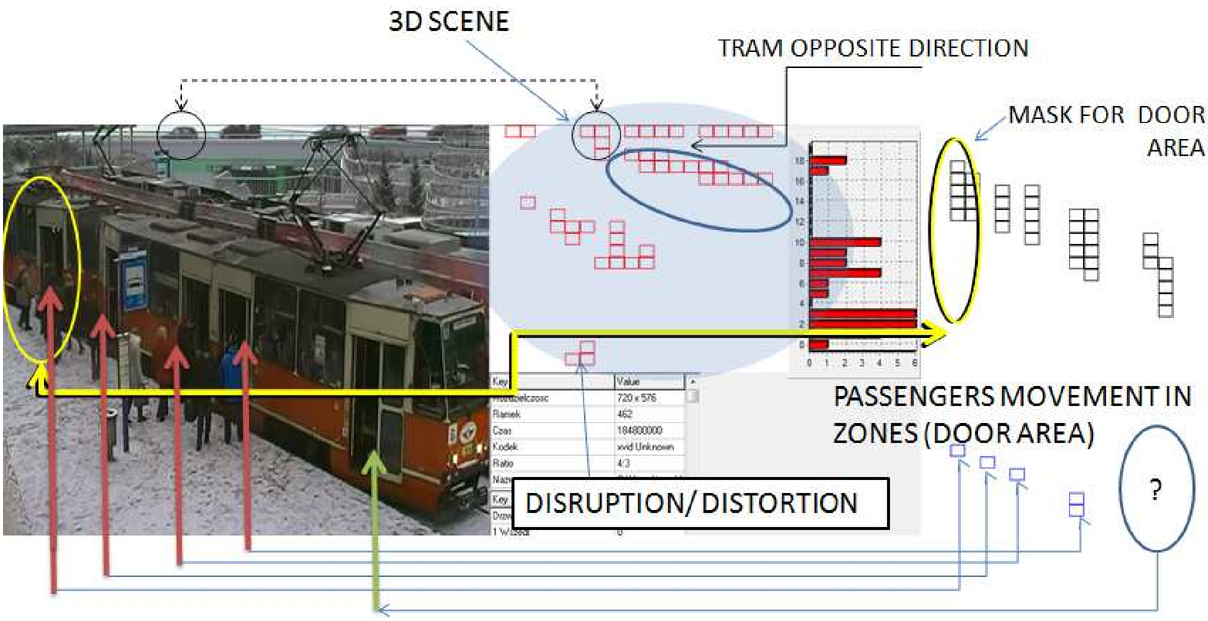
Transmitted format: date, time, point_no, relation (direction), PTvehicle_no, door_no (in/out), exchange_time
06_02_2013/10:01:12/11241/0/634/1(3/2)/2(1,2)/3(0,2)/4(1/1),00:17
06_02_2013/10:11:12/11241/0/841/1(1/1)/2(3,2)/3(3,0)/4(8/1),00:15
06_02_2013/10:21:12/11241/0/34/1(0/2)/2(1,3)/3(0,2)/4(0/1),00:12

Tabular format:

date	time	point_no	relation	PTvehicle_no	door_no (in/out)	exchange_time
06_02_2013	10:01:12	11241	0	634	1(3/2)/2(1,2)/3(0,2)/4(1/1)	00:17
06_02_2013	10:01:12	11241	0	841	1(1/1)/2(3,2)/3(3,0)/4(8/1)	00:15
06_02_2013	10:01:12	11241	0	34	1(0/2)/2(1,3)/3(0,2)/4(0/1)	00:12

Source: Own research

As opposed to the classic (optoelectronic) measurements of the occupancy of the means of transportation and of the number of passengers participating in the exchange, the process itself may be monitored by a single recorder (CCTV) per vehicle/car/set. In practice, from these authors' experience, in case of the sets of vehicles, two or more CCTV cameras should be mounted because of the perspective-related contraction effect (occurring independently from the location of a camera). Compared with the technique of using the optoelectronic sensors mounted in the door area, the proposed process is less sensitive to the presence of residual passengers remaining in the door zones (in Figure 2 a passenger coming on board will remain in the door zone, leaning against the door). Such a case, with a modern vehicle monitoring system, will disable shutting the doors. In the proposed case, the system of recording the passenger flows operates from the outside and is therefore independent from the flows. A number of other parameters, such as passenger height, their speed of moving and other may be recorded in the proposed system. This allows a rough estimation of the type structure of a passenger stream. In practice, the investigated group may be divided into the sub-groups of school youth (7-13 years old), other passengers and disabled passengers on wheelchairs (the width of the wheelchairs is important in these cases). Due to the method of data acquisition the system use, as opposed to the optoelectronic system is not limited to the door area. It is possible to evaluate the exchange processes over a larger area of a service point of a public transportation system, allowing an increase in the quality and the quantity of the observed variables. Figure 3 illustrates the mutual references of the individual acquisition areas (here: broader passenger exchange).



Source: Own research.

Fig. 3. A process of recognition of the parameters of a passenger exchange process
Rys. 3. Proces rozpoznania parametrów wymiany pasażerów

Figure 3 illustrates in a high level form a concept of operation of a passenger exchange identification algorithm at a tram stop Rondo gen J. Ziętka, Brynów direction, tram line no 6. The line is served by Tramwaje Śląskie (regional tram operator) and the tram stop located on the biggest roundabout in Katowice. Due to the perspective-related contraction of the tram in the view, the data acquisition concerns only the passenger exchange process in the first car (head of the set). Visible in the background are the vehicles (cars on the top of figure 3) going around the central island of the roundabout. The algorithm detects even smallest movements at the data acquisition scene (the resolution depends on the parameters of the camera, its settings, the distance from the registered scene, lighting etc.; it may come as high as an order of single centimetres). As a result of such a high resolution the number of events related to moving object detection may be very high (including the detection of pseudo-moves, resulting for example from the vibrations of the ground). To remediate this, exchange zone masks are defined (which may be any part of the frame of the scene but usually are set as the doors outlines). Red squares on a white background correspond to the traffic detected in a scene (the detection area is presented in the scale of 1:2 with respect to the recorded image area). Blue squares correspond to the movements detected in the area of all the doors of the public transportation vehicle concerned (in the scale of 1:2 again). The migration of the moving objects between the exchange areas is detected and processed (a statistical analysis of the data corresponding to the analysed scene) by the movement area data processing algorithm.

A CONCEPT OF A FLEET MANAGEMENT SYSTEM

The presented system of identification of the characteristics of a passenger exchange process is supposed to serve a single public transportation vehicle at a time (potentially, in the future, a single set) at a service point by means of a CCTV-FPGA-GSM set mounted on a street light pole, a dedicated mast, any near located buildings etc. The information returned is a characteristic of the passenger exchange process, including the information on the date and time of a recording, vehicle number, service point number, number of doors, number of passengers boarding and alighting (in/out in Table 1), as well as other parameters. Based on the measurements of the dimensions of the identified objects, the registered exchange stream may be categorised as to the types of passengers. This allows an identification of a share of disabled persons in the streams, of people taking cycles on board or carrying oversize luggage (all these may be achieved by proper calibration of the algorithm). In such a system the information is collated in real time as a density function of a number of requests registered in time on the territory of the transportation network monitored by that system. In this sense a timetable may be adapted dynamically so that it matches optimally the needs for transportation service requested in a specific inhabited area. By engaging flexible scheduling systems the supply of the means of transportation may be matched to suit the process. The supply is delivered JIT (just-in-time) and at a quality level adequate for a required standard of service. Apart from balancing the supply this also leads to the savings in the means of transportation (in case of observed small or decreasing demand) as well as to the increase of the quality of service (in case of high observed demand or of the increase in the demand). In case of such a methodology the dispatching system is reduced to assigning the fleet items to the extreme values of the passenger exchange density function at service points. A more detailed discussion of this problem goes beyond the scope of the present paper. It is worth mentioning that in the Polish contemporary legal system a function of dynamic adaptation of timetables goes beyond the definition of a public transportation (being: 'a universally available regular transportation service for the people, performed at specified time intervals and on a specified one transportation line, several transportation lines or over a transportation network' Dz. U. 2011, nr 5, pos. 13). Some experimental deviations from the definition (such as for example the Telebus service in Krakow) have been noted.

An added value is in this case is the passenger exchange observation process itself, related to singe door of the means of transportation. A study of the characteristics of this type allows an optimal selection of the available means of transportation related not only to the technical parameters of the infrastructure but also to the characteristics of the request stream. The described system allows also collecting the data for design and construction centres where modern means of transportation are designed.

DISCUSSION AND CONCLUSIONS

Is the passenger exchange measurement system described in the paper a rational one? Firstly, it needs to be stressed that the number of service points may be higher than the number of vehicles in the fleet. In this context, the number of measurement points mounted at the doors of the means of transportation may be lower than the number of external points (mounted on the poles and masts at the service points, at (PT stops to PT vehicle ratio ca. 4:1). Also, a cost of a CCTV-FPGA-GSM system is higher (in low series production) than the cost of optoelectronic devices mounted at the doors. From this perspective it seems to be more rational to use the optoelectronic solution. Any comparison should, however, take into account a much higher flexibility of the system based on CCTV (and of course one should remember that even such a system may also be mounted above the vehicle doors).

A system based on CCTV provides a much higher number of data allowing an identification of structures of passenger streams and covers a much wider area. Such a system allows for example to measure waiting times of passengers at the stops (a function which cannot be implemented in the other PT vehicle system). Also other functionalities, such as security monitoring of the public transportation service points may be integrated into the proposed system (a problem of a throughput of the transmission channels). In addition, the described system allows a diversification (in theory - fully flexible) of passenger streams structures, which is important from the perspective of a carrier or a public transportation operator.

The proposed system is independent from the type of means of transportation. It may be installed on the lines served by buses, trolleybuses, underground (tube), trams or any other means of transportation of high capacity and/or occupancy. As the exchange zones may be set up freely, there is no need for the typical doors to be present. This broad range of features and capabilities makes the system an excellent complement for other instruments of improvement of the mobility in cities (described in [European Platform on Mobility Management], [Sobh et al. 2007], [Sierpiński 2011], [Sierpiński and Celiński 2012], [Toolbox for Mobility Management Measures in Companies]).

At the present moment, the dichotomy between the characteristics of supply and demand on the public transportation lines leads to a non-rational management of the vehicle base (an example has been shown in Figure 4).

Source: Own research (Katowice, 14 of November 2012, 3.47 PM).

Fig. 4. A dichotomy effect of the supply and demand characteristics in public transportation
Rys. 4. Efekt dychotomii charakterystyk podaży i popytu w transporcie zbiorowym

One more functionality of the discussed measurement system is worth mentioning. The system allows a comparison of public transportation related traffic models in a transportation network (this would be possible under the condition of a broad coverage of the system over the network concerned). The knowledge of these models in turn allows an optimization of the routes of public transportation. For example, heavily loaded passenger service points may be converted into multimodal exchange nodes due to achieved maximum seamless effect. The system also eliminates the needs for additional studies of passenger streams, contributing to the better return on investment related to the system installation and maintenance.

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DYNAMICZNE ZARZĄDZANIE FLOTĄ TRANSPORTU ZBIOROWEGO

STRESZCZENIE. **Wstęp:** Artykuł dotyczy problematyki zarządzania ilostanem środków transportu zbiorowego w przedsiębiorstwach transportu publicznego. Zaproponowano koncepcję akwizycji parametrów wymiany pasażerów w komunikacji zbiorowej w czasie rzeczywistym. Przedmiotowa akwizycja odbywa się na bazie wideorejestracji wymiany pasażerów.

Metodyka badawcza: W przedmiotowej metodyce wykorzystano materiały wideo zarejestrowane w trakcie procesu wymiany pasażerów w środkach transportu zbiorowego. Proces wymiany pasażerów rejestrowano z wykorzystaniem kamer przemysłowych CCTV w standardzie PAL. Proponowana metodyka zarządzania ilostanem środków transportu opiera się na dynamicznym pomiarze strumieni ruchu podróżnych. Pomiar wykonywany jest w punktach dostępu do infrastruktury transportu zbiorowego.

Wyniki: Tworzone charakterystyki popytu pozwalają nie tylko na szacowanie wielkości strumieni ruchu w transporcie zbiorowym, ale również na ich jakościowy opis. Tego typu podejście umożliwia elastyczne konstruowanie oferty przewozowej w celu równoważenia popytu na realizację podróży. Ponadto operator transportu zbiorowego, na podstawie tego typu badań, jest w stanie elastycznie dysponować flotą.

Wnioski: System taki może określać jakość transportu zbiorowego. W aspekcie systemów ITS zwraca uwagę możliwość wykorzystania tej metodyki w celu konstrukcji dynamicznych rozkładów jazdy.

Słowa kluczowe: Transport zbiorowy, Zarządzanie flotą, Rozpoznawanie obrazów , CCTV.

DYNAMISCHE FUHRPARK-VERWALTUNG IM MASSENVERKEHR

ZUSAMMENFASSUNG. Einleitung: Der Artikel befasst sich mit der Problematik der Fuhrpark-Verwaltung im Massenverkehr in Unternehmen des öffentlichen Verkehrs. Es wurde ein Konzept der Parametererfassung in Echtzeit beim Passagierwechsel im Massenverkehr vorgeschlagen. Die vorliegende Erfassung basiert auf Videoaufnahmen von Passagierwechseln.

Methoden: Man benutzte in der vorliegenden Methodik die Videomaterialien, die während des Passagierwechsels in Massenverkehrsmitteln aufgenommen wurden. Der Prozess des Passagierwechsels wurde mittels CCTV-Kameras in PAL-Standard registriert. Die vorgeschlagene Methodik der Fuhrpark-Verwaltung basiert auf der dynamischen

Durchflussmessung des Passagierverkehrs. Die Messung erfolgt an der jeweiligen Haltstelle mit Zugang zur Infrastruktur des öffentlichen Verkehrs.
Ergebnisse: Die erstellten Nachfrageeigenschaften machen es möglich, nicht nur die Kapazität des Verkehrsflusses im Massenverkehr zu einzuschätzen, sondern auch eine qualitative Beschreibung anzufertigen. Ein solcher Ansatz ermöglicht eine flexible Erstellung von Beförderungsangeboten, damit man den Bedarf an die zur Reisedurchführung benötigte Kapazität feststellen und deren Sicherung gewährleisten kann. Darüber hinaus ist der Betreiber des Massenverkehrs auf der Grundlage dieser Art von Untersuchungen im Stande, flexibel über einen Fuhrpark zu verfügen.
Fazit: Ein solches System kann die Qualität des Massenverkehrs bestimmen. In Bezug auf die IST-Systeme wird die Möglichkeit der Verwendung dieser Methodik empfohlen, insbesondere dann, wenn dynamische Verkehrspläne zu entwerfen sind.

Codewörter: Massenverkehr, Fuhrparkverwaltung, Erkennung von Bildern, CCTV.

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