dents using various detection algorithms and with traffic meters installed at entrances in order to increase road capacity. They automatically calculate predicated trip times based on the current traffic situation and the information generated on variable speed limit signs and via the Internet [28].

Fig. 3 presents an example of cooperation between ITS and variable speed limit signs during management of road traffic on expressways.

Fig. 3. An example of using intelligent transportation systems for road traffic management through information on variable speed limit signs

Intelligent transportation systems work with systems for automatic detection of accidents using various detection algorithms and with traffic meters installed at entrances in order to increase road capacity.

6. Intelligent transportation systems and their role in road traffic management

Intelligent transportation systems (ITS) refer to information and communication systems that are designed to provide services connected with various types of transportation and traffic management, make it possible to provide users with information and ensure a safe and coordinated use of transportation networks. The scope of application of intelligent transportation systems includes [29]:

– road traffic management systems;

– public transport management systems;

– systems for management of the transportation of cargo and a fleet of vehicles;

– systems for management of road incidents and rescue services;

– systems for managing traffic safety and monitoring the violation of regulations.

Intelligent transportation systems use a number of information and communication technologies such as: the Internet, mobile networks (GSM), traffic monitoring devices (sensors, detectors, controllers, video detectors), TV surveillance equipment (surveillance cameras), weather monitoring and measurement devices and systems, variable message signs, satellite navigation systems (GPS), radio communication systems (DAB, RDS-TMC), geographical databases (GIS) and road databases and electronic cards [30]. Mutual relations and links between the different areas of transportation management and ITS are presented in Fig. 4.

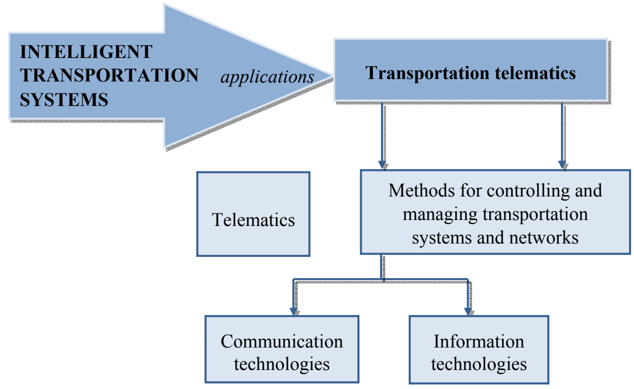

Fig. 4. Components of Intelligent Transportation Systems

In cities, a very important role is played by traffic engineering, especially the management of traffic lights. Appropriate coordination and management improves the flow of traffic (Fig. 1), and can also become an element of integrated systems for transportation management, supporting or working with telematic systems.

The aim of telematic solutions is to automatically obtain, process and properly interpret information, and transmit data in an efficient and cost-effective way, all in real time. The various types of devices and tasks can consist of different systems and sub-systems connected in a network covering the area of a city, region or country. Such solutions are possible thanks to the use of appropriate devices (inductive loops, video cameras) that are connected with controllers and computers to enable a more effective use of road infrastructure. The sub-systems that use ITS are presented in Fig. 5.

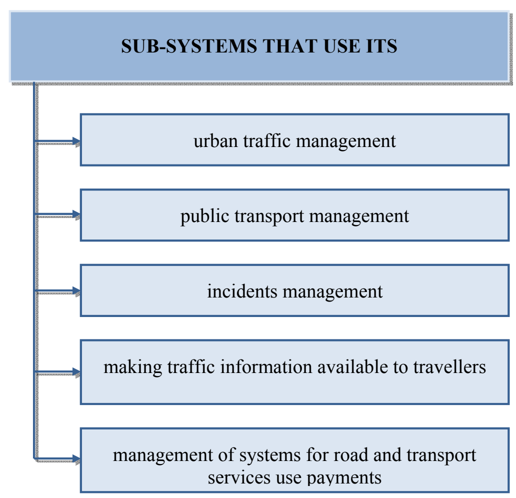

Fig. 5. Sub-systems that use ITS

The term Intelligent Transportation Systems refers to systems that cover a wide range of various technologies (telecommunications, IT, automatic and measurement technologies) and management techniques used in transportation to protect the life of traffic participants, increase the effectiveness of a transportation system and protect the resources of the natural environment [31]. These systems are also designed to provide services connected with the different transport modes and road traffic management, to effectively inform users and ensure a safer, coordinated and intelligent use of transport networks [32]. Among the characteristics of Intelligent Transportation Systems (ITS), it is worth highlighting: integration of technologies, tools and software to ensure an efficient information flow, the system's ability to take independent decisions in different situations, flexibility and hight adaptability – ability to create configurations depending on the needs – and effectiveness understood as universality of benefits.

The characteristics of ITS show that such systems can be a solution to transportation problems in cities and thus successfully support the concepts of urban logistics.

Each subsystem of an ITS system has specific requirements regarding communication channels, which have to match the needs of a specific sub-system, its topology, users, taking into account the costs of both the construction and use of the system. Of importance are also connections that impact financial settlements between road traffic participants, administration and road owners. The key element of these systems is information distributed by various types of communication means. Due to the use of telecommunications and IT devices, these systems are in fact communication and information systems. Therefore, an important issue is information security of Intelligent Transportation Systems (ITS) [33].

Intelligent Transportation Systems (ITS) are created by implementing various interoperating telematic solutions supported by appropriate, dedicated applications. Elements comprising Intelligent Transportation Systems (ITS) are presented in Fig. 6.

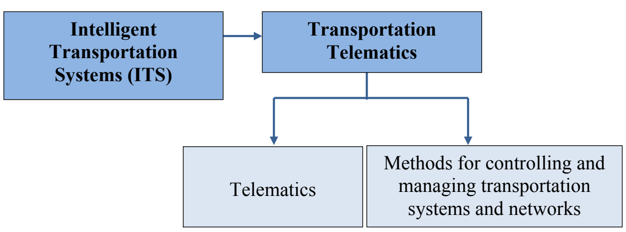

Fig. 6. Elements of Intelligent Transportation System (ITS) (source: own study)

Intelligent Transportation Systems (ITS) constitute a wide range of various tools based on information technology, wireless communication and vehicle electronics. Telematic technologies are located in elements of transportation infrastructure and vehicles. The main aim of such activities is to manage road traffic in terms of management of vehicles, cargo and routes for improvement of safety, reduction of congestions, shortening of travel times and reduction of fuel consumption. The scope of the use of intelligent transportation systems is presented in Table 1.

Intelligent solutions in road traffic management determine the architecture of Intelligent Transportation System (ITS), i. e. a range of (logical, physical and communication) links among the elements of systems established by Intelligent Transportation System (ITS) to create scalable solutions [34]. Very often, different architectures do not indicate specific technologies, thus becoming open systems and increasing competitiveness of implemented solutions.

Table 1

Division of Intelligent Transportation Systems

ITS category	Service Nr	Service name
Traveler information	1	Pre-trip information
	2	On-trip information
	3	On-trip public transport
	4	Route Guidance and Navigation
Traffic management	5	Transportation planning support
	6	Traffic control
	7	Incident management
	8	Policing, enforcing traffic regulations
Vehicle	9	Vision enhancement
	10	Automated vehicle operation
	11	Longitudinal collision avoidance
	12	Safety readiness
Emergency	13	Emergency notification and personal security
	14	Emergency vehicle management
	15	Hazardous Materials and incident notification
Safety	16	Public travel safety
	17	Intelligent junctions

7. Intelligent Transportation System (ITS) in terms of road traffic management

The variety of Intelligent Transportation Systems (ITS) and their uses determines road traffic management in various ways. In urban areas, characterised by high density of road infrastructure, solving the issues of road traffic management through infrastructure development is the least effective approach. The effects will be much more visible in non-urban areas. Intelligent Transportation Systems work very well, among other things, in: traffic management on expressways, the functioning of public transport, etc. Intelligent Transportation Systems can also be used to improve information exchange among drivers, carriers and logistics centres [35, 36].

The benefits of using Intelligent Transportation Systems in terms of road traffic management [37]:

– Increasing the capacity of roads by 20–25 %;

– Improving the safety of road traffic (reduction of the number of accidents by 40–80 %);

– Reduction of travel times and energy consumption (by 45–70 %);

– Improvement of the quality of the natural environment (reduction of exhaust emission by 30–50 %);

– Improvement of the comfort of travelling and traffic conditions for drivers, public transport users and pedestrians;

– Reduction of the costs of fleet vehicle management;

– Reduction of the costs connected with maintenance and renovation of road surfaces;

– Increasing economic benefits in a region.

In order to successfully achieve the above-listed objectives, the process of road traffic management should be based on access to data that arrives automatically and at a proper time interval. Some data has to be available in real time (e. g. alerts, emergency connections, images from cameras). Other data may arrive with little delays.

8. Neural networks in the aspect of road traffic management

The different attributes of neural networks allow them to be used in various elements and modules of an intelligent system for road traffic management. Thanks to the function of classification and recognition, a network learns the basic characteristics of presented patterns, and on this basis makes the right classification decision. Through approximation, a network can act as an approximator of a multivariable function, and association enables a network [38] to remember a set of patterns in such a way that after being presented with a new pattern it will respond by indicating the pattern it remembers that is most similar to the new one. Data grouping, in turn, allows a network [39] to automatically discover similarities in processed data, whereas prediction enables forecasting of future executions or statistical characteristics of a stochastic process. The appropriate neural network architecture is also characterised by low sensitivity to errors in a data set; while in a classical computer programme a data error may lead to completely wrong results, a neural network can ignore such an error. A neural network's ability to work effectively after suffering a partial damage, e. g. removal of a few neurons or links among them, also makes it suitable for use in road traffic management systems.

The characteristic of neural networks that is most often used in road traffic management systems is its ability to predict various traffic parameters, such as capacity, traffic volume and queue length, based on historical data. I generation road traffic management systems use a set of control plans with parameters set off-line based on a given time of the day, taking into account a constant cycle length. II generation road traffic management systems have an online optimisation procedure which uses predicted values of traffic volume 5–10 minutes prior to inputting the calculated control plan.

III generation road traffic management systems enable online optimisation based on the prediction of traffic volume registered 3–6 minutes prior to the selection of a control plan, taking into account a variable cycle length, whereas IV generation road traffic management systems adapt management plans to the current traffic volume rather than to predicted values, or to values predicted within the interval of several seconds.

An example can be road traffic management systems that predict the length of vehicle queues at the next junction using traffic intensity profiles taking into account time losses and vehicles stops, updated every few seconds. Queue lengths are minimised by changing splits, offsets and cycle lengths.

In three-level, adaptive road traffic management systems, the key to the optimisation process is accurate estimation and prediction of traffic flows using three types of detectors. A master unit is responsible for monitoring, diagnostics and supervision of the optimisation of the junction network covered by a system. At a lower level is a master controller. At the lowest level is a local controller.

9. Road traffic management system presented as a model

A model of a modern road traffic management system with the proposed prediction module that uses a neural network is presented in Fig. 7.

In the prediction module, a neural network was used to forecast traffic volume, with the following assumptions [41]:

– measurements of traffic volume parameters at regular intervals constitute a time sequence;

– if the values in such a sequence change cyclically, we can, based on that, predict the value that has not been yet measured at a given moment;

– time window is historical data that can be used to predict another value of the sequence;

– short-term prediction usually refers to one or two values forward;

– long-term prediction covers longer measurement periods.

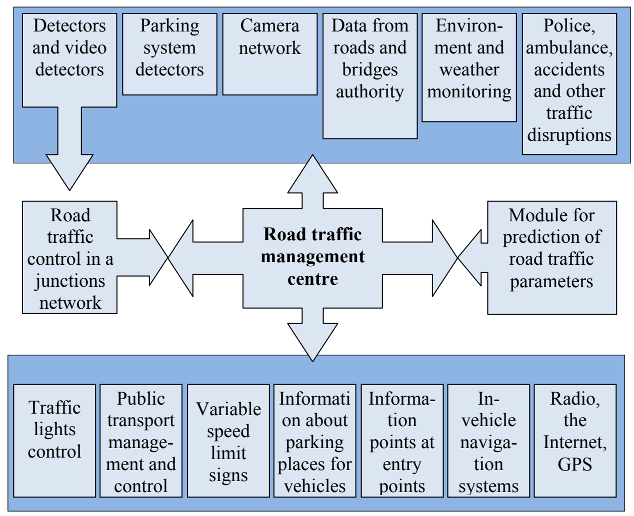

Fig. 7. Diagram of a road traffic management system

The idea of the proposed data prediction using a time window and a neural network is presented in Fig. 8.

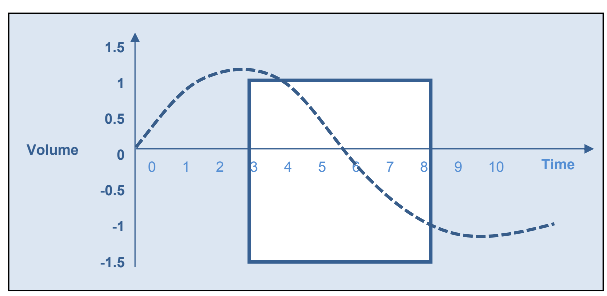

Fig. 8. Time window — input of neural network

A neural network will make it possible to obtain a fast short-term prediction, up to 5 seconds, which has a significant impact on road traffic management. It has been assumed that traffic volume in the location examined on Monday, Tuesday, Wednesday and Thursday will be similar. On Saturday, due to people going shopping to supermarkets, traffic volume will be different than on Sunday. Observations also show that on Friday, due to people going away for weekends, traffic volume is distributed differently than on the other weekdays. Therefore, four neural networks: for Saturday, Sunday, Monday and Friday, have been proposed. Daily cycles were divided into 60-second time windows with a 5-second step, which gives 12 values in total. The training sequence will consist of 1440(24×60) time windows, each with 12 values.

10. Discussion of results of research of traffic management systems using Intelligent Transport Systems and neural networks

The interpretation and discussion of the obtained results makes it possible to draw conclusions and propose solutions in the area of contemporary issues – analysis of intelligent transportation systems that use neural networks with respect to the recommended model of road traffic management. With a view to further research, the most advanced information technologies were characterised and classified, which revealed some of their shortcomings and limitations, especially in terms of basic methodological problems of designing such technologies in the area of planning, control and management. The new prospects and advantages offered by the research concentrate around qualitative methods for supporting design decision-making in the area of management, and possibilities of using neural networks in flexible intelligent transportation systems. Designing flexible intelligent transportation systems attracts continuous interest and currently constitutes one of basic directions of research that is of fundamental importance in the study of engineering and transportation management. The research, though limited, shows that the possibility of road traffic management largely depends on the level of undertaken activity involving the use of neural networks. As the above-presented research results, so different from those obtained by other researchers, show, this requires overcoming quantitative limitations. The need to change the paradigm of perception refers to the design, functioning and management of road traffic using neural networks. This statement takes on a new importance during the shift from the extensive to the intensive phase of economic globalisation. The extensive phase is characterised, among other things, by a simple migration of individual data. However, it can be assumed that in the long run more competitive will be those systems in which innovative techniques of road traffic management have been implemented, thus allowing, among other things, the existing road infrastructure to be used. Such an approach is a characteristic of intensive globalisation, which in the future will prevail over the present one, as the extensive growth possibilities of the existing systems will be exhausted. Thus, this situation imposes new requirements on the forms of flexible intelligent transportation systems, which are one of the tools for increasing the potential of neural networks. Therefore, efforts should be taken to create new forms of prospective directions of road traffic management in line with the evolutionary progress in the area of fully automated ITS. With the complexity of these systems growing dynamically, conventional technologies can no longer meet the requirements of modern civilisation. This leads to decreased control that a human being exerts over the systems they create, which in the area addressed in this paper is manifested in ITS's low tolerance to disruption, considered to be the major disadvantage of such systems. An increase in this control, without the need for a human being to be engaged in each case, as well as an increase in the control over the complexity of systems, without the loss of their functionality, leads to the phenomenon of intelligent transportation systems that use neural networks. A promising path in this regard is to take advantage of the natural paradox of constructing reliable systems from unreliable elements. The above-presented model of road traffic management does not diminish the importance of partial, universal solutions. An example of that is simulation using ITS based on neural networks that can communicate within heterogeneous networks.

11. Conclusions

In the research, the variety of applications of intelligent transport systems in the fulfillment of tasks at the level of traffic management were indicated. Researchers found the application of this system for autonomous vehicles [42]. Good compliance of the measurements made with reality was achieved, and the presented errors are so small that such a solution can be included as an algorithm that can be used in measurements. The study points to qualitative research indicators:

1. Efficiency of applied solutions within the framework of Intelligent Transport Systems (ITS) results in taking system actions aiming at the development of Intelligent Transport Systems. The implementation of Intelligent Transport Systems modules is a solution and a useful instrument for measuring traffic volume, controlling related processes, discovering optimal potentials and internal and external road communication.
2. Intelligent transportation systems refer to a wide range of various technologies that involve communication, information, automatic and measuring solutions and management techniques which are used in transportation to protect the life of traffic participants, increase the effectiveness and efficiency of the transportation system and protect the natural environment.
3. The neural network makes it possible to obtain results for short-term prediction. Therefore, it can be used in traffic management systems, which require the inclusion of an unprecedented parameter for the optimization process, e.g. in the form of intensity or length of the queue. Intelligent transport systems and neural networks are used in forecasting traffic conditions, and decision-makers can use the model proposed by the authors to solve traffic management issues.

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