EKSPLOATACJA I NIEZAWODNOŚĆ
MAINTENANCE AND RELIABILITY

Eksploatacja i Niezawodnosc – Maintenance and Reliability
Volume 24 (2022), Issue 4
journal homepage: http://www.ein.org.pl

Article citation info:
Murawski J, Szczepański E, Jacyna-Gołda I, Izdebski M, Jankowska-Karpa D. Intelligent mobility: A model for assessing the safety of children traveling to school on a school bus with the use of intelligent bus stops. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2022; 24 (4): 695–706, http://doi.org/10.17531/ein.2022.4.10

Indexed by: Web of Science Group

# Intelligent mobility: A model for assessing the safety of children traveling to school on a school bus with the use of intelligent bus stops

Jakub Murawski[a], Emilian Szczepański[a], Ilona Jacyna-Gołda[b], Mariusz Izdebski[a], Dagmara Jankowska-Karpa[c]

[a]Warsaw University of Technology, Faculty of Transport, ul. Koszykowa 75, 00-662, Warsaw, Poland
[b]Warsaw University of Technology, Faculty of Mechanical and Industrial Engineering, ul. Narbutta 85, 02-524 Warsaw, Poland
[c]Motor Transport Institute, ul. Jagiellońska 80, 03-301 Warsaw, Poland

## Highlights

- An analysis of the literature in the area of children travel to/from school was made
- The research procedure for children's travel with the use of IoT was developed
- An original model for the assessment of the children's mobility system was developed
- The developed model was verified on the real example of a children's travel system

## Abstract

The aim of the article is to develop a model for assessing the safety of children's travel. Safety is the most important indicator describing the mobility system of children, even more important than the costs of operating it. Due to the dynamic development of intelligent solutions, it is possible to undertake additional activities supporting the improvement of children's safety when traveling to and from school. However, their implementation requires an adequate assessment of a children's mobility system. Currently, there are no solutions that could comprehensively support the decision-making process in this sphere. The article presents the issues of children's mobility, a literature review in this area, mathematical model for assessing school bus travel, and a computational example. The presented approach is an original solution allowing for evaluation of the existing systems and their development scenarios. In addition, it enables the comparison of children mobility systems of different complexity and scale.

## Keywords

mobility management, safety, transport of children, Internet of Things, intelligent mobility.



## 1. Introduction

Children's mobility is a complex issue and is widely discussed in the literature due to travel safety [23] and children's health [4]. The problem is significant since the number of trips of one child on the route home-school or school-home is approximately 380 times a year, and can contribute to a high traffic volume resulting from the large number of children traveling [24]. Hence, even small changes in the mobility of children can have a significant impact on traffic volumes, air pollution around schools [3] spatial planning [22], environmental impact [41], social conditions [21], economic issues [5], travel planning [16], and children's behaviour in traffic [38] etc.

The decision made by parents on means of transport (e.g. taking a child to and from school in a passenger car) can be impacted by insufficient level of road safety or limited availability of other forms of transport. However, it influences the increase in car traffic, which results in lowering this safety [33]. Therefore, an important issue is to control and reduce the risk in individual areas. This can be achieved by developing models that minimize the likelihood of an accident (e.g. [10]), but also by ensuring the roadworthiness of vehicles from a systemic perspective [12].

These issues indicate the need to develop a comprehensive, integrated children mobility management support system that will ensure the safety of children from the moment they leave home until they return from school [15]. Such a system should ensure the use of school buses and take into account the needs of all stakeholders and users of school transport, i.e. parents (guardians), school representatives, transport providers, municipal authorities and other entities, such as the police or road managers. This means that in order to ensure the proper implementation of school transport and to increase the safety of children traveling to and from school, it is essential to integrate the activities of all the above-mentioned stakeholders and to appropriately define the scope of their duties and tasks.

As shown by statistical data, the interest in the safety of children brings the desired results. Fig. 1 shows the number of road accidents involving pedestrians under the age of 14 in Poland in 2010-2019. As it can be seen, the number of accidents involving children is constantly decreasing, and the level of safety of vulnerable road users is

(*) Corresponding author.
E-mail addresses: J. Murawski (ORCID: 0000-0003-2902-3882), jakub.murawski@pw.edu.pl, E. Szczepański (ORCID: 0000-0003-2091-0231), emilian.szczepanski@pw.edu.pl, I. Jacyna-Gołda (ORCID: 0000-0001-8840-3127), ilona.golda@pw.edu.pl, M. Izdebski (ORCID: 0000-0002-9157-7870), mariusz.izdebski@pw.edu.pl, D. Jankowska-Karpa (ORCID: 0000-0001-5146-4882), dagmara.jankowska@its.waw.pl

increasing. A similar trend is visible in other European Union countries. However, this does not change the fact that the number of accidents involving children pedestrians is significant. For example, in Poland in 2019 there were 723 accidents involving young pedestrians under the age of 14, in which 15 children were killed, 220 were seriously and 504 slightly injured [42]. It is significant that according to the World Health Organization, road transport accidents are the most common cause of death among children over 5 years old [43].

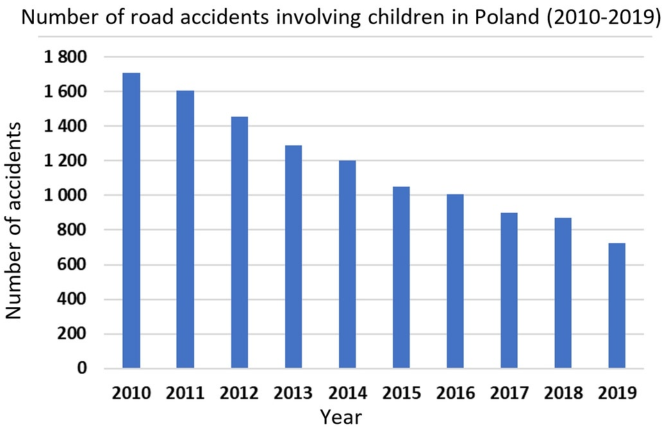


*Fig. 1. Number of road accidents with children pedestrians in Poland in 2010-2019*
*Source: own study based on Polish Road Safety Observatory data [42]*

Taking all of the above into account, according to authors of the article, the improvement of school travel safety is a particularly important issue and requires proper adaptation of the infrastructure and equipping the transport system with appropriate intelligent tools for monitoring children's travel to and from school.

The authors of the article presented a developed proprietary model for assessing school travel safety, considering the equipment with IoT tools. The research covers trips by organized school transport in non-urban areas, however it is possible to adapt the model to children travels made by public transport, as well as by other means of transport or on foot. The presented research is based on the effects of the Safeway2School project [44]. Extending the research would require mapping additional means of transport, taking into account their characteristics, as well as the assessment of integrated transfer nodes presented, for example, in the work of Jacyna et al. [11]. These considerations will be the subject of further studies.

The article is mapped out as follows. Section 2 presents the current state of knowledge broken down by areas related to the research topic. Section 3 presents the concept of the proposed method for using intelligent solutions in children's travel to school. Chapter 4 contains a decision-making model which studies the indicators of bus travel safety, based on the developed concept. The use of the developed concept of the proprietary safety model was verified on the real data of the selected part of the road network, as presented in section 5. The article ends with a summary containing the conclusions of the considerations and indicates recommendations for the stakeholders of the entire process of organizing children's travel to and from school.

## 2. The state of knowledge in the field of safe travel of children to and from school

### 2.1. The choice of transport means for children school travel

The decision on how to arrive to school reflects the highest possible level of safety of a child. This thesis is confirmed by research [39], which shows that for parents who bring their children to school by car, the decisive factors for such a choice were: ensuring the highest possible level of safety and the comfort of travel. Indeed, taking a child to school by car, thanks to the presence of a parent, provides the child with a high level of safety, but on the other hand, this mode of transport has many disadvantages. First of all, the use of a passenger car results in the reduction of physical activity for children, and thus may have an impact on weight gain [27] and lowering the health of children (e.g. increasing the risk of cardiovascular diseases) [4]. Apart from that, the use of a passenger car has a negative impact on the natural environment, is inconsistent with the idea of sustainable development [24] and ineffective from an economic point of view. In the literature, there are also studies indicating that car use has negative social effects, because children spend less time with their peers [21].

Therefore, it is extremely important to develop and implement solutions that improve the safety of children in transport. Thanks to that, it is possible to reduce selected risks associated with other forms of transport than using a passenger car to get to school, and thus the use of other types of transport that can not only ensure the safety of children, but also can have a positive impact on children's health, and not be harmful to the environment [2].

It is worth noting, however, that it is not possible to determine the best means of transport in advance, as this issue should be considered individually in each case. The choice of a given means of transport on a given route is associated with certain risks, which may depend, among others, on the length of the route from home to school, available road infrastructure (e.g. sidewalks and bicycle paths), accessible pedestrian crossings, traffic volume on streets around the school, speed of vehicles around the school, availability of school transport, location of bus stops, spatial development in the school surroundings and many other factors [37]. Moreover, as indicated by the authors [32], an undoubtedly important aspect in the choice of means of transport is the assessment of the accessibility of public transport.

### 2.2. Activities increasing children school travel safety

The organizational and technological solutions can be distinguished among the activities increasing the safety of children in transport,. The most popular forms of ensuring safety for children traveling to school are traffic calming zones on the streets around educational units, which can be classified as organizational solutions. In these zones, various measures are applied to ensure safety of all road users. Different tools are used for this purpose, with reduction of the speed limit being the most common one. The conducted research shows that noticeable effects in terms of increased safety are achieved by limiting the speed to at least 30 km/h [34]. Other solutions used in traffic calming zones around schools include additional horizontal and vertical signage, pedestrian refuge, narrowed lanes, restriction of entry for selected types of vehicles, or additional lightning. Zones of this type may be introduced during the morning and afternoon rush hours, or they may be valid throughout the whole day [2, 18].

An example of a more restrictive measure to ensure the safety of children in road traffic is project "Schulstraße" implemented in Vienna, which closes streets in the immediate vicinity of schools to car traffic for half an hour during the peak morning traffic. The aim of the project is to contribute to the improvement of road safety and to be an incentive to change the means of transport to a more environmentally friendly one, e.g. a bicycle or a scooter. The first effects of the described project are extremely positive, and its implementation is planned by other cities as well (e.g. Wrocław). The "Schulstraße" project is one of several activities implemented in Vienna, which are in line with the idea of Smart City. They can include, among others promoting pedestrian traffic, using facilities for electric vehicles or restricted parking zones [26].

Solutions aiming to improve road safety have been also introduced in Sweden, where in 1997 the parliament adopted the long-term strategy "Vision Zero". It assumes the development and shaping of the transport system in such a way that in the future no one is killed or seriously injured as a result of a road accident. Therefore, all transport solutions are designed in such a way as to ensure maximum safety for all road users. As a result, the number of road accident victims is decreasing annually, and the country's road transport system is considered as one of the safest in the world (9 people under the age of 17 died as a result of road accidents in Sweden in 2019). Despite this, further innovations aimed at achieving the goal specified in the strategy are being implemented. Apart from Sweden, strategies based on "Vision Zero" have also been adopted by among others Denmark, Norway and the USA [1].

The subject of systemic guaranteeing the safety of children on the way to school was the subject of, inter alia, Safeway2School project, funded by the European Commission under the 7th Framework Program. As part of the project, innovative solutions in the field of school travel planning, warning systems for school bus drivers were developed, as well as the formulation of educational programs dedicated to all stakeholders of the school transport system. The developed solutions were tested in pilot locations in Sweden, Austria, Poland and Italy, which made it possible to evaluate their usefulness and effectiveness [44].

The implementation of experimental concepts in operating transport systems is difficult to apply due to the scale and their sensitivity. All modifications and improvements entail high costs and therefore must be preceded by detailed studies on the developed analytical or simulation models. The authors of the work [14] indicate such regularity by presenting the issues of the development of transport systems and decision-making problems related to the issues of the impact of transport on the environment. Impact and evaluation models for transport solutions need to be developed. Świderski et al. [35] presented a transport service evaluation model based on artificial neural networks, while Rudyk et al. [28] proposed an analytical model for assessing vehicle fleet management in terms of safety, which was used to feed the rationality of the simulation model. In case of school transport travels, there is a noticeable lack of a tool allowing for its assessment in terms of safety and a comprehensive approach to children's mobility problem.

### 2.3. Using IoT solutions for monitoring children travels to and from schools

Solutions based on the Internet of Things technology take an important place in the literature on road safety. In trying to define IoT, it can be said that it is a set of physical (real) objects, connected in such a way that they can communicate with each other (send and receive data) without human interference [36]. IoT has a huge potential to be used in many areas of life, including road traffic. As indicated in [6], IoT provides communication vehicle-to-vehicle (V2V) as well as vehicle-to-infrastructure (V2I). Thus, it is possible to ensure communication between cars, which can help avoid collisions [8]. The communication channels provided by the use of IoT technology are presented in Fig. 2. The authors of the work [20] emphasize the great importance of IoT in the development of logistics systems, including external transport, and the potential it has in terms of supervision over the correct implementation of processes and improvement of systems.

As mentioned, the applications of IoT technology in road transport are widely described in the literature. IoT technology can also ensure communication between the vehicle and traffic lights. In [19], a solution is described which, thanks to the use of data from motor vehicles and information on pedestrian traffic, allows functional optimization of road lights. Another possible application of IoT technology is to provide vehicle-to-pedestrian (V2P) communication. For example, [9] describes a technology that allows a vehicle to be warned about an approaching pedestrian and pedestrian (using a dedicated mobile application) about a risk from an oncoming vehicle. Taking into account the above considerations, it can be said that the IoT technology in the future will make it possible to limit or even exclude the role of humans in driving a car, which can contribute to a significant improvement in road safety [40].

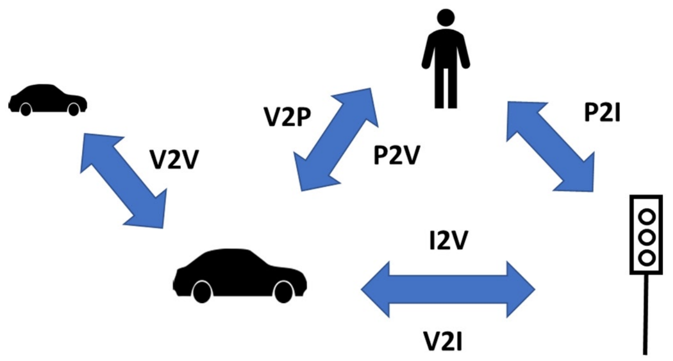


*Fig. 2. Communication channels provided by IoT technology*
*Source: own study*

In the context of the described subject, it is worth emphasizing that the IoT technology is also applicable in terms of improving the safety of children traveling to schools. Among the technological solutions that improve safety of children, there are various types of applications that enable tracking of school buses. As a rule, their operation is based on the data collection concerning, inter alia, school bus location. The data collected on the server is made available to selected stakeholders, e.g. parents, school representatives or transport organizers. In the past, solutions of this type were most often based on GPS technology (as described in [7, 29]) and, slightly less frequently, on passive RFID technology [30]. Commercial applications of this type include TrackSchoolBus app. It should be emphasized that the functioning of the mobility management support system must be based on a properly developed architecture, equipped with devices for collecting and transmitting information, but also on data warehouses allowing for data collection and analysis, as well as transferring information among transport process stakeholders. Such solutions are implemented, for example, in cargo transport, an example of which can be the EPLOS [13] system and its architecture. Similar solutions can successfully operate on a micro scale basis in terms of children mobility management. However, currently the literature lacks examples of a systemic approach covering such a large range of stakeholders who should be involved in the process of children's travel to school.

The use of IoT technology in the field of monitoring school buses opens new possibilities. For example, [25] presents a system that allows the student's absence monitoring, unscheduled stops, deviation from the route or exceeding the speed limit. On the other hand, the solution described in [31] allows for the identification of fuel leakage or control of the temperature inside the bus. Another idea for using IoT technology is for an intelligent bus stop, which was described in [17]. In this case, the bus stop is a closed, air-conditioned unit (stops of this type can be found, among others, in the Persian Gulf countries). Thanks to the use of IoT technology, it allows, among others optimal management of electricity by predicting the occupancy level at the stop, remote control of air conditioning and lighting, and measuring the level of air pollution around the stop. However, there are no solutions that are considered in this article concerning additional control, e.g. lighting of a stop and emitting warning signals for other road users.

Based on the analysis of current knowledge and literature review, it should be stated that it is necessary to conduct research aimed at developing a concept for the development of transport systems with regard to safety issues. In this article, the concept of Intelligent Bus Stops described in [17] was extended and it was planned to integrate IoT technology in the supervision of children's travel to school. Moreover, a proposal was made of an analytical model, based on the existing evaluation models, dedicated to the assessment of the safety of children's travel to school. This model has the potential to be used in simulation models. Considering the dynamic development of IoT technology, it can be expected in the near future that further transport solutions based on this technology will become available, which can bring many benefits to society, also in the context of improving the safety of children on the way to school. Hence, a dedicated model, which is highly flexible and can be expanded with additional elements, will be an important tool in assessing the impact of implementing various concepts and solutions in the field of safety.

## 3. Procedure of the study method in the field of supporting children's travel to and from school with the use of IoT tools

Figure 3 shows a scheme of a mobility system using intelligent solutions (IoT). The basic element of such a system is an intelligent bus stop. It can be equipped with many different elements that improve the safety of passengers, including getting on and off the bus. Such a bus stop can be equipped with additional lighting activated on the basis of reading sensors and beacons or NFC transmitters when a child arrives there (and is equipped with a smartphone application or an additional transmitter). Also, while getting on and off the bus, additional lighting may be activated in the bus stop area, informing other road users about the necessity to become more alert. Allocating unique numbers to transmitters can be used for monitoring the journey of many road users, as well as for collection of data allowing for further improvements in the children's mobility system. Additional equipment may include cameras or photocells.

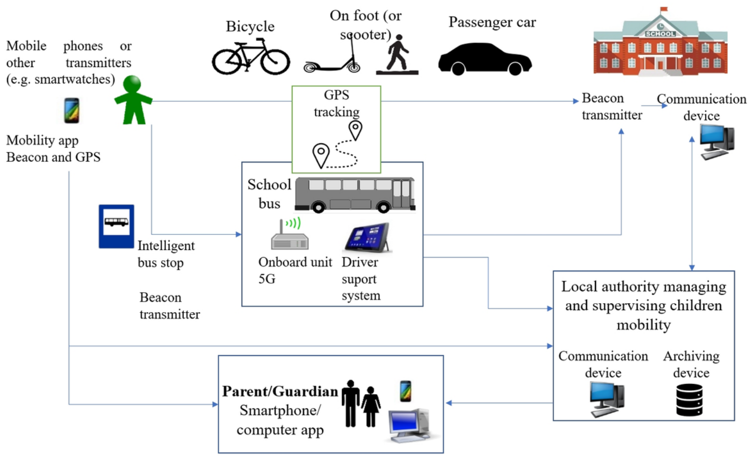


*Fig. 3. Information/data flow in children's mobility management system with the use of IoT*
*Source: own study based on [20]*

The travel process to and from school is similar for each mode of transport. This similarity is mainly expressed in the stages of the journey; however it is superficial. In reality, each way of getting to school or returning home has different characteristics due to elements such as time, comfort, safety and additional travel support equipment. Currently, in most cases this process is not supported by smart solutions. In case of children and adolescents, smartphones play a main role as they allow for communication with the guardians. There are no systemic solutions that integrate communication among children, school, children mobility management office and guardians. With the use of intelligent infrastructure provided by the Internet of Things, it is possible to implement solutions that increase the travel safety and, at the same time, the flow of information, and allow for an increase in the share of independent journeys made by children. Figures 4 and 5 show the different processes of children's travels to school.

As it should be noted, the simplest process and, at the same time, the one in which the share of additional equipment is the

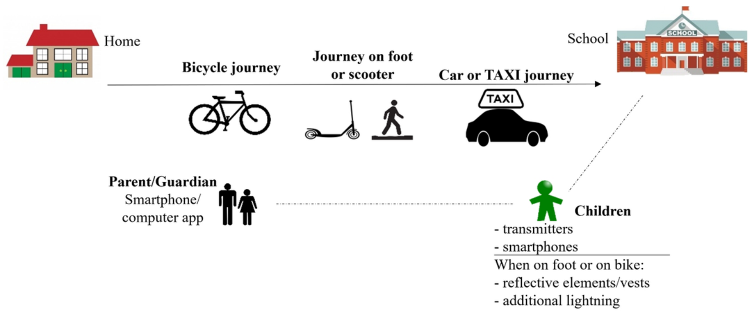


*Fig. 4. Process of school journey by bicycle/scooter/on foot/in car (without public transport)*
*Source: own study*

lowest, is a journey made by a passenger car. A child under the care of a parent/guardian does not need to be equipped with any additional systems. Assuming that the child is brought to school and taken home by the parent/guardian, it remains under the supervision of the parent all the time, thus the level of safety (from the parent's point of view) is quite high. Transmitters (with GPS tracking function) can assist in supervising the child's safety when traveling to school by taxi. Another, uncomplicated process, but with a lower level of safety, is commuting to school by bike or on foot (including a scooter). The child's safety depends to a large extent on the existing infrastructure (e.g. sidewalks, bicycle paths), but also on child's education and awareness levels or additional equipment (e.g. lighting, reflective materials). In this case, equipping the child with a transmitter and automatic notifications sent to school and guardians is desirable.

The most extensive process and at the same time the one in which an extensive system based on the Internet of Things can be used is the child's trip to school by a school bus. Due to long distances to schools, poorly developed infrastructure for pedestrians and cyclists, as well as the route to school leading through dangerous streets and complicated intersections, journeys by this means of transport are often organized by municipalities in the form of organized school transport. Also, parents often choose this mode of transport for their children, which makes it much easier for them to organize their daily activities without having to drive and pick up children from school, and thus the congestion around schools and on access roads remains lower. Therefore, school buses are a good choice for traveling to and from school. In case of this solution, it is possible to use many additional elements, e.g. infrastructural ones, including Intelligent Bus Stops, which can significantly increase the safety of

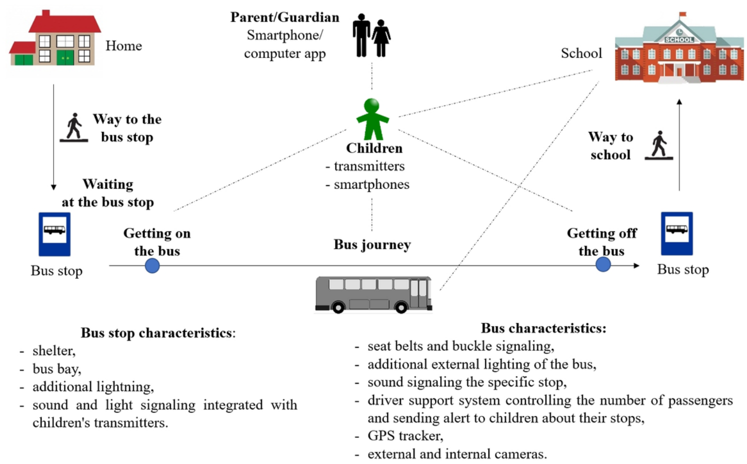


*Fig. 5. Process of school journey by school bus including the characteristics of additional equipment of individual elements of the system*
*Source: own study*

children traveling to and from school. Additionally, parents/guardians and the school representatives can be kept informed of the child's travel status. The use of beacon transmitters enables Bluetooth communication and confirmation of the location of the child, especially in case of weak or no GPS signal, as well as in the absence of a GPS receiver. An alternative to beacon transmitters can be NFC communication, but it is less popular than Bluetooth.

Nowadays, the safety of children traveling to school is one of the most important topics for students, parents, schools, and transport system managers. Due to the increase in the popularity of advanced electronic devices, various transmitters or smartphones, the implementation of solutions improving safety of children is possible with relatively low financial outlays. However, it is necessary to assess the impact of individual elements and its activities on the safety of the children. Therefore, the article proposes a formalized method of assessing children's travel to school by bus as a function of safety.

The study procedure in the field of supporting children's travel to and from school with the use of IoT tools is presented in Figure 6. Within this procedure, 7 stages were distinguished, which constitute a comprehensive approach to the implementation of improvements in the area of children's mobility. This method is universal, and it is possible to implement it in different means of transport, as well as in different areas.

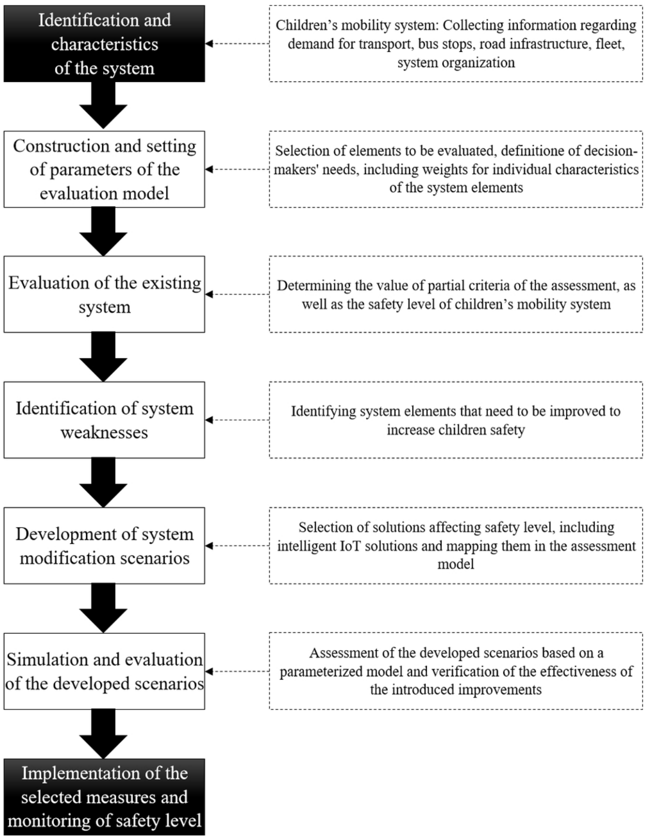


*Fig. 6. Stages and phases of school travel in children's mobility system*
*Source: own study*

The article examines one of the four main means of children transport to reach school, i.e. traveling by organized school bus, due to the high popularity of this mode and also the greatest impact of intelligent systems on this journey's safety. Access to school in the community is considered and it has been assumed there is no other method of traveling to school by any other form of public transport. Travel by public transport is possible in other locations where this kind of transport is organized, i.e. larger towns. The authors focused mainly on the areas where accessibility of public transport is limited and the process of reaching the school is complicated.

## 3. The formalization of the mobility assessment model in the safety function

### 3.1. Model assumptions and system features

The assessment model for decision support of child mobility management will be presented in a systemic perspective, i.e., monitoring children's travel to school in a door-to-door perspective. The model includes an installation of the Smart Bus Stops on the route of school buses and equipping children with special transmitters (or telephones with a dedicated application).

A children's mobility system meets the demand for transporting primary school children from their place of residence to schools. The diagram of such a system, taking into account all stages of the journey, broken down into the phase to and from school, has been presented in Figure 7. Each phase may consist of different stages.

The phase in individual stages can be carried out by various transport means, while phases 2 and 3 are carried out only by the school bus. Phases 1 and 4 are carried out on foot, and phases 1.2 and 3.4 can be carried out by a passenger car (with a parent/guardian or taxi), bike, scooter or on foot. Due to the assumptions mentioned above, the authors considered phases related to bus travel, i.e. 1 and 2 as well as 3 and 4.

Phases 1 and 2 as well as 3 and 4 (the bus journey) are complex and have to include both used infrastructure and assistive devices. In addition, the length of a journey or the number of bus stops will also affect the assessment of a children's mobility system. There may be many travel routes to school in a system.

The described model provides a system assessment for Phase 1 - travel to school. The safety assessment criterion ( $\overline{F_{B\_A}}$ ) was chosen for the mobility assessment. The total assessment of a safety level with the use of the bus will be expressed as follows:

$$\overline{F_{B\_A}} = \overline{F_{B1}} + \overline{F_{Bp}} + \overline{F_{B2}} + F_{B\gamma} + F_{B\theta} \tag{1}$$

It was assumed that a safety assessment will be the sum of 5 components, which mathematical notation is presented in section 4.2. The first three components are directly related to the implementation of stage 1, i.e. $\overline{F_{B1}}$ concerns the assessment of reaching the bus stop, $\overline{F_{Bp}}$ concerns the waiting time at the bus stop, $\overline{F_{B2}}$ concerns the bus journey assessment. The two additional components $F_{B\gamma}$ and $F_{B\theta}$ are determined by the decision-maker and can be added to the overall security level. The element $F_{BA\gamma}$ has an interpretation of the index correcting a level of safety due to knowledge gained by the students during the training and lessons related to road safety. Moreover, the element $F_{BA\theta}$ adjusts a level of safety with additional children's equipment, such as reflective vests, telematics devices or personal

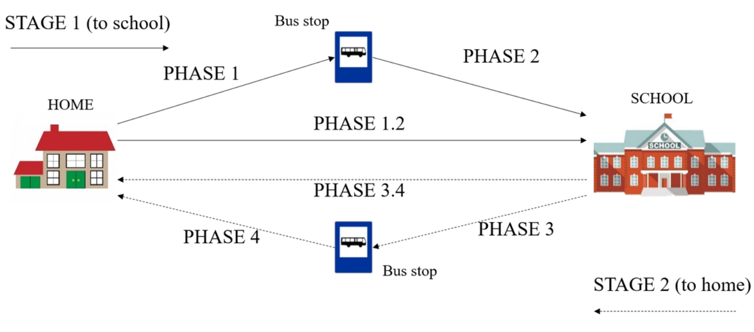


*Fig. 7. Stages and phases of travels to and from school in a children's mobility system*
*Source: own study*

lighting. They mainly affect children travelling by the school bus, but can also be used to travel to school by other means.

The safety assessment requires including many system features. To determine its level, a set $Q$ containing the weights of individual characteristics was defined. It was written as:

$$Q = \begin{Bmatrix} q_l(1), q_l(2.1), q_l(2.2), q_l(2.3), q_l(3), q_l(4) \\ q_p(1), q_p(2), q_p(3), q_p(4.1), q_p(4.2), q_p(4.3), \\ q_b(1), q_b(2), q_b(3), q_b(4), q_{st}(1), q_{st}(2), q_{st}(3) \end{Bmatrix} \quad (2)$$

The individual elements of the above-described set were divided into:

– determining the influence of the characteristics of a connection ($q_l$),
– determining the influence of the characteristics of a bus stop ($q_p$),
– determining the influence of journey and transport mean ($q_b$ and $q_{st}$).

Weights can be modified and changed depending on the needs and preferences of the model user. After calibration through appropriate adjustment of the weights, they should not be changed when different scenarios or systems are compared and assessed. Weights can be interpreted in various ways, depending on the needs of a model user. The paper assumes that weights will be treated as points allocated depending on the respective system characteristics. These points will be assigned from a set of integers. They can have positive or negative values.

The weights used to assess children's travel to the bus stop are presented in Table 1. They can also be used to build a more complex model that includes the assessment of journey to school by scooter, foot or bicycle. In the case of including in a model the journeys by a passenger vehicle, it would be necessary to introduce weights referring to, for example, the road category or the safety of the connection.

Another group of points allocated to a system relates to bus stops. It is essential due to the significance of the stage of waiting for the bus to arrive and getting children on and off the bus and the impact of these stages on the overall safety of children travelling to school. The group of weights related to these factors is defined in Table 2.

Another group of weights used for an assessment is the one related to the bus journey to school. This is the phase of the journey in which the infrastructure also plays an important role, however, equipping the vehicle with additional security systems can significantly increase the level of safety of children as passengers. The defined weights are presented in Table 3.

The system's safety assessment function consists of many elements related to all phases of the journey to school. Since stage 2 (returning

*Table 1. The group of weights related to the assessment of connections between nodes*

| Weight | Description |
|---|---|
| $q_l(1)$ | points (a weight) allocated for the presence of a sidewalk at a given connection |
| $q_l(2.1)$ | points allocated for the wide shoulder, it was assumed that there is no sidewalk in this case |
| $q_l(2.2)$ | points allocated for the narrow shoulder |
| $q_l(2.3)$ | points allocated for the other solutions or lack od additional improvements |
| $q_l(3)$ | points allocated for the lighting of a given connection |
| $q_l(4)$ | points allocated for the speed of vehicles on given connection, according to a principle the higher speed, the lower safety |

*Table 2. The group of weights related to the assessment of bus stops*

| Weight | Description |
|---|---|
| $q_p(1)$ | points (a weight) allocated for the presence of the bus stop turnout |
| $q_p(2)$ | points allocated for the presence of the bus stop shelter |
| $q_p(3)$ | points allocated for the presence of the bus stop lighting |
| $q_p(4.1)$ | points allocated for the presence of the intelligent lighting activated by the child's transmitter |
| $q_p(4.2)$ | points allocated for the presence of the road signs and the light signals, vertical and horizontal on the road |
| $q_p(4.3)$ | points allocated for the presence of other solutions improving safety |

*Table 3. The group of weights related to the assessment of school buses and bus routes*

| Weight | Description |
|---|---|
| **Points allocated for bus route** | |
| $q_b(1)$ | points (a weight) allocated for the number of stops on the bus stops during given route, the fewer stops, the higher the score |
| $q_b(2)$ | points allocated for the length of the bus route, the shorter route, the higher score |
| $q_b(3)$ | points allocated for the speed on given route |
| $q_b(4)$ | points allocated for the road lighting |
| Points allocated for bus equipment | |
| $q_{st}(1)$ | points (a weight) allocated for the equipping of the bus with the seat belts for passengers |
| $q_{st}(2)$ | points allocated for the additional lighting for the bus, which is activated at the bus stop |
| $q_{st}(3)$ | points allocated for the additional telematics equipment of the bus integrated with the system |

home) is analogous and the only difference is the waiting at the bus stop, its evaluation wasn't described. The road to school is critical in this case. The components of the safety evaluation function are the assessment of reaching the bus stop, the assessment of the bus stop and the assessment of the bus route weighted with the share of serviced notifications (the number of children getting on the bus). The considerations do not include access to the school from the bus stop, as it is assumed that it is a safe section (usually, the bus stop is at the school or the school area).

### 4.2. The assessment function of the bus journey

An assessment of the bus journey safety level requires the calculation of individual components of the function $\overline{F_{B\_A}}$. Its first element $\overline{F_{B1}}$ can be interpreted as the assessment of all phases of reaching the bus stop in a system for all bus routes:

$$\overline{F_{B1}} = \sum_{d\in D} \sum_{(w',w)\in L \wedge w\in\Psi(d)} f_{B1}(d,w',w)$$

It is the sum of the assessment of the arrival phases safety level of the $d$ -th route - $f_{B1}(d,w',w)$, using the house-bus stop connection $(w',w)$ belonging to the set of the connections $L$. Considerations taking into account only bus stops which belongs to the set of bus stops visited during given bus route $\Psi(d)$. The assessment of reaching a bus stop is based on the characteristics of a connection between the home and a bus stop and the number of children using this connection. This assessment is made on each bus route ($d$) and at each bus stop ($w$) belonging to a set of bus stops visited during a given bus route $\Psi(d)$:

$$\forall d\in D \;\; \forall w: w\in W \wedge r(w)=2 \wedge w\in\Psi(d) \;\; \forall w': w'\in W \wedge r(w')=1$$

$$f_{B1}(d,w',w)=\frac{x_a(d,w',w)}{x_{ap}(d,w)}\left[\begin{array}{l}\left[q_l(1)c_{lch}(w',w)\right]+\\ \left[\begin{array}{l} q_l(2.1)c_{lps}(w',w)+\\ q_l(2.2)c_{lpw}(w',w)+\\ q_l(2.3)(1-c_{lps}(w',w)-c_{lpw}(w',w))\end{array}\right]\left[1-c_{lch}(w',w)\right]+\\ q_l(3)c_{los}(w',w)+\\ q_l(4)\left[\dfrac{100-V_{sr}(w',w)}{100}+\dfrac{V_{\min}}{100}\right]\end{array}\right]\cdot \left(\left(1-\alpha_P(w',w)\right)\frac{l(w',w)-l_{Pgr}}{l(w',w)}\right)$$

The $r(w)$ parameter in the above function takes the value 1 when the node is interpreted as a home, and 2 when the node is interpreted as a bus stop. This function consists of three main elements (Figure 8 shows a graphic interpretation of the assessment of access to the bus stop). The first element is the share of the number of children using a connection to the $w$-th bus stop ($x_a(d,w',w)$), in relation to the overall amount children using this bus stop ($x_{ap}(d,w)$). The second element is a connection assessment, which depends on connection characteristics and the allocated weights of the individual characteristics 2.1)+$q_l$(2.2)+$q_l$(2.3), $q_l$(3), $q_l$(4)). The characteristic of a connection includes:

- $c_{lch}(w,w')$ – the percentage of the pavement in relation to a connection length,
- $c_{lps}(w,w')$ – the percentage of the wide shoulder in relation to a connection length,
- $c_{lpw}(w,w')$ – the percentage of the narrow shoulder in relation to a connection length,
- $c_{los}(w,w')$ – the percentage of the illuminated road in relation to a connection length,
- $V_{sr}(w,w')$ – the average speed of a connection, it is assumed that it cannot be higher than 100 kmph,
- $\alpha_P(w,w')$ – the indicator determining whether the level of safety is influenced by the length of the foot connection; it takes the value 1 when the length of the link $l(w,w')$ is greater than $l_{Pgr}$ for foot journey,
- $V_{min}$ – speed of the cars on a connection, which does not affect safety,

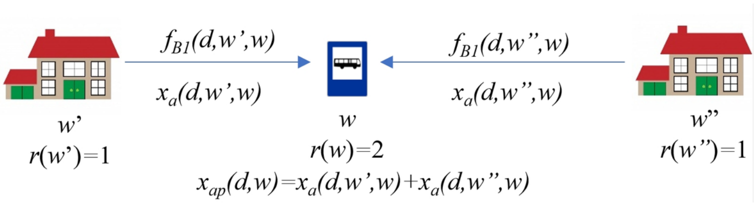


*Fig. 8. Graphical interpretation of a safety assessment elements of access to a bus stop*
*Source: own study*

The assessment function of the access to the bus stop is weighted by the influence of the length of the route, if it is longer than the assumed $l_{Pgr}$ (the limit length of an access to a bus stop for safety reasons).

The second element of a safety assessment of the journey to school using the bus is waiting time at a bus stop. As in the case of assessment of access to a bus stop, this function can also be applied to all bus stops in the system and can be formulated as:

$$\overline{F_{Bp}} = \sum_{d\in D} \sum_{w\in\Psi(d)} f_{Bp}(d,w)$$

This element depends on the characteristics of a bus stop and the weights of its individual features. It is weighted by the number of children using a given bus stop ($x_{ap}(d,w)$) to the number of children transported on the entire bus route $x_{atr}(d)$.. It can be formulated as below

$$\forall d\in D \;\; \forall w: w\in W \wedge r(w)=2 \wedge w\in\Psi(d)$$

$$f_{Bp}(d,w)=\frac{x_{ap}(d,w)}{x_{atr}(d)}\left[\begin{array}{l} q_p(1)c_{pz}(w)+q_p(2)c_{pw}(w)+q_p(3)c_{pos}(w)+\\ q_p(4.1)c_{pt1}(w)+q_p(4.2)c_{pt2}(w)+q_p(4.3)c_{pt3}(w)\end{array}\right]$$

In the above function, the following parameters characterizing a bus stop were adopted:

- $c_{pz}(w)$ – determining whether there is a bus stop turnout, takes the value 1 if there is a bus stop turnout or 0 if there is no bus stop turnout;
- $c_{pw}(w)$ – determining whether there is a bus stop shelter (1 – yes, 0 – no),
- $c_{pos}(w)$ – determining whether there is a bus stop lighting (1 – yes, 0 – no),
- $c_{pt1}(w)$ – determining whether a bus stop is equipped with additional lighting activated by a child's transmitter and a bus (1 – yes, 0 – no),
- $c_{pt2}(w)$ – determining whether a bus stop has additional light and / or sound marking activated by the child's transmitter (1 – yes, 0 – no),
- $c_{pt3}(w)$ – determining whether a bus stop has other additional ICT and IoT devices (1 – yes, 0 – no).

The third element is the trip to school by bus. The safety assessment of this element will be performed for an entire system as a sum over all routes in system. It is expressed as below:

$$\overline{F_{B2}} = \sum_{d\in D} F_{B2}(d)$$

The assessment of this element take into account getting on and off a bus and bus journey. The value of this element is weighted by the number of children traveling on the $d$ -th route ($x_{atr}(d)$) in realtion to all travelers using bus in a system ($x_{as}$). This function has been written as:

$$\forall d \in D \quad F_{B2}(d)=\frac{x_{atr}(d)}{x_{as}}\cdot\left[\begin{array}{l} q_b(1)\left(1-\frac{\sum\limits_{w\in\Psi(d)}\operatorname{sgn}(w)}{\sum\limits_{d\in D}\sum\limits_{w\in\Psi(d)}\operatorname{sgn}(w)}\right)+q_b(2)\left(1-\frac{\sum\limits_{(i,i')\in\Phi(d)} l(i,i')}{\sum\limits_{d\in D}\sum\limits_{(i,i')\in\Phi(d)} l(i,i')}\right)+ \\ q_b(3)\cdot\frac{\sum\limits_{(i,i')\in\Phi(d)} V_{sr}(i,i')}{\left|\Phi(d)\right|}+q_b(4)\cdot\left[c_{los}(i,i')\right]+ \\ +\sum\limits_{s\in S} y_a(d,s)\cdot\left[\begin{array}{l} q_{st}(1)c_{stpasy}(s)+ \\ q_{st}(2)c_{stos}(s)+ \\ q_{st}(3)c_{sttel}(s) \end{array}\right] \end{array}\right]$$

This function includes elements related to a bus route and the transport means itself. The bus route assessment includes the number of stops ($w$) visited on the $d$-th bus route; the length of the $d$-th bus route consisting of connections $l(i,i')$ belonging to the set of connections $\Phi(d)$ on the $d$-th bus route, the average speed on the connection $V_{sr}(w,w')$ and the share of the length of the illuminated road. On the other hand, the assessment related to the characteristics of the s-th vehicle (the parameter $y_a(d,s)$ - determines the assignment of the $s$-th vehicle to the $d$ -th route) includes:

- $c_{stpasy}(s)$ – the presence of seat belts and necessity to fasten seat belts on a bus,
- $c_{stos}(s)$ – the additional lighting of a bus
- $c_{sttel}(s)$ – the level of integration of a bus with telematics systems.

## 5. Verification of the model based on the distribution of the traffic flow in VISUM

The practical application of the approach to the issues of managing the mobility of school children presented in the paper is shown on the example of a real transport system. The PTV VISUM was used to carry out the analyzes.

Verifying the correctness of the presented child mobility management system in school-age with the use of the Smart Bus Stops and radio transmitters has been carried out through a comparison of the system performance indicators with the current system without additional support. Two comparative variants were used to simulate the effectiveness of the school-age mobility management system using smart bus stops and radio transmitters.

In the first variant, both systems are compared, considering the maximum flow of children traveling to school. A time interval from 7:00 AM. to 8:00 AM has been assumed in the first variant. During this time, the highest traffic levels within the school area are generated. The second variant was simulated for the lowest traffic situations to check how both systems behave in two extreme road situations. In a second variant, the assumed simulation period is from 11:00 AM to 12:00 PM.

Firstly, the transport network of the analyzed research area should be defined to verify the child mobility management system. The transport network, including point and line elements, is shown in Fig. 9 (point elements represent intersections, while the sections have an interpretation of connections between individual intersections). The analyzed area is the municipal community of Radzyń Podlaski, located in the Lubelskie Voivodeship in Poland.

The division of the area into traffic areas generating sources of traffic flows between the place of residence of children and the school is shown in Fig. 10 (region 28 marked red - location of the destination point – a school).

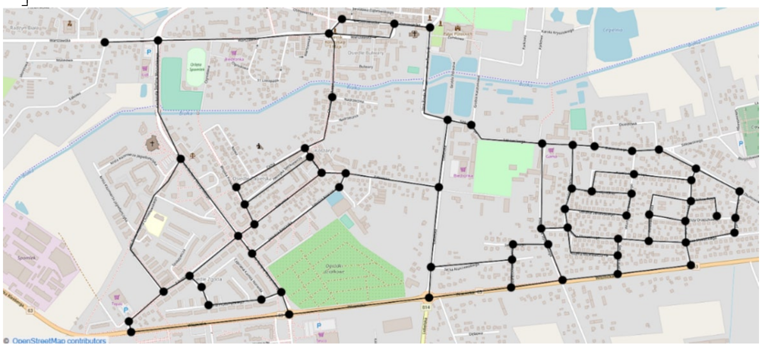

*Fig. 9. Transport network in the analyzed child mobility management system. Source: own study based on PTV Visum*

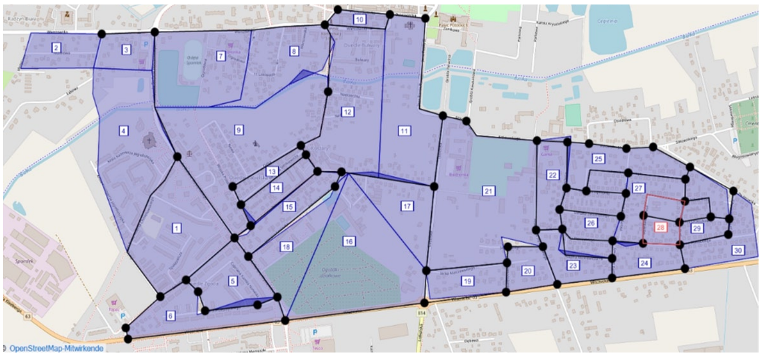

*Fig. 10. Communication areas in the territory of the child mobility management system Source: own study based on PTV Visum*

In order to determine the effectiveness of a child mobility management system for public transport (school bus), including Smart Bus Stops, the parameter of the distance between the starting bus stop and the child's place of residence was defined - Table 4. This parameter determines the total travel time of the child from leaving the home to arrival at school.

*Table. 4. Distance between home and bus stop*

| Area No. | Distance to bus stop [km] | Area No. | Distance to bus stop [km] | Area No. | Distance to bus stop [km] | Area No. | Distance to bus stop [km] | Area No. | Distance to bus stop [km] |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 0,25 | 7 | 0,22 | 13 | 0,14 | 19 | 0,42 | 25 | 0,24 |
| **2** | 0,3 | 8 | 0,12 | 14 | 0,16 | 20 | 0,14 | 26 | 0,11 |
| **3** | 0,12 | 9 | 0,23 | 15 | 0,12 | 21 | 0,35 | 27 | 0,23 |
| **4** | 0,23 | 10 | 0,34 | 16 | 0,11 | 22 | 0,24 | 28 | 0,14 |
| **5** | 0,24 | 11 | 0,23 | 17 | 0,34 | 23 | 0,14 | 29 | 0,12 |
| **6** | 0,3 | 12 | 0,12 | 18 | 0,34 | 24 | 0,33 | 30 | 0.14 |

*Source: own study based on PTV Visum*

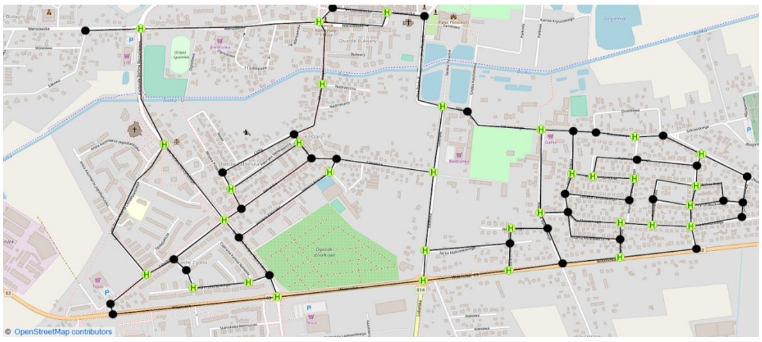

*Fig. 11. Location of Smart Bus Stops in the transport network.*
*Source: own study based on PTV Visum*

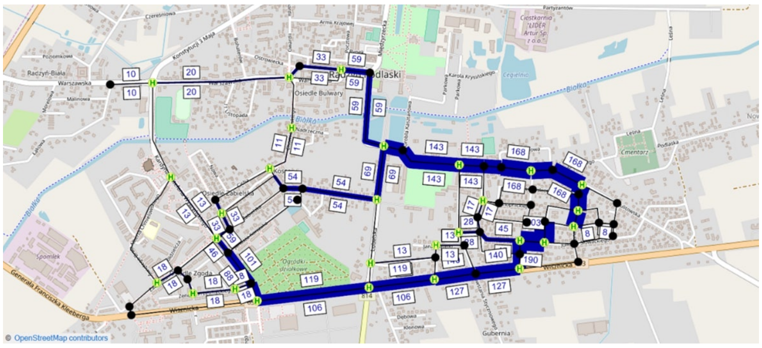

*Fig. 12. The flow of passengers in the morning hours in the Smart Bus Stops system*
*Source: own study based on PTV Visum*

Verification of a child mobility management system with the use of Smart Bus Stops and public transport was simulated for 29 intelligent bus stops - Fig. 11.

In order to operate all bus stops, four bus lines have been designated covering all Smart Bus Stops. The hourly volume of the passenger flow on individual sections of the line is presented in Fig. 12.

In the analyzed case study, the community of Radzyń Podlaski has 4 school buses and each bus is assigned to one line. The efficiency indicators in a child mobility management system including Smart Bus Stops are presented in Table 5.

In order to operate all bus stops in the morning, three bus lines covering all Smart Bus Stops have been designated. The hourly volume of the passenger flow on individual sections of the line is presented in Fig. 13. The efficiency indicators in a child mobility management system, including Smart Bus Stops, are shown in Table 6.

For the presented simulations of bus journeys, a safety assessment was carried out in a child mobility management support system. The assessment was carried out based on the developed mathematical model. The following assumptions have been made:

– only bus trips were considered, taking into account access to a bus, the modal split with passenger vehicles, pedestrian trips or bicycles was not taken into account, it will be topic of further research,
– the influence of speed was omitted due to the equal speed of 50 kmph in each section,
– the assessment related to the bus equipment was omitted because the same buses were adopted on each line,

*Table. 5. The effectiveness indicators of a child mobility management system including Smart Bus Stops for the morning hours*

| Line No. | Travel time [h] | Length of route [km] | Fuel consumption [l] | Total travel time [h] | Total fuel consumption [l] |
|---|---|---|---|---|---|
| 1 | 0,21 | 7 | 3,01 | 0,77 | 9,89 |
| 2 | 0,15 | 5 | 2,15 | | |
| 3 | 0,19 | 5 | 2,15 | | |
| 4 | 0,22 | 6 | 2,58 | | |

*Source: own study based on PTV Visum*

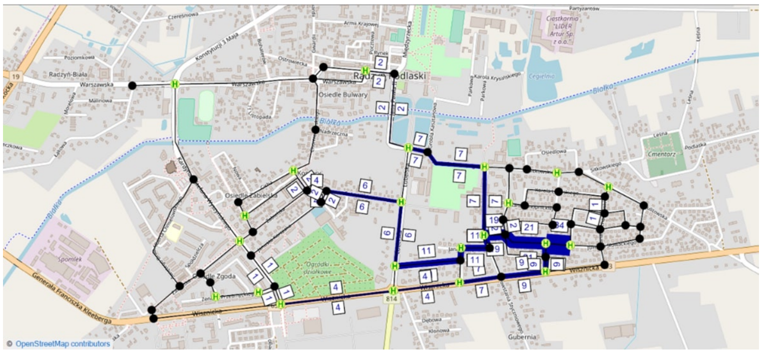

*Fig. 13. The flow of passengers in the forenoon hours in the Smart Bus Stops system*
*Source: own study based on PTV Visum*

– due to the nature of a transport network, it was assumed that there are either sidewalks or wide shoulders along with the connections (in the analysis of access to a bus stop).

For the assumptions mentioned above and weights presented in Table 7, three phases of the journey were assessed. The first phase is accessing a bus stop, the second phase is waiting at a bus stop, and the third phase is the bus journey. The results of an assessment are presented in Table 8. The obtained results are weighted by the number of students using a bus on their way to school to get the absolute value of an assessment suitable for comparing the adopted solutions at different times of the day. It should be noted that an assessment of the systems is very similar, which is also the result of the high quality of a transport network and bus stops. An assessment could give completely different results in communities or cities with worse road conditions and poorer additional infrastructure.

*Table. 6. The effectiveness indicators of a child mobility management system including Smart Bus Stops for the forenoon hours*

| Line No. | Travel time [h] | Length of route [km] | Fuel consumption [l] | Total travel time [h] | Total fuel consumption [l] |
|---|---|---|---|---|---|
| 5 | 0,11 | 4 | 1,72 | 0,25 | 4,3 |
| 6 | 0,05 | 3 | 1,29 | | |
| 7 | 0,09 | 3 | 1,29 | | |

*Source: own study based on PTV Visum*

Table. 7. The effectiveness indicators of a child mobility management support system, including Smart Bus Stops

| Weight | Description | Points |
|---|---|---|
| $q_l(1)$ | points allocated for the presence of a sidewalk at a given connection | 5 |
| $q_l(2.1)$ | points allocated for the wide shoulder, it was assumed that there is no sidewalk in this case | 2 |
| $q_l(3)$ | points allocated for the lighting of a given connection | 3 |
| $q_p(1)$ | points allocated for the presence of the bus stop turnout | 5 |
| $q_p(2)$ | points allocated for the presence of the bus stop shelter | 2 |
| $q_p(3)$ | points allocated for the presence of the bus stop lighting | 3 |
| $q_p(4.1)$ | points allocated for the presence of the intelligent lighting activated by the child's transmitter | 3 |
| $q_p(4.2)$ | points allocated for the presence of the road signs and the light signals, vertical and horizontal on the road | 2 |
| $q_b(1)$ | points allocated for the number of stops on the bus stops during given route, the fewer stops, the higher the score | 4 |
| $q_b(3)$ | points allocated for the speed on given route | 4 |
| $q_b(4)$ | points allocated for the road lighting | 2 |

Source: own study

Table. 8. The assessment of the safety of a children's mobility system using Smart Bus Stops for the morning and forenoon hours

| General data | | | | | | | |
|---|---|---|---|---|---|---|---|
| | In the morning | | | | In the forenoon | | |
| Demand | 385 | | | | 49 | | |
| Number of lines | 4 | | | | 3 | | |
| Line No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Line length [km] | 7 | 5 | 5 | 6 | 4 | 3 | 3 |
| Lighting | 0,89 | 0,76 | 1 | 0,98 | 0,89 | 0,98 | 0,96 |
| Number of children | 107 | 81 | 119 | 78 | 15 | 17 | 17 |
| Number of bus stops | 6 | 4 | 7 | 4 | 4 | 7 | 4 |
| **Safety assessment** | | | | | | | |
| $\overline{F_{B1}}$ - access to a bus stop (max. 10) | 5,51 | | | | 5,60 | | |
| $\overline{F_{Bp}}$ - waiting at the bus stop (max. 15) | 8,85* / 12,49** | | | | 8,86* / 12,82** | | |
| Journeys of each line | 2,06 | 1,66 | 2,42 | 1,65 | 2,18 | 2,21 | 2,61 |
| $\overline{F_{B2}}$ - summary trip assessment (max. 10) | 7,78 | | | | 6,99 | | |
| $\overline{F_{BA}}$ - summary assessment (max. 45) | 22,15* / 25,78** | | | | 21,45* / 25,41** | | |
| Percentage share (from the maximum possible points) | 49%* / 57%** | | | | 48%* / 56%** | | |

*without Smart Bus Stops / ** with Smart Bus Stops

Source: own study based on PTV Visum

As the developed example of pilot studies shows, in the assessed system, greater emphasis should be placed on increasing children's safety during access to a bus stop. On the other hand, an assessment indicated that the system obtained just over 50% of possible points (in the variant with Smart Bus Stops). However, it should be noted that it is impossible to get all possible points, and the maximum number of points represents the ideal situation. The presented research is at the conceptual level, and due to the costs and time of implementation of the architecture discussed in the paper, it was necessary to conduct simulation studies. The second factor forcing the use of simulation tests at this stage is the difficulty in implementation due to administrative barriers. The preliminary results allow stating that the proposed considerations are effective and may be the basis for further research, both in domestic and international conditions. The developed assessment model can support policymakers in managing child mobility.

## 6. Summary and conclusions

Children's safety plays a critical role in the area of children's mobility, especially from the parent's perspective. In times of many threats, not only related to road traffic, but also in criminal related situations (kidnapping, persecution, etc.), the importance of technology is unquestionable. However, it should be noted that the use of tracking technology may also limit the privacy rights and may also be a subject of cybercrime. The use of any supervision in online technology must therefore be preceded by detailed research and fully secured against unauthorized access. This does not however apply to the use of intelligent infrastructure, such as smart bus stops, which communicate with transmitters or children's smartphones. It should be clearly stated that the prevalence of advanced technologies has great potential in terms of improving the children safety level.

The research presented in the article was aimed at developing the concept of children mobility management system and providing a tool for assessing children's travel to school by school bus. The verification presented in the article was to present the correctness and usefulness of the developed method. Due to the difficulty in obtaining detailed and reliable data essential to feed the method, it was necessary to carry out calculations for an isolated fragment of children's mobility system. An approach to children's mobility management system was presented and the use of the developed mathematical model applied to children's travel to school in a selected municipality. The use of the developed model for the safety assessment allows for the identification of the existing mobility system, but also for the assessment of other options for its modification and system operation under various conditions. In addition, the design of the model makes it possible to compare different systems of various complexity.

Further work in the practical aspect using the presented approach will require the acquisition of accurate data, collected over a longer period of time, for various municipalities and schools. This will allow for a proper assessment of the current state and the possibility of proposing concepts to improve the mobility system and the level of safety on a larger scale. In the research aspect, further work will consist in extending the model with additional ways of transporting children to school, as well as research in urban areas. Moreover, it will be possible to implement the analytical model in the simulation environment. This will allow for quick variations of different scenarios to further develop the mobility system. Such model can be made, for example, in the Flexsim or Anylogic environment.

## References


1. Belin M-Å, Tillgren P, Vedung E. Vision Zero – a road safety policy innovation. International Journal of Injury Control and Safety Promotion 2012; 19(2): 171–179, https://doi.org/10.1080/17457300.2011.635213.
2. Bina M, Confalonieri F, Abati D et al. Analysis of traffic upon school departure: Environment, behaviour, well-being and risk factors for road crashes. Journal of Transport & Health 2021; 22: 101119, https://doi.org/10.1016/j.jth.2021.101119.
3. Chaudhry S K, Elumalai S P. Active and passive transport choice behavior for school students and their exposure to different transportation modes. Recent Advances and Emerging Issues in Transport Research – An Editorial Note for the Selected Proceedings of WCTR 2019 Mumbai 2020; 48: 2916–2928, https://doi.org/10.1016/j.trpro.2020.08.191.
4. Davison K K, Werder J L, Lawson C T. Children's active commuting to school: current knowledge and future directions. Preventing chronic disease 2008; 5(3): A100.
5. Eguizábal S E, Berodia J L M, Portilla Á I, Ponce J B. Optimization model for school transportation design based on economic and social efficiency. Transport Policy 2018; 67: 93–101, https://doi.org/10.1016/j.tranpol.2018.01.015.
6. Elliott D, Keen W, Miao L. Recent advances in connected and automated vehicles. Journal of Traffic and Transportation Engineering (English Edition) 2019; 6(2): 109–131, https://doi.org/10.1016/j.jtte.2018.09.005.
7. Ghareeb M, Ghamlous A, Hamdan H et al. Smart bus: A tracking system for school buses. 2017 Sensors Networks Smart and Emerging Technologies (SENSET), 2017: 1–3, https://doi.org/10.1109/SENSET.2017.8125055.
8. Guerrero-ibanez J A, Zeadally S, Contreras-Castillo J. Integration challenges of intelligent transportation systems with connected vehicle, cloud computing, and internet of things technologies. IEEE Wireless Communications 2015; 22(6): 122–128, https://doi.org/10.1109/MWC.2015.7368833.
9. Hussein A, García F, Armingol J M, Olaverri-Monreal C. P2V and V2P communication for Pedestrian warning on the basis of Autonomous Vehicles. 2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC), 2016: 2034–2039, https://doi.org/10.1109/ITSC.2016.7795885.
10. Izdebski M, Jacyna-Gołda I, Gołda P. Minimisation of the probability of serious road accidents in the transport of dangerous goods. Reliability Engineering & System Safety 2022; 217: 108093, https://doi.org/10.1016/j.ress.2021.108093.
11. Jacyna M, Gołębiowski P, Szczepański E. City transport service model taking into account different means of transport. Proceedings of 19th International Scientific Conference Transport Means. Kaunas, Lithuania: Publishing House "Technologija, 2015: 160–168.
12. Jacyna M, Semenov I. Models of vehicle service system supply under information uncertainty. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2020; 22(4): 694–704, https://doi.org/10.17531/ein.2020.4.13.
13. Jacyna M, Wasiak M, Jachimowski R et al. The Concept of EPLOS Database of the Transport Infrastructure. In Kersys R (ed): Transport Means 2019. Sustainability: Research and Solutions. Proceedings of 23rd International Scientific Conference, Publishing House "Technologija": 2019: 1250–1255.
14. Jacyna M, Wasiak M, Lewczuk K et al. Decision problems in developing proecological transport system. Annual Set The Environment Protection 2018; 20: 1007–1025.
15. Jankowska D M. Integrated system for safe transportation of children to school - with the use of intelligent transport systems (ITS). Journal of KONES 2008; Vol. 15, No. 2: 137–144.
16. Jankowska-Karpa D, Wnuk A. Strategie planowania podróży, jako narzędzie poprawiające bezpieczeństwo dzieci w ruchu drogowym. Transport Samochodowy 2015; z. 2: 65–88.
17. Kamal M, Atif M, Mujahid H et al. IoT Based Smart City Bus Stops. Future Internet 2019, https://doi.org/10.3390/fi11110227.
18. Kattan L, Tay R, Acharjee S. Managing speed at school and playground zones. Accident Analysis & Prevention 2011; 43(5): 1887–1891, https://doi.org/10.1016/j.aap.2011.04.009.
19. Kumari A, Deepshikha, Satish B A. Automated traffic control for pedestrian safety. 2017 International Conference on Innovative Mechanisms for Industry Applications (ICIMIA), 2017: 145–149, https://doi.org/10.1109/ICIMIA.2017.7975589.
20. Lewczuk K, Kłodawski M. Logistics information processing systems on the threshold of IoT. Zeszyty Naukowe. Transport / Politechnika Śląska 2020; 107: 85–94, https://doi.org/10.20858/sjsutst.2020.107.6.
21. Mandic S, Barra S L de la, Bengoechea E G et al. Personal, social and environmental correlates of active transport to school among adolescents in Otago, New Zealand. Journal of Science and Medicine in Sport 2015; 18(4): 432–437, https://doi.org/10.1016/j.jsams.2014.06.012.
22. Mårtensson F, Nordström M. Nordic child friendly urban planning reconsidered. In Bishop K, Corkery L (eds): Designing cities with children and young people, 1st edition. New York, Routledge: 2017: 36–46.
23. Mehdizadeh M, Nordfjaern T, Mamdoohi A R, Mohaymany A S. The role of parental risk judgements, transport safety attitudes, transport priorities and accident experiences on pupils' walking to school. Accident Analysis & Prevention 2017; 102: 60–71, https://doi.org/10.1016/j.aap.2017.02.020.
24. Nasrudin N, Nor A R M. Travelling to School: Transportation Selection by Parents and Awareness towards Sustainable Transportation. Procedia Environmental Sciences 2013; 17: 392–400, https://doi.org/10.1016/j.proenv.2013.02.052.

25. Raj J T, Sankar J. IoT based smart school bus monitoring and notification system. 2017 IEEE Region 10 Humanitarian Technology Conference (R10-HTC), 2017: 89–92, https://doi.org/10.1109/R10-HTC.2017.8288913.
26. Roblek V. The smart city of Vienna. In Anthopoulos L (ed): Smart City Emergence, Elsevier: 2019: 105–127, https://doi.org/10.1016/B978-0-12-816169-2.00005-5.
27. Rosenberg D E, Sallis J F, Conway T L et al. Active Transportation to School Over 2 Years in Relation to Weight Status and Physical Activity. Obesity 2006; 14(10): 1771–1776, https://doi.org/10.1038/oby.2006.204.
28. Rudyk T, Szczepański E, Jacyna M. Safety factor in the sustainable fleet management model. Archives of Transport 2019; 49(1): 103–114, https://doi.org/10.5604/01.3001.0013.2780.
29. Sadeghian P, Håkansson J, Zhao X. Review and evaluation of methods in transport mode detection based on GPS tracking data. Journal of Traffic and Transportation Engineering (English Edition) 2021; 8(4): 467–482, https://doi.org/10.1016/j.jtte.2021.04.004.
30. Shaaban K, Bekkali A, Hamida E B, Kadri A. Smart tracking system for school buses using passive RFID technology to enhance child safety. Journal of Traffic and Logistics Engineering; 1(2): 191–196, https://doi.org/10.12720/jtle.1.2.191-196.
31. Shinde P A, Mane Y B. Advanced vehicle monitoring and tracking system based on Raspberry Pi. 2015 IEEE 9th International Conference on Intelligent Systems and Control (ISCO), 2015: 1–6, https://doi.org/10.1109/ISCO.2015.7282250.
32. Soczówka P, Klos M, Zochowska R, Sobota A. An analysis of the influence of travel time on access time in public transport. Scientific Journal of Silesian University of Technology. Series Transport 2021; 111: 137–149, https://doi.org/10.20858/sjsutst.2021.111.12.
33. Stark J, Frühwirth J, Aschauer F. Exploring independent and active mobility in primary school children in Vienna. Journal of Transport Geography 2018; 68: 31–41, https://doi.org/10.1016/j.jtrangeo.2018.02.007.
34. Sun D, El-Basyouny K, Ibrahim S, Kim A M. Are school zones effective in reducing speeds and improving safety? Canadian Journal of Civil Engineering 2018; 45(12): 1084–1092, https://doi.org/10.1139/cjce-2018-0060.
35. Świderski A, Jóźwiak A, Jachimowski R. Operational quality measures of vehicles applied for the transport services evaluation using artificial neural networks. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2018; 20(2): 292–299, https://doi.org/10.17531/ein.2018.2.16.
36. Thibaud M, Chi H, Zhou W, Piramuthu S. Internet of Things (IoT) in high-risk Environment, Health and Safety (EHS) industries: A comprehensive review. Decision Support Systems 2018; 108: 79–95, https://doi.org/10.1016/j.dss.2018.02.005.
37. Transportation Research Board. The Relative Risks of School Travel: A National Perspective and Guidance for Local Community Risk Assessment – Special Report 269. Washington, DC, The National Academies Press: 2002. doi:10.17226/10409, https://doi.org/10.17226/10409.
38. Wang H, Morgan C, Li D et al. Children's fear in traffic and its association with pedestrian decisions. Journal of Safety Research 2021; 76: 56–63, https://doi.org/10.1016/j.jsr.2020.11.010.
39. Westman J, Friman M, Olsson L E. What Drives Them to Drive?—Parents' Reasons for Choosing the Car to Take Their Children to School. Frontiers in Psychology 2017, https://doi.org/10.3389/fpsyg.2017.01970.
40. Yongjun Z, Xueli Z, Shuxian Z, shenghui G. Intelligent transportation system based on Internet of Things. World Automation Congress 2012, 2012: 1–3.
41. Travel and Environmental Implications of School Siting. U.S. Environmental Protection Agency: 2003.
42. Dzieci w wieku 0-14 lat w ruchu drogowym dla okresu od 2010 do 2019 roku. Polskie Obserwatorium Bezpieczeństwa Ruchu Drogowego: 2020.
43. Global Status Report on Road Safety 2018. Geneva, World Health Organization: 2018.
44. Integrated system for safe transportation of children to school(SAFEWAY2SCHOOL). [https://cordis.europa.eu/project/id/233967].