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Katarzyna SOLECKA[1]

MODELLING TOOLS TO INTEGRATE PUBLIC TRANSPORTATION

Summary. One of the main problems within cities is the lack of convenient public transport connections, which offer passengers a comprehensive and efficient means of transportation from one place to another. Urban transport integration is intended to improve the functioning of public transport and, thus, is an activity that significantly contributes to the quality of transport services within cities. Transport integration may include solutions provided by urban public transport, as well as solutions based on the integration of public transport with individual transport modes. This article presents a comprehensive approach to the integration of urban transport. Exemplary tools integrating urban transport, along with examples of modelling in software for traffic microsimulation, are shown.

Keywords: transport integration; modelling; traffic simulation.

1. CONCEPT OF INTEGRATION IN URBAN PUBLIC TRANSPORT

Integration (Latin: integratio, English: integration) is understood as a consolidation or connection, creating unity from parts, or folding or simultaneously coming together [19, 25]. Typically, in urban public transport services, the term *integration* is used for solutions that ensure continuity in terms of a “door to door” journey.

[1] Faculty of Civil Engineering, Cracow University of Technology, Warszawska 24 Street, 30-716 Cracow, Poland. E-mail: ksolecka@pk.edu.pl

The integration of transport may concern:

- various modes of public transport
- public and individual transport

In the context of integrating public transport systems, various solutions are suggested [1, 7, 8, 9, 11, 12, 16, 20, 21, 26, 28, 29, 31], such as: facilitating changes to the means of transport for passengers by proper planning of a transport network; contemplating various means of transport; development of infrastructure in order to create good connections and comfortable changes; designing transport services that combine journeys via various means of transport at any distance with coordinated timetables; a common tariff; interchanges; and appropriate equipment that facilitates interchanges in a multi-modal information environment for passengers. In the below, a brief description is given of the various solutions that integrate urban public transport:

Interchange - This is a place where different carriers and different means of transportation meet, and where passengers arrive with a view to changing their means of transport [29]. As an integration solution, it helps the passengers to change between the means of transport. It can be used as a place of marketing and promotional activities in support of public transport. In Szymalski's [23] study, an interchange node, according to the Swiss, is a place in the transport system, where, during a trip, one can change the means of transport at least between two different modes of transport.

Common tram-bus tracks - This type of solution is based on the common use of separated tracks by trams and buses [27]. Integration of public transport vehicles in this case can take place in two ways, i.e., by separate streets for trams and buses, and by separated common bus and tram lanes.

Common stops for public transport vehicles - These stops constitute an element in the spot infrastructure of the transport system. They represent a designated place where a bus or a tram can stop to allow the passengers to enter/exit the vehicle. When the roadway is shared with the tram road, the stops perform the function of a common bus and tram stop [30].

Coordinated timetables - A timetable is a work schedule for carriers and vehicle drivers. For customers, however, it represents an essential part of the transport offer [11]. A timetable for a public urban transport line should correspond to the time and spatial distribution of transport needs. According to transport law [17], the coordination of timetables consists of establishing interconnections between different modes of land-based transport in relation to contact points on the basis of a timetable, with an agreed course of communication lines and hours of departure of vehicles, thereby providing regular public transport with a particular regard to the following: transport needs reported by local, county or regional municipalities, as well as securing transportation needs in relation to carriers.

Common tariff (fare and ticket integration) - This is one of the main instruments of transport policy and one of the most important activities in the integration of public transport. It can only be made where there is integration of tariffs or tickets. It is important, however, to strive for the establishment of common and internally integrated tariffs for public transport services involving one common ticketing system at the same time. Integration of fares and tickets is the first step on the way to full integration. Integration of fares and tickets allows passengers to purchase a single ticket, which is valid in relation to transportation involving two or more carriers (organizers) [14]. Integration of tariffs should be understood as the unification of principles respected by the carrier and the travellers (the rights and obligations of the carrier) and the resulting tariff rates, which refer to the prices for the performed services. The passengers has an “integrated” ticket with which s/he can travel on and change to various means of transport, from the place of departure to the place of arrival.

Integration of information - This covers all levels of the transport network supporting urban, agglomeration or regional transport. It serves to provide passengers with stress-free transport options throughout the transport system. An integrated passenger information system means that passenger information is shared across the network, regardless of the carrier and mode of transport. We can distinguish different sources of information for public transport passengers: information provided in service points, via telephone, via the Internet, and at stops and stations. An additional convenience for passengers concerns information provided in real time. This allows passengers to travel with more flexibility and constitutes a better response to delays and/or interferences in the network. Information on public transport should take into account all stages of the journey, as well as the associated costs [5], such as access to the stop (information on the location of the stop and information about the possibilities of getting to it), awaiting the arrival of the vehicle (information concerning the timetable, information about the delays, failures and alternative lines), information about the journey by means of public transport (information about the length, travel route and the travel costs), change in the mode of transport (information about the location of interchange nodes while waiting for a new vehicle) and access to the journey destination (information on service objects, factories etc. in the vicinity of the bus stop and opportunities to walk to them).

Integration of transport policy with other policies affecting land use planning or infrastructure-related investments. This is based on the specific planning of a spatial urban form with the existing transport network. Proper use of land and transport infrastructure has to ensure the alignment of planning and land management, as well as transport planning.

With regard to the integration of public and private transport, the following can be distinguished [4]:

Park and ride (P&R) - This is a system of interchanges consisting of car parks located in the vicinity of stations, railway stations and other public transport stops. P&R parking lots are often accompanied by public use buildings, such as shopping centres. Drivers can leave cars in parking lots before continuing their journey to the city centre by public transport.

Bike and ride (B&R) - This is analogous system to the “P&R” system, but is designed for cyclists who, having reached key transport hubs, can safely leave their bicycles and continue their journey with the use of public transport. B&R is a solution that integrates public transport and individual transportation (i.e., the bicycle), thereby helping to improve the availability of public transport and the limited range of individual transportation options. Using a bicycle as a means of transport reduces the time to reach the public transport hub, particularly when compared to walking on foot. B&R may be complemented by a city bicycle system, which is a city network of bicycle rentals, located close to public transport hubs in key city locations. As such, it is possible to use a bicycle, both before and after using public transport.

Transporting bicycles on public transport - This option involves transporting bicycles on special platforms pushed by trams, carrying bicycles on special racks installed on buses and carrying bicycles inside the means of public transport in specially prepared holdings.

Personal rapid transit (PRT) system - This is based on the use of publicly available vehicles from which passengers get on and off at different stations, in similar ways to bus or tram stops. However, unlike buses or trams, but similarly to passenger cars, PRT vehicles can usually accommodate two to six passengers. They can use the PRT system individually (e.g., taxis), indicating the desired end stop to which the PRT system takes them without stopping at intermediate stops. PRT vehicles do not circulate according to a strict timetable; rather, they are available on request from the passenger. Depending on the type of PRT option, they travel on routes that are specially prepared and protected in relation to other traffic (on the level of the ground, elevated or suspended), which are intended exclusively for them [2].

Solutions of a legal and organizational nature - Such solutions enable the use of appropriate modifications, as follows:

- allowing the vehicles used by more people (HOV) to drive in lanes
- involving lanes that are separated for buses and on tram-bus tracks (TTA)
- exemption from fees/discounts for the use of public transport for drivers leaving their cars on a P&R site
- conditional permission to transport bicycles on public transport
- introduction of IT systems to facilitate journey planning and booking parking spaces in P&R parking lots

2. MODELLING SOLUTIONS THAT INTEGRATE PUBLIC TRANSPORT

Simulation is a numerical technique used to conduct experiments on certain types of analytical/mathematical models, which describe, via a digital machine, the functioning of a complex system over a long period of time [15]. In the available literature, there are many definitions of the term *simulation*. According to the PWN encyclopaedia [3], computer simulation is a method of reproducing phenomena occurring in the real world (or some of their characteristics and parameters) via their mathematical models, as defined and supported using computer programs. It is particularly used to analyse such phenomena and processes whose direct observation would not be possible or would be too expensive. The simulation model is the final result of a series of activities to highlight and formalize the parameters of a real system, as well as determine the relations between these parameters in time, in order to find their counterparts in the secondary system. The simulation model describes the functioning of the system using events that take place in the individual components of this system[10]. It reflects the travellers' needs to travel between specified points and allows their implementation through a simple road and transport infrastructure description model. It is an excellent analytical tool, which may significantly facilitate the problem-solving process.

There are three basic levels of traffic simulation: macroscopic, mesoscopic and microscopic simulation. Macroscopic models evaluate urban traffic at a high level of aggregation, in terms of traffic flow without focusing on the components. Macroscopic simulation describes the system, including interactions occurring between the components at a low level of detail. It takes into account the characteristics of a transport network, such as capacity, speed limits, volume and density. A microsimulation model describes the behaviours of individuals included in the traffic flow, as well as the interactions that occur between them. A crossing or a selected road fragment can be regarded as areas of research (e.g., transport corridor). A mesoscopic simulation is carried out at an intermediate level of detail. It describes individual vehicles, but does not account for interactions taking place among them. It fills the gap that exists between the general level of description of a macro simulation traffic system and a detailed description of a micro stimulation. Examples of modelling tools, which integrate urban public transport in Visum software for macro simulation of traffic, are presented below.

3. MODELLING OF TOOLS THAT INTEGRATE URABAN PUBLIC TRANSPORT IN VISUM SOFTWARE FOR MACRO SIMULATION OF TRAFFIC

This article presents the simplest ways of modelling macro simulation of traffic using selected tools in Visum software, which integrate urban public transport options, such as [22] interchange nodes, common stops, common bus-tram tracks, common tickets, passenger information and coordinated timetables. In contrast, examples of modelling tools, which integrate urban public transport with individual transport, can be found in [4].

3.1. Interchange nodes

In order to model an interchange node, it is important to design the route of the means of transport to minimize the transfer time of a passenger from one stop to another. When modelling, it is important to control the following elements: change in the location of the bus stop in terms of connecting to the network using connectors, occasional pedestrian access from one stop to another in order to change the means of transport, and change in the value of the attribute “penalties for interchange” [18, 22] between the given means of transport.

Take the example in Figure 1, which supposes that, along the PKP (Polish Railways), there is a tram line (black line). The passenger needs 7 min to walk from the tram stop (T) to the railway station (PKP). As a result of the introduction of a new tram line (dotted line), which runs above or near the bus stop (A), the access time (Td) between these stops is reduced to 40 s, because the distance between the stops is reduced. Both bus and tram stops are located as close to the railway station as possible. In places where it is possible, transfer times between the stops have to be measured (in person or by using applications of interactive maps from the Internet [6], assuming the speed of a person to be 4km/h). In which case, the data are then entered to the model. In interchange nodes, a lower value of attribute, which concerns a penalty for a change, was introduced, such that the value of penalties for the changes are defined on the basis of available studies, as presented in the literature [18] or on the basis of own survey results.

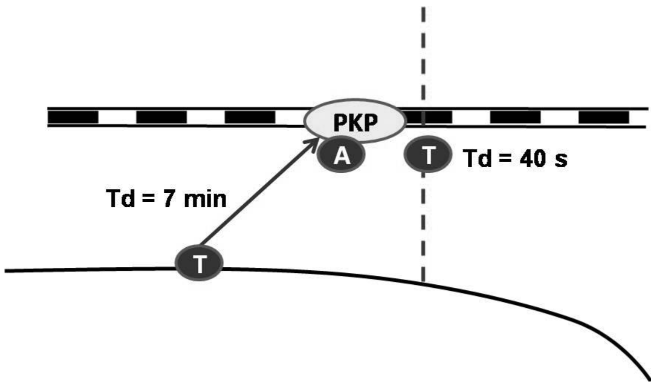

Fig. 1. An example of the modelling interchange node [22]

3.2. Common stops

In order to model a common stop, it is important to lead the route of the means of transport in such a way that access time of the passenger from one stop to another was 0 min. When modelling, we control the following elements: change of location of the stop (the introduction of the stops on one platform) and occasional pedestrian access from one stop to another in order to change the means of transport.

The example (Fig. 2) assumes that the tram line (bottom line) runs in parallel to the bus route (the top line), such that the passenger needs 5 min to walk from the tram stop (T) to the bus stop (A). As a result of a change in the course of the bus line within the vicinity of the tram stop, the introduction of a bus onto the common bus and tram track in the area of the stop (dashed line) means that we manage to shorten the access time (Td) between the two stops to 0 min. The process of changing the means of transport is done within the common platform. In places where it is possible, transfer times between the stops have to be measured (in person or by using applications with interactive maps from the Internet [6], assuming the speed of a person is 4 km/h).

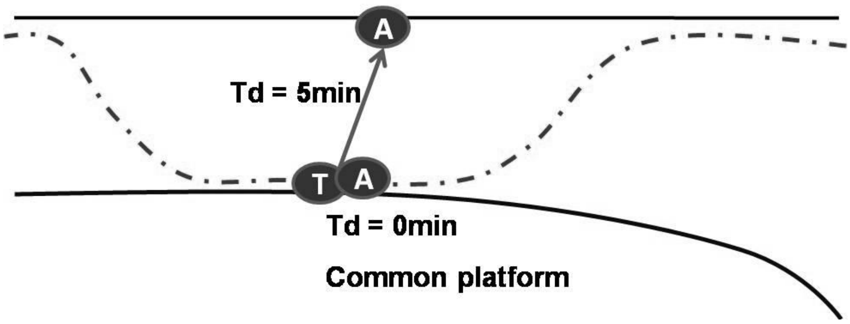

Fig. 2. An example of modelling a common stop [22]

3.3. Common tram-bus tracks

In order to model common tram-bus tracks, it is important to lead the bus line within the same roads as the tram lines. This causes an increase in the speed of bus lines. On the entire length of the common track for trams and buses, it is important to implement common tram-bus stops, which in turn leads to shortening the access time of the passengers from one stop to another in order to change the means of transport. The design of such solutions can be done by shifting the course of bus routes onto the tram routes, permitting a higher speed for buses in the common tram-bus track, thereby reducing the speed of trams circulating on the common tracks, relocating tram/bus stops and positioning them on the same platform, and improving the access time of a pedestrian from one stop to another in order to change the means of transport.

In the example (Fig. 3), assuming that the tram line runs in a separated track, the travelling speed of the tram is V = 35 km/h, while the bus line, which runs along the street, circulates with all other vehicles, in which the average drive speed (without stops) of the bus is V = 22 km/h. The passenger needs 4 min to walk from the tram stop (T) to the bus stop (A), such that access time Td = 4 min. Introduction of the bus onto a common bus and tram track means that the access time between these stops is reduced to 0 min, while the drive speed of the bus is increased by about 10-15km/h, thus the speed of the tram can be reduced to about 5 km/h. The process of changing the means of transport is done within the same platform.

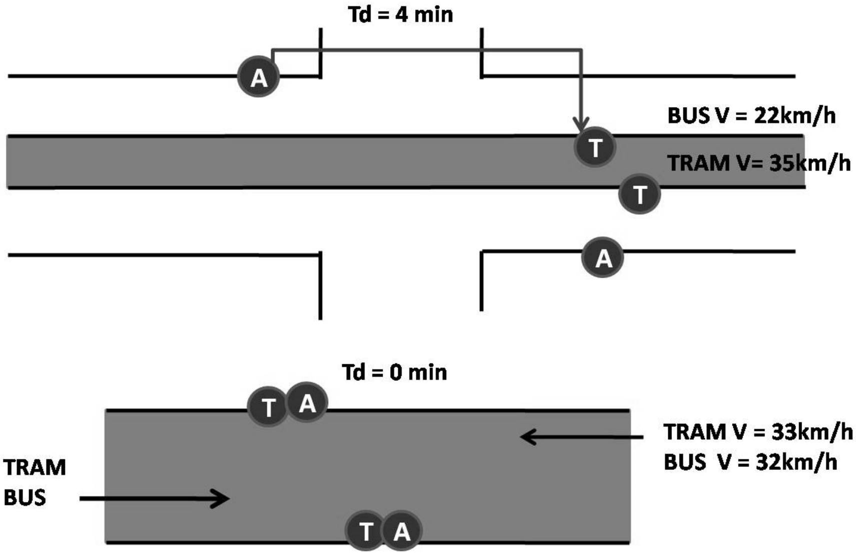

Fig. 3. An example of modelling a common tram-bus track [22]

3.4. Joint ticket

A joint ticket is a form of integration involving the implementation of a single, universal ticket, which is recognized by all carriers of different types of transport. The implementation of such a solution can be modelled in tools for the simulation of traffic through the introduction of an additional attribute, namely, "penalties for a change" to a different means of transport, which is not in the system (e.g., PKP). When having a joint ticket, the penalty for a change is smaller; however, in the absence of a joint ticket, the penalty for a change is higher. The amounts of penalties should be assumed on the basis of the research presented in the literature or based on our own surveys [18, 22].

3.5. Information for passengers

Information for passengers is another tool regarding the integration of an urban public transport system. It suggests modelling two cases of the availability of information for passengers, as follows:

- The first case concerns the lack of information about the departure times of public transport vehicles, as well as passengers who do not have any information about the departure times of public transport vehicles. In the Visum software, it is modelled in the following way: if the passenger does not have additional information, s/he must decide whether to take the arriving line or not. The passenger selects a line from the set of lines, which arrive in the first instance. Additionally, the model is characterized by the frequency in terms of the time "gap" between the two lines, which is not constant, but exponential.
- The second case concerns a situation in which the passengers know the departure times of vehicles. The passengers know the departure times of vehicles and the frequency of travel. The optimal strategy can be formulated as follows: a passenger gets on the line (selects the lines), which, in effect, offers the lowest cost from the current offer of departure times. Unlike the previous case, passengers do not get on the first incoming line because they

know the waiting times. In other words, the decisions that the passengers make are not subject to unspecified influences.

3.6. Coordination of timetables

Generally, the coordination of a timetable is based on the timetables introduced to the software. When dealing with models based on the frequency of travels (such as the model created for the city of Cracow), an integration tool for the coordination of timetables can be replaced by the instrument: in other words, modularity and frequency, which results in a reduction in the waiting time for the change of vehicle and leads to the coordination of timetables. In models based on the frequency of travels, there is no point in introducing the coordination of timetables, due to the failure to obtain satisfactory results in the end (e.g., coordination of timetables in several points will cause inconsistency of the model). Modelling of the modularity and frequency tool consists in changing the frequency parameter for the basic and supplementary bus and tram lines, thereby maintaining modularity, such that, for example, the introduction on the basic bus and tram lines travel at a frequency of 6 min. Meanwhile, on the supplementary bus and tram lines, travel frequency is every 12 min.

4. SUMMARY

Transport integration brings many benefits to all users of the transport system. For example, a well-planned, operated and managed interchange helps to reduce the time needed to change the means of transport, as well as the time spent on waiting for the means of transport, which in turn leads to a reduction in the travel time. Common bus and tram tracks significantly increase transport capacity in the transport route. The result of the introduction of buses onto the tram tracks is to facilitate their movement, thus reducing a loss of time on certain sections. Solutions of this type contribute measurable benefits to those passengers who start their journey and change vehicles, as it gives them the possibility to use only one stop, thereby reducing the risk of accidents in connection with the need to cross the road in order to change the stop. Common stops mean that the passenger does not have to decide whether they go to a bus or a tram stop, which means that they are ensured that they will benefit from the quickest solution. Creating common stops for public transport increases passenger safety, given that, when changing vehicle, they are not in conflict with individual transport vehicles. Taking into account the coordination of timetables, we can say that timetables are an underrated tool for shaping the transport offer. The regularity of service makes that the customer feel that public transport is secure and reliable. Coordinated timetables primarily reduce the time lost by passengers while waiting for another vehicle during transfer operations. The coordination of timetables is beneficial in economic and financial terms. One of the main advantages of the integration of tariffs and tickets is, as previously mentioned, the ability to travel using a joint ticket on various means of transport. As a result, using the services offered by urban public transport, passengers do not have to worry about the knowledge of tariffs of individual carriers, or the need to look for places to buy tickets or validate them etc. Considering the integration of individual transport with public transport, it is important to pay special attention to the P&R system. This system has many advantages and benefits, which include, among others [13, 24], reducing the occupancy of parking spaces in city centres, enabling the regaining of urban space for pedestrians and cyclists, reducing urban congestion and increasing the number of journeys made on public transport.

The mentioned benefits of integration, both on public transport and involving public and individual options, clearly impact on improving the quality of life in cities. They lead to an improvement in the travel conditions on public transport and contribute to the fact that passengers perceive it as a more friendly and convenient way to travel. This increases the attractiveness of the services, which in turn leads to an increase in the number of passengers and the level of revenue from tickets.

However, given that the real public transport system was well integrated, it is important to firstly carry out a number of experiments and computational simulations. Specialized software for traffic simulation helps to predict how an integrated public transport system will work in the real world, even before it is implemented Thanks to the simulation, it is possible to analyse activities associated with traffic in the city, assess the impact of new solutions and optimize them. Thanks to a well-conducted simulation, it is possible to avoid most of the errors already made at the stage of the design phase. It is important to create simple simulation models, even if they will accurately reflect the behaviour of the modelled tool or of the entire system. A model that is incorrectly built can consequently lead to incorrect simulation or misinterpretation, which may lead to erroneous results and serious consequences, including financial consequences. That is why substantive preparation is crucial. When creating the model, it is important to pursue the biggest simplifications as possible. Thanks to this, the model becomes more understandable and easier to analyse. Moreover, in the case of modernization, improvement in existing solutions and computer simulation are essential, given that trials and tests of real systems are avoided. Simple methods of modelling solutions, as described in the article, which integrate public transport in the Visum software for macro simulation of traffic, may be a clue in solving problems related to the integration of transport.

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