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Improving the Efficiency of Rail Passenger Transportation Using an Innovative Operational Concept

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Abstract: In an increasingly fast-paced world, emerging mobility demands must be met by competitive services that are in line with the principles of sustainable transportation concepts. It is not possible to know exactly what the mobility solution of the future will be, but it is certain that it will require a reduction in car use. A dramatic increase in energy prices will have an impact on the transportation sector, but making public transportation attractive to large numbers of people could reduce unit costs. Public transportation systems can be made more efficient through flexible transportation concepts and by combining individual passenger demand for travel. In the field of rail passenger transportation, practice uses fixed timetables, which do not take into account the changes in ad hoc travel needs. This results in significant losses due to unjustified unnecessary stops and longer travel times. This article presents an operational concept that enables ad hoc passenger demands to be met. The concept ensures minimum energy consumption and a higher level of passenger demand satisfaction through multilevel demand management. A case study was presented to prove the developed theory.

Keywords: management in rail passenger transportation; A-FTS; ad hoc passenger demand protocol; flexible transportation system; FTS case study

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1. Introduction

Mobility demands are present for all members of society in any life situation. Geographical mobility refers to the migrations of individuals or groups: moving from one place to another in an increasingly globalized world; traveling to attractive destinations; and actual journeys made by certain members of society [1]. In this research the term mobility refers to people's complex journeys and not to the possibility of mobility. It is not known what the mobility solution of the future will be, but the reduction of individual car [2] use will be a priority goal. It is true that the passenger car enables a broad and flexible satisfaction of mobility demands, but it has a number of negative environmental and social effects: (i) overcrowding of residential areas (roads and parking lots) [3]; (ii) high specific environmental polluting effect [4]; (iii) high financial investment [4]; and (iv) high operating and maintenance costs [5]. There are many other mobility alternatives to individual car use, such as public transportation (fixed/flexible) and shared mobility options. Many other alternatives of these services are already available today, but individual interests/convenience, hurried lifestyles, and social alienation hinder their spread. Traditional public transportation is limited in its service by the fixed travel time, the fixed distance, and the preannounced schedule [6]. Although these management activities can be well-planned in the case of public transportation, it cannot serve travel demands flexibly. That is why public transportation systems can be called supply-based transportation systems. From a logistical point of view, supply-based production is called the push production [7], so PuT can be symbolized by the push theorem (Figure 1). In this article, individual/private transportation is referred to as PrT and public passenger transportation as PuT. In the case of PuT, services are entirely supply-based and operate on a scheduled timetable. At the same time, demand-responsive mobility provides more flexibility for individual destinations, whereas in general (in the case of MaaS) there are even more mobility alternatives to choose from, but the service area is limited [8].

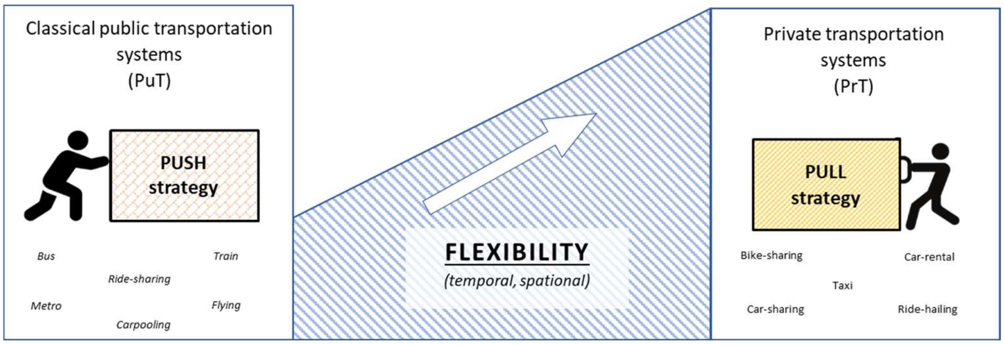

Figure 1. The categorization of flexibility of different transportation services based on passenger demand or service provider supply (authors' own).

The coordination of mobility-as-a-service (MaaS) [9] systems with existing transportation systems would further advance the problem area described above. MaaS services can mostly be operated competitively in densely populated areas, otherwise they are currently being pushed out of the market. Mobility demands can be served with PrT and community PuT services, whereas temporal and spatial flexibility are extremely different (Figure 1).

The concept of flexible transportation systems (FTS) is a service concept that can be adapted to the mobility demands of frequented and sparsely populated areas. The application of FTSs was successful in the case of bus transportation systems, where they began to be used to serve punctual and small travel demands [10]. The purposes of the FTS and DRT (demand-responsive PuT system) are to implement demand-based PuT and to create a rapidly responsive transportation system. Passenger transportation covers the serviced area and flexibly adapts to travel demands in both the spatial and temporal [5] it is a general thesis. However, passenger transportation system important aims are to make it predictable and for passengers to be able to plan with it.

This research aims to explore the concepts of economic and sustainable flexible PuT systems. Therefore, the private mobility modes (car, taxi) are not examined, due to their negative effects [11]. Electric cars are not considered sustainable mobility in the context of this article since, according to research [12,13], their ecological footprint will only decrease later than that of internal combustion cars, they have a high investment cost, and they are not accessible to all people, compared to public transport. The research will result in the definition and systematic development of flexible operational variants of existing globally applied model transportation system concepts.

After the introduction, the literature review is presented in the next paragraph, where the current situation of railways and the potential of rail transportation are highlighted. In addition to this, the FTS systems (A-FTS, B-FTS, C-FTS) used in our research are also presented. In the third chapter, the complex system design of the A-FTS system is presented, together with a description of the operation of each subsystem. Then, the A-FTS passenger demand-processing method is presented, together with the ad hoc passenger demand management module. A case study is then used to validate the available A-FTS operational concept, in which a real railway service is planned step by step.

2. Literature Review

2.1. General Review

PuT has an important role to play in serving remote, dispersed, underdeveloped, and sparsely populated rural areas, which have always had difficulty in accessing services and facilities [14]. However, they also play an important role in urban and high-density areas, but their higher demand makes their occupancy more competitive [15]. PuT solutions can be grouped at several levels according to the size of the served area, its quality, and the used infrastructure. Fixed-route transportation, which can serve long distances on a micro/macro level as a tram, and on a macro-regional level as a railway, can solve the simple mobility of large masses. At the same time, due to the constraints of the transportation route, the flexible operating characteristics are logically difficult to implement [16]. The distance travelled by a fixed-route transportation vehicle is always constant between two endpoints. Therefore, the only parameter that can affect the flexibility of the service on the fixed route is the temporal parameter. This level of flexibility can provide benefits to passengers during low-traffic periods, but in addition to earlier arrival times for passengers, a number of other benefits can be identified on the service provider's side.

In the case of fixed-route transport, transportation safety is high [17], and therefore its popularity is also, although a high level of maintenance work is expected in this respect [18]. Railway transportation systems have high network capacities [19], which also supports schedule reliability, contributing to high-level digitization tools [20] and supported intelligent train control systems [21]. The passenger counting system and process monitoring can be easily implemented with a modern identification device [22], which provides statistics and examines documents certifying travel entitlement. Furthermore, the closed platform area, where only persons authorized to travel can be, is considered an additional factor [23] that increases passenger safety. It is a typical procedure in railway transportation that, in order to balance the low-traffic periods, trips are supported with fare discounts. In China, on the other hand, by applying lower-priced flexible seat prices, it was possible to increase the capacity utilization level, the efficiency of capacity planning, and the total revenue [24]. Similar to booking a flight ticket, the first thing to do is to buy the ticket for the trip, and then the exact seat is only allocated a short time before the trip (or direct booking is available for additional cost). The previous example is a particularly good solution to control the uncertainty of demand, but it is strongly related to the topic of capacity utilization. The increase in capacity utilization is able to function at the highest possible level if the tracking [25] of all railway vehicles, equipment, and devices is solved in the case of traffic and train control systems [19]. In this way, it is possible to effectively manage the connection of the means of transportation that can be used in the given case to the individual flights, depending on the optimal utilization. Data for this are provided by the efficient asset registration system, in which the tracking system stores data in an integrated manner. It can minimize the invested resources by obtaining energy from stops and unmoved weights [26] for the provision of flexible rail transportation services.

In railway transportation, it is not possible to apply flexible fares [27] as easily as in the case of flexible bus services found in the literature. Furthermore, pricing has always been a critical point in this transportation option. In the case of PuT, it operates with a large amount of government support, while market demand-based mobility services are more expensive, as they are operated only on a commercial basis. There is not much previous research in the case of ad hoc or random journeys that can be used in railway passenger transport, only about time-dependent demand fluctuations [28]. At the same time, increased energy prices, which also affect global economic processes, greatly influence mobility habits [29]. PrT (mainly personal cars) will become more expensive. Although the rise in energy prices also affects the PuT sector, specific costs can be kept low with flexible demand satisfaction and adequate capacity planning. In the case of PuT, there are many options to reduce energy consumption, such as modules and logics that support optimal acceleration [30]. Such PuT solutions can also reduce the energy uses of global transportation sectors by reducing private travel, thereby reducing the overall environmental impact to a more manageable level.

2.2. Flexible PuT Conceptions

For the application of flexible transportation systems, operating models are usually designed according to basic transportation properties, as can be seen in the literature [5,31].

There are groupings and typifications in the field, but it is difficult to find basic research results that support the transition to flexible operation at a minimal or even drastic level in current transportation systems [5].

From the point of view of the organization of flexible transportation, it is necessary to identify the possible FTS versions, which differ from each other in terms of service and network characteristics. These can be peculiarities [5,31]: (i) spatial and temporal constraints; (ii) applied traffic level; and (iii) available flexibility. The study [31] served as a basis for delineating further research directions and mapping the little-researched traffic areas. This is shown in Figure 2.

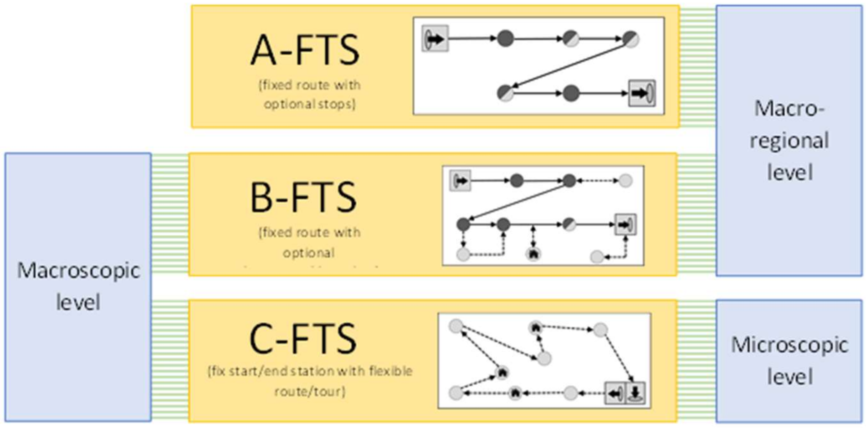

Figure 2. Categories and levels of integration of the FTS concept (authors' own based on [31]).

These flexible transportation concepts transparently summarize the elements and parts of PuT where it is relevant to incorporate flexible operation. Furthermore, they can be identified as unique characteristics where they can be influenced based on individual flexible operational characteristics and properties. In all cases, a dedicated PDMS (prediction demand management subsystem) subsystem deals with the processing of passenger demands.

Category of flexible transportation systems conceptions [31]:

- **A-FTS:** a flexible PuT concept in which the transportation vehicle (on a fixed route or flexed route) always travels the fixed route between the starting point and the end point; individual stops can be considered fixed and optional in the system; stops can be identified by handling passenger demands; stops related to passenger demand are co-ordinated by PDMS. It can be coupled with macroregional transportation classification because it can be used for long-distance transportation. Approximately 100–250 km.
- **B-FTS:** flexible PuT concept, in which case there is a one-line route (spine) between the starting point and the end point, which is fixed; the transportation vehicle always travels to all the fixed/optional stops on the ridge, but in case of travel demand, it travels the optional detours and branches from the ridge line; passenger demands are processed by the PDMS subsystem; door-to-door transportation service is also available. At this level, the system can be applied at the macroregional and macro level because of the conditional boardings, such as, for example, for flights across cities of 1–2 million people.
- **C-FTS:** the level of flexible transportation systems when only the starting and ending points are fixed in the passenger transportation system; the start and end points are located in the same place, therefore the journey → vehicle route problem; the transportation vehicle touches alighting and/or boarding stops according to passenger demand; PDMS organizes journeys based on optimal capacity utilization. C-FTS is a self-organizing, almost entirely demand-responsive sector that can be used to serve urban districts and small towns. It is a microscopic solution.

Among the FTS levels, A-FTS tries to adapt its service to passenger demand in an area that has not been researched thus far. At the same time, the consideration of ad hoc passenger demand during the final timetable also shows a new approach in macroregional transportation systems. Thus, among the three FTS concepts, in this research, the A-FTS level was further analyzed in detail from the point of view of operation.

The flexible PuT levels presented above represent a new approach for FTSs, as shown in the previous three years of research by authors [5,31]. The FTS or DRT systems used in the last 20 years can only rarely be applied competitively in populated areas [5]. Nevertheless, these systems are organized according to the needs of microcommunities and provide an efficient PuT service for the mobility difficulties of passengers [27]. In contrast, FTS and DRT systems could only satisfy travel demands that arrive in the pretrip period, and therefore ad hoc passenger demand satisfaction can no longer be handled by the respective occupancy.

Further literature review revealed that many studies have not investigated flexibility (spatial/temporal), levels of flexibility, or connected services [5,31]. Case study and pilot FTS systems have been analyzed and elaborated in the literature. The aim of the current research is to formulate general basic ideas and theses for the resilience of PuT systems. Furthermore, it will develop new innovative scheduling procedures and PuT management proposals reflecting on an identified research gap at the A-FTS level. The development and implementation of an A-FTS system on railways is also unique within the research gap, as there is no example of this in the literature and among the systems in common use today.

This can be identified as a problem because PuT service during low-traffic periods has limited or no saleability. If individual travel or PrT or other services cannot be used by a passenger, this can be identified as a serious social problem, such as waiting at night for the first PuT possibility at morning, etc. This is why the FTS concept to be presented will be applicable, as travel destination demand does not disappear in low-traffic periods, but decreases.

These flexible transportation levels are a new way of approaching these FTS solutions, as there has been no spatial/temporal flexibility-based organization of these FTS solutions. At the same time, the application on rail is a new trend in the application of AGVs [5,31]. The FTS or DRT systems that have been deployed in the last 20 years have been organized around the needs of sparsely populated areas in microcommunities [31]. However, in the case of scheduled services operated by national transport companies, they have not yet been implemented competitively [5].

3. A-FTS Conception Description

In this chapter, the framework for an A-FTS flexible transport concept will be presented. Its area of application in PuT systems will be identified, and then the entire A-FTS operational system plan will be presented. After that, the layout architecture and structure of the subsystems will be described, with particular emphasis on the information flows among the modules.

3.1. Framework for A-FTS

The theorem of the flexible transportation concept of A-FTS can be applied in the organization of transportation to satisfy the passenger demand arising in low-traffic periods. At the same time, it can be effectively used in macroregional transportation in terms of the spatial (Figure 3). The advantages provided by the flexible operation of the A-FTS concept are recommended for application during low-traffic periods. This new transportation organization approach differs from traditional transportation in that the passenger vehicle only stops at the stops identified during the processing of passenger demand in the preannounced timetable. In contrast, this is not feasible during high-traffic periods, as traditional PuT is more suitable for serving a large number of passengers' demands. To determine the application periods of the two types of transportation organization theorem, they can be derived based on long- and short-term demand forecasts [32]. During the flexible operation provided by A-FTS, the vehicle covers the entire route, mainly because the distance (s) traveled on the railway is always constant during the transportation between the start and the end station.

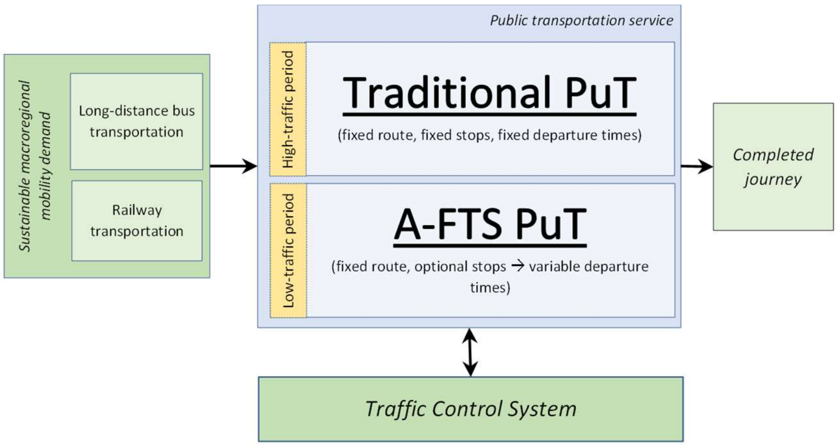

Figure 3. Placement of A-FTS in the organization of PuT services (authors' own).

In general, the operational feature of bus transportation is that the transportation vehicle stops at the relevant stop only when there is a demand for passengers to alight and/or board. However, due to the missed stops, extra time is created in the schedule data of the later stops, so the indicated departure time can be misleading and can result in an unsuccessful trip. Therefore, it is necessary to map the possible change of the journey times depending on the changing passenger demand, thus a flexible operation in time can be defined. If this system is connected with digitalization technical devices and platforms [33], then a new 21st-century transportation service can be implemented through it. This service is able to adapt and react to stochastic passenger demands [34].

Flexible operation within the A-FTS system is ensured by the PDMS subsystem based on the defined stops. The travel time can vary depending on how the passenger demand develops in the phases before the departure of the journey. For passengers, a shorter travel time can result in a higher-quality level of transportation service. The operational system plan of A-FTS was built based on the logic of use during fixed-route transportation. The present research, the A-FTS concept, is the implementation of flexible transportation elements that can be connected to railway passenger transportation, which is considered a new approach.

The basis of the flexible operation logic of A-FTS is that the vehicle stops at the stops indicated in the timetable only if there is a need to alight and/or board. The processing and management of demands ensures a transportation service that serves the actual passenger demands.

Even in the case of A-FTS application, a digital system or platform [33] is essential, on which short-term passengers demands can be registered. In this digitalization system, passengers must enter their alighting and/or boarding demands, based on how the expected arrival/departure times can be forecasted depending on the existing demands. Of course, this would provide a reasonable time window for information in an announced scheduled timetable. The maximum travel time among the two endpoints would be the travel time calculated by stopping at the alighting and/or boarding points. Then, in the period immediately before the departure of the journey or depending on ad hoc passenger demands, the time parameters can be normalized [35]. The travel time of the given journey affected by passenger demands cannot be greater than the maximum travel time announced in advance.

The operational logic and the available passenger transportation benefits will be shown in a later chapter. First, the operational system plan of the A-FTS concept is presented in detail, together with the flow of information between modules.

3.2. Layout Architecture of A-FTS

The presentation of the A-FTS system in this article will take place in a railway context through fixed-route transportation. Bus transportation is capable of spatially flexible service.

That is why it is concentrated on the mode of railway transportation where the vision of a flexible transportation service has not been researched and investigated so far.

In the case of railways, the A-FTS flexible transportation conception ensures temporal flexibility by utilizing existing infrastructures. It can be a viable application for macrolevel fixed-track passenger transportation (tram, suburban-railway), but mainly in the field of macroregional and long-distance train transportation.

Regarding the design and operational system elements illustrated in Figure 4, there are common sections between traditional PuT and FTS designs. From the point of view of this article, the presentation and investigation will take place from the perspective of A-FTS. As a result, in Figure 4 all processes are presented as the planning of operation at the A-FTS level, since the individually grouped modules represent one of the novelties.

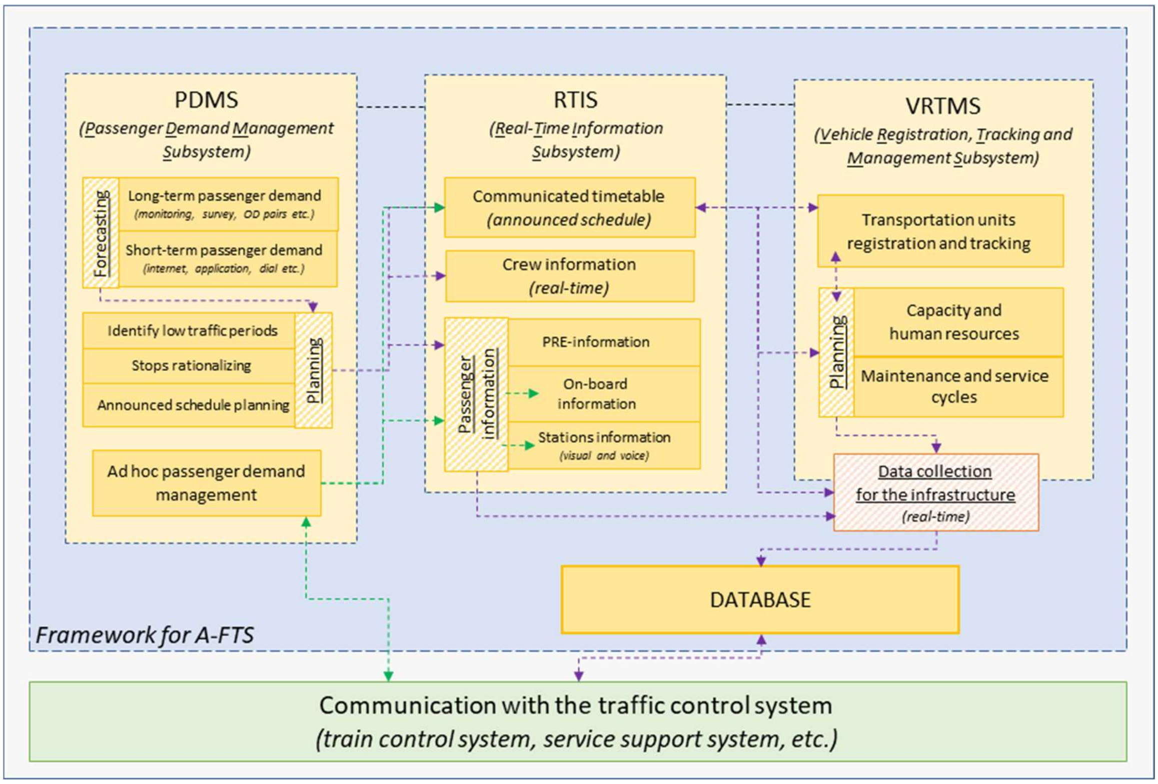

Figure 4. Layout architecture of A-FTS (authors' own).

3.2.1. Passenger Demand Management Subsystem

The PDMS subsystem consists of three modules: (i) forecasting; (ii) planning; and (iii) management of ad hoc demands. Together, these serve as a basis for other areas of the service.

Passenger demand forecasting plays a very important role in PuT [36], so within the A-FTS system it performs this task within PDMS. In order for a journey to serve passengers according to their demands at the A-FTS level, a demand forecast must be carried out, during which the passenger demands are examined (at several levels). The passenger demand forecast consists of long-term and short-term forecasts [37]. Long-term forecasts can be made based on the travel and utilization statistics of the given area [38]. The statistics contain how many passengers alighted and boarded at which stops at each time of day [39], as well as which were the most popular travel OD pairs, which can be stored in multidimensional OD (origin-destination) matrices [40]. OD information may come from the processing of cellular phone information [41]. This information aggregates the structure of historical data [38,42]. If there are data from flexible transportation services that are already available, then the historical database must also contain them. Moreover, digital passenger demand request interfaces must be provided to the service areas [33]. It is possible that by applying the traditional theorem, the survey conducted in the target area must be carried out, and public forums must be organized. The available data can be analyzed using algorithms based on artificial intelligence, using deep learning methods and pattern search algorithms [36,38]. The data analysis procedures can be used to identify the commuting habits, busy areas/conditions, and high-traffic periods specific to the given OD [43]. In the long-term demand forecast, continuous monitoring of the number of passengers can also provide reliable data [44]. In the case of the long-term forecast presented above, short-term forecasts can provide planning information from more detailed data. It is also necessary to show the demand for specific times of the day or even 15-min periods. In the case of railway transportation, it is enough to analyze time of day, since the alternation of low- and high-traffic periods is not as sharp as, for example, in the case of PrT. In the case of transportation service companies, the already-used IInternet ticketing applications are accepted as short-term forecasts. In this way, demands received in the hours immediately before the departure of the journey, necessary for flexible operation, can be processed. This means assessing short-term demand at the A-FTS level. These data can be received outside of the phone application, but also through a phone notification (due to seniors) [35]. With this information, a more accurate forecast can be given for the flights serving the given period. Overall, it can be concluded that the long-term forecast examines the constantly present travel demands of the served areas, while the short-term forecast provides planning information for a specific journey. The efficient processing of planning information serves to ensure that the timetable matches real passenger demands as accurately as possible during central passenger information.

The planning of the schedule timetables relies on the forecast data within the PDMS subsystem. During planning, the primary conclusions to be drawn from the available data are whether it is necessary to advertise a journey in the given service area in the given period as an A-FTS flexible journey. There are high-traffic periods when flexible operation does not make sense, as there are passengers alighting and/or boarding at every stop, so significant travel time savings would not be possible. Thus, it is a key task in planning to identify suitable periods for A-FTS. If it is possible to identify an A-FTS service period, then the relevant stops and railway stations must also be rated. Stations can be: (i) fixed high-traffic stations, which are usually cities with a large population or frequent transfer points; (ii) optional stops for smaller settlements; or (iii) buffer stations. The logic of the buffer stations is necessary because there would be a critical time gain between the announced schedule and the schedule after the vehicle's departure, so the transportation vehicle spends the announced departure time at this station waiting.

It may happen that there are passenger demands that enter the subsystem immediately before or after the departure of the journey. That is, the given demand is not contained in the announced schedule designed based on predictive demands. Such requests are called ad hoc passenger demands. Ad hoc passenger demands can only be interpreted as boarding and alighting demands relating to the starting point of the journey or the remaining sections of the journey relative to one's current location. These demands can only be served if the unplanned stop does not disturb other journeys outside the A-FTS transportation system (for example, other fixed-route and cargo journeys) or does not affect the time data indicated in the announced schedule. Disruption means a negative operational impact, i.e., other journeys are forced to slow down and/or stop. Therefore, at the A-FTS site, the PDMS subsystem needs a continuous information connection with the traffic management system. This includes a vehicle tracking system and vehicle-to-vehicle communication (V2V) [45] that can quickly respond to requests and then notify the passenger of the decision. The decision mechanism for assessing ad hoc passenger demand applicable to A-FTS is defined in Section 4.

3.2.2. Vehicle Registration-Tracking Management Subsystem

The vehicle registration, tracking, and registration subsystem (VRTMS) can support organizational and operational tasks not only at the A-FTS level, but also in the entire approach system. In order to increase traffic safety in the field of train interference, it is necessary to identify and track vehicles moving on the tracking [46]. Tracking is possible with static blocks between two stations, smaller temporal or spatial space blocks (static or moving), or real-time data communication along the railway [47]. However, these solutions do not satisfy efficient capacity planning, as flights are identified and not motor trains, locomotives, or wagons. The capacity of railway vehicles is absolutely not uniform, so more accurate location data and stock databases are needed for capacity planning [48,49]. Data related to each rail transportation unit, such as registration and maintenance information, must also be assigned. One of the foundations of flexible PuT is that, based on forecasts of passenger demands, transportation is carried out by rail transportation units with the appropriate capacity. The goal of the strategy is to minimize energy consumption and costs while fully serving passenger demands. During the execution of the processes of the VRTMS subsystem, up-to-date information on the geographical location and availability of the elements of the vehicle fleet [46] is always available from continuous monitoring. In addition to all this, the subsystem also supports vehicle maintenance and service activities, which also contributes to the planning of service routes [18] and the determination of the related human resource management [47].

Looking at the subsystem allocation layout model of the VRTMS subsystem (Figure 5), it can be concluded that it relies heavily on traditional traffic management, traffic organization, and infrastructure registration databases. At the same time, there is a direct connection among the elements of the VRTMS subsystem and the other subsystems. Data and information related to rail transportation units can be accessed through identification solutions. In the case of identification solutions, it is necessary to delineate two directions. First of all, the technique of identifying the rail transportation units must be solved, which can be done on a trackside, boardside, or mixed basis [50]. The trackside solution means that the identification devices are built as part of the rails, so that the rail transportation units in front of the readers can be identified as they pass (the reader unit is part of the rail transportation unit, and the tag is placed on the transportation infrastructure). During the board identification solution, the reading device used during identification is located on the rail transportation unit, and the tags to be identified are located on the rails [48]. Mixed operation occurs when the rail transportation unit is prepared for both types of identification techniques, as different identification options are available on different sections of the transportation infrastructure. It is also important to describe the identification technology used. This can be done with short-term radio frequency identification (RFID), mobile communication signal transmission (GSM-R—Global System for Mobile Communications—Rail) [51], or GPS-based positioning [48]. These identification technologies are modern solutions used in Europe. During the tracking, based on the Figure 5, it is not necessary to transmit only the movement/journey information to the databases. For the elements of rail transportation units registered, in the case of passing through the exits and entrances of the stations, the module must enter or exit the identified transportation units in the infrastructure register or logging of the given station. Advanced multidimensional identification OCR (Optical Character Recognition) gates [52] can be placed in these entrances and exits, as all information displayed on the passing train and its wagons can be found out through the intelligent system, and a digital image of the train can also be stored. The digital visualization can be used not only as a supplement to tracking systems, but information on transportation units and possible damage can also be viewed back. Overall, tracking can be implemented by processing data from identifications. During monitoring, there are also techniques that can be done on a distance or time basis, including real-time monitoring [47] that provides the most accurate data (Figure 6).

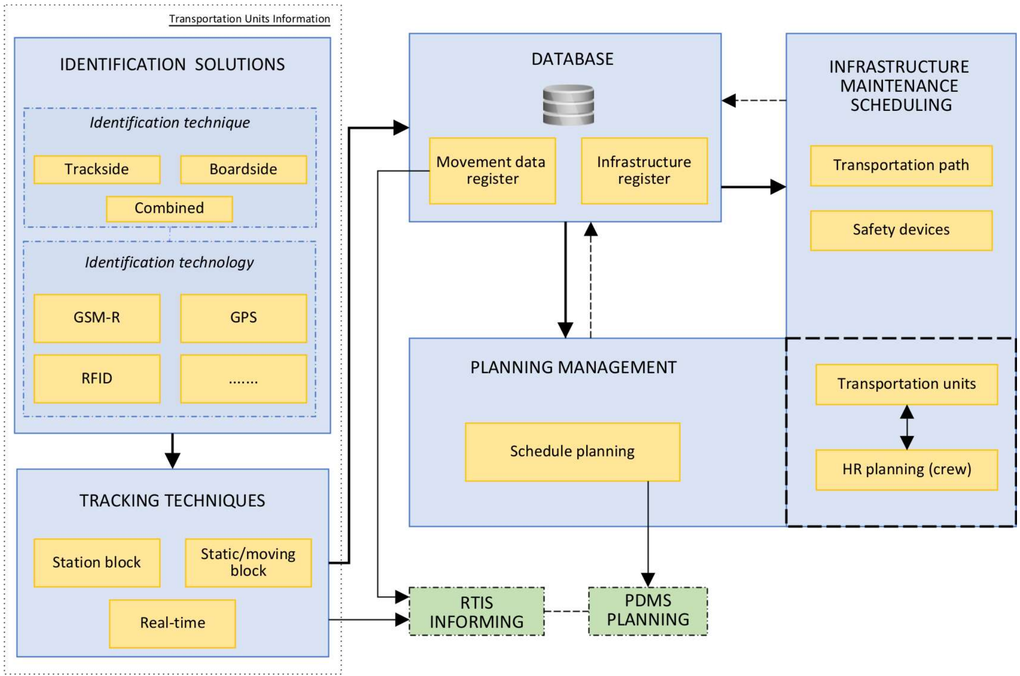

Figure 5. VRTMS subsystem allocation layout model (authors' own).

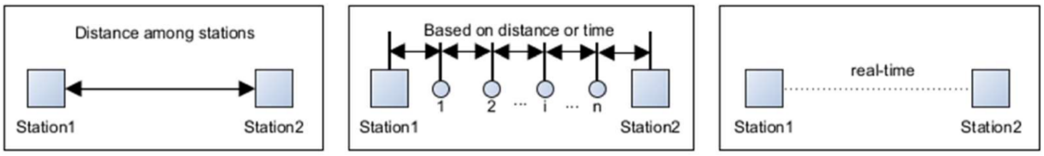

Figure 6. Rail tracking techniques (authors' own).

The use of static block between two stations is a point-by-point tracking technique in which the traffic management does not have precise information about the transportation vehicle, only which station it left and which one at which it will arrive. The mode of identification using a static block between two stations is rare, so it is not advantageous to use it in busy and long-distance networks [53]. The one more specific option is when the distance between two stations is resolved into given blocks based on time or distance. The equipment required for identification is placed on the border lines of the blocks, so the tracking of transportation units is one degree more accurate [54]. Even more accurate monitoring can be achieved by reducing the above-mentioned intervals, but the cost of the installation would increase depending on this, so a solution is needed that requires the use of completely different technology. This technology can be the previously mentioned GSM-R system through continuous data communication, which means the installation of transmitter towers next to the transportation track at every distance of transmission and reception, so that continuous monitoring with an accuracy of up to few seconds can be realized [51]. In addition to this solution, tracking with similar accuracy can also be achieved using GPS, which maps the route of the rail transportation unit via the satellite connection [48]. In general, for an effective tracking system, it is not enough to use a technology that serves a technique, since the failure of one of the solutions is possible. The basis of the tracking of rail transportation units is the identification of different data contents at certain locations, so there is a significant correlation between the two areas. These areas transmit information to the A-FTS flexible traffic system RTIS subsystem for accurate information.

In the case of the A-FTS framework, it was also seen that the data are collected in the database, and in the event of a need for information for planning, it comes from the database. In the case of the VRTMS subsystem, the information registered in the database can be divided into two parts. One is the register of the movement data of transportation units, and the other is the register of information related to infrastructures. The infrastructure register provides important information for planning management, which provides data for HR planning to a greater extent and for scheduled timetable planning linked to the PDMS subsystem. For human resources (HR) planning, the data from the infrastructure register is important because multilevel human resource capacity is based [55] on information from the schedule and infrastructure status [56]. At the same time, there is feedback to the database regarding the results of the designs. On the other hand, the infrastructure maintenance schedule is largely based on the data files in the database. The maintenance schedules must also be stored in the database, as planned maintenance affects the scheduling of rail transportation units. Furthermore, the maintenance schedule of the safety devices and rail transportation infrastructure may affect the passenger transportation activity announced in the timetable [56]. In this way, travel time changes caused by closures and restrictions can be calculated using the real-time passenger information [57].

The operation of the VRTMS subsystem is complex and includes not only flexible transportation service requirements, but also processes that can be used to plan community passenger transportation services with a traditional schedule.

The A-FTS flexible transportation concept layout architecture and the connections among modules are illustrated in Figure 4. The operation of the system, the connections among the subsystems, and the information flows are explained in the following subchapter.

3.2.3. Real-Time Information Subsystem

The RTIS is the main information subsystem of A-FTS and the entire traffic system, which fully serves traffic communication. It receives data from other subsystems and from real-time communication with traffic control systems.

In transportation, the basic information for passengers is the scheduled timetable announced in advance. The timetable includes the announced conditions (OD), the affected stops, and the corresponding time parameters [57]. Scheduled timetables are prepared on the basis of long-term passenger demand forecasts, which reach passengers through various communication channels (for example, boards, Internet, and timetable applications). Traditional PuT timetables contain fixed arrival and departure parameters, which render the system inflexible. Therefore, scheduled times usually change in a negative direction due to flight delays, which also affects other transportation units operating in the network. The scheduled timetable of a schedule is to provide information, so the parameters are only displayed with larger character sizes. It contains: [Origin]; [Destination]; [Departure time]; [Destination]; [Platform]. If the schedule contained too much information, the information would not be acceptable or informative for the passengers [6].

In the case of the flexible transportation service (A-FTS), if there is no demand to alight and/or board at a stop, the rail transportation unit will not stop. If there is no stop, the vehicle may arrive earlier at the next announced stop and modify the time parameters in the entire transportation system. The scheduled time-window timetable structure is therefore being introduced and applied in the A-FTS-level transportation service. If there are several optional stops in the system, when approaching the endstation, there are increasingly large time differences in terms of time window. Furthermore, the transportation service can also be negatively evaluated due to the wide time windows, so it is necessary to eliminate this problem by introducing buffer stations.

Internal communication is important in the role of a transportation service company, as is real-time service information in transportation systems. It is important for employees to receive the quality information needed to perform their tasks at the right time and to have time to react to them. Compared to the passenger information systems, the service information module is more detailed and contains information that affects the operation, which is not communicated to the passengers. This is a completely different type of information module, which can include crew and related travel data.

The role of passenger information is important in the A-FTS flexible transportation system; as compared to the planning of journeys, plans, and scheduled timetables, the implementation can change on several levels. It can be stated that the passenger information at the A-FTS level has several levels. It is based on the planned and announced central timetable information from the PDMS, depending on the long-term passenger demands of the service period. This is followed by a minimal schedule correction based on short-term passenger demands received in time before the departure of the flight, which can minimally modify the scheduled time windows. This information is then synchronized in the timetable applications, in the audio and visual information systems at the stops, and on the on-board passenger information surfaces. If an ad hoc passenger demand is received and can be fulfilled, data are synchronized accordingly on the previously described interfaces. It is important that ad hoc requests involving large changes in travel time are not supported, as they would greatly affect the travel quality of other passengers.

4. A-FTS Passenger Demand Processing Methodology and Ad Hoc Demand Management Protocol

The layout of the architecture of the subsystems of the A-FTS was presented above. It has already been mentioned that traditional PuT and flexible transportation at the A-FTS level have a common cross-section in terms of certain operational and planning processes presented. Thus, these operating conditions do not stand out in scientific processes, but the modules supporting planning and operation related to A-FTS do. Among such innovative approaches, in this article it is necessary to highlight the logic of managing ad hoc travel demands.

4.1. Defining a Model Structure

The important task of flexible transportation services is to serve passenger demands at a level that avoids unnecessary stops within the service. For the decision mechanism of the system of ad hoc passenger demands, the mathematical connections among schedules and different passenger demands must be laid down. In the case of A-FTS, the scheduled timetable is defined at several levels, which may change depending on the time and available passenger demands. Table 1 contains the A-FTS relevant schedule definitions.

Table 1. Schedule types appearing at the A-FTS level (based on Section 3.2.1).

Mark:	$\overline{ST}^j$	$\overline{SCH}_0^j$	$\overline{SCH}_{real}^j$	$\overline{SCH}_{act}^j$
Application:	set of j-th journey stops	announced schedule of a set of j-th journey stops	real schedule of a set of j-th journey stops	actual schedule of a set of j-th journey stops
Type of passenger demand:	-	long-term demands	short-term demands	ad hoc adjudicated demand

The stops in the given transportation system are marked by $\overline{ST} = \{1, \ldots, \theta\}$; the journey (train) is marked by $\overline{T} = \{1, \ldots, \gamma\}$ sets. If $j \in \overline{T}$, then it is true depending on passenger demands:

$$\text{in the case of traditional PuT } \forall\, j \in \overline{ST} \tag{1}$$

$$\text{in case of A-FTS transportation } \neg\forall\, j \in \overline{ST} \tag{2}$$

Based on the (1) condition, the initial state of the model assumes that the given flight stops at every stop. The organization of flexible transportation differs from this in that, according to (2) condition, that journey does not stop at all the stops. Only those that are affected by passenger demands and a buffer time against exceeding the time window are required.

Long-term demand forecasts can be used to identify long-term travel needs, which provide a basis for editing the schedule. Based on such needs, it is possible to calculate and obtain information about OD pairs and traffic at stops. The sign of the j-th journey's announced schedule is a $\overline{SCH}_0^j$.

Short-term passenger demands for individual journeys ($\overline{PD}^j$ in the case of j) can be submitted in the period before the departure time, which can be up to 1 day. The second level of passenger demands collection can already be linked to the specific passenger demands of individuals. In this way, in the short period before the departure of the current journey, specific information is available on the service company's website, for example, which stops are expected. At the A-FTS level, this is called the real schedule, the sign of which is, for the j-th journey, $\overline{SCH}_{real}^j$. In the case of a real schedule, (3) condition is valid, that all passengers at the A-FTS level submit their preliminary demands ($\overline{PD}^j$) via the available platforms, which are processed by the module. These demands must be combined with the announced schedule data of $\overline{SCH}_0$. From this, a so-called real schedule is created, which is properly adapted to the passenger demands.

$$\forall\ \overline{PD}^j \in\ \overline{SCH}_{real}^j \tag{3}$$

The real schedule provides more accurate information for passengers, and it can also be one of the advantages of flexible transportation, which can also include a reduction in travel time. On the operational side, crew are able to prepare the transportation vehicle for the journey more precisely. In addition, a number of operational savings and capacity savings due to flexible operation can be identified. More precise information is also available to serve the given situation, so that the transportation vehicle with the optimal capacity can be selected or assembled according to the passenger demands. The preliminary planning information database can also affect the clarification of the HR plan, and depending on this, the information on the service information interfaces is updated based on this.

The third level is the management of ad hoc passenger demands. The peculiarity of flexible transportation systems is that the transportation is carried out only on the basis of data received in advance. In the case of A-FTS, it is possible to incorporate ad hoc demands into the operation of the system. There are cases when service quality is negatively affected by serving an ad hoc demand, so the system must have a module that examines several possibilities and decides whether the request can be satisfied. As a result of the decision, the actual schedule can be modified with a minimum correction, and the changes calculated from the schedule data create the actual schedule (SCH_{act}).

Before describing the management of ad hoc passenger demand, it is important to describe the structure and relative position of the above-defined schedule versions.

$$\left(\overline{SCH}_{act}^j \cup \overline{SCH}_{real}^j\right) \subseteq \overline{SCH}_0^j \subset \overline{ST}^j \tag{4}$$

Figure 7 shows the relative versions of the schedules of the given journey. The passenger demands typical of the low-traffic period result in a smaller number of stops than the number of stops on the entire line. At the same time, it can also be established that ad hoc passenger demand may also affect stops that are not served during the actual schedule arrangement. This is also why it is important to declare the decision logic of ad hoc travel requests because the actual schedule may change to a minimal extent depending on this.

4.2. Ad Hoc Passenger Demand Management Methodology

The set of ad hoc demands for a given flight j is denoted as the set $\overline{AHD}^j$. Submission of ad hoc requests is entered into the A-FTS system via the digitalization platform provided by the transportation service company. The module within the PDMS subsystem handles the received demand individually. The examination processes of ad hoc passenger demands are contained in Figure 8.

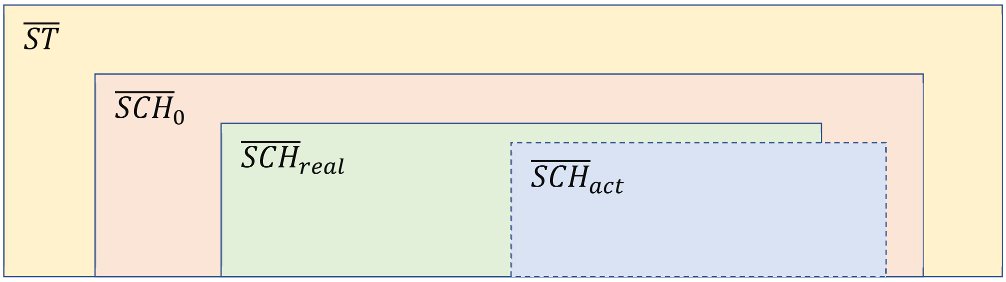

Figure 7. A-FTS timetables based on (4) condition (authors' own).

The first check in the decision tree after the demand-journey identification is whether the demand contains a departure for the START station. It is necessary to examine this fact at such an early stage since different situation assessment methods will be included at the later decision level. Related to this, ad hoc demand will be assessed in a situation assessment according to the START or RIDE protocol. It is important to note whether the received request fulfills the input data criteria of the ad hoc passenger demand management protocols. These steps are explained in detail in the following paragraphs.

At the second decision-making level, it is examined whether the received demand already contains the $\overline{SCH}^j_{real}$. If yes, then the demand can be fulfilled since the stop has already been planned based on another demand. In this case, the actual schedule data will not be changed. If $\overline{SCH}^j_{real}$ is not included, the examination continues.

At the third decision-making level, the decision module examines whether the journey has already started. If not yet, in this case too, the stop will be planned in the $\overline{SCH}^j_{real}$. If yes, the classification of the stop marked on the received demand will be an ad hoc demand. When the module detects this, it starts the situation evaluation processes at the next level based on $\overline{SCH}^j_{real}$ and the current traffic management information.

At the fourth level, the two sides are already more sharply separated from each other. In the left branch, there is the START ad hoc demand, and on the right side, the RIDE ad hoc demand management process. At this level, it is no longer possible to attach to the $\overline{SCH}^j_{real}$ schedule, so the $\overline{SCH}_{act}$ schedule can come into effect at this level, which includes changes based on ad hoc demands. The START protocol examines the stop marked on the passenger demand from the point of view of whether the performance remains within a safety standard.

The decision logic of the ad hoc decision passenger demand module is a transparent and easily programmable tree. The case study is not aimed at examining this part. Regardless, it is an important task to deal with this part, but this will be possible during the validation of the A-FTS subsystem that will be completed in the future, which will require the publication of more research and journals.

The START and RIDE protocols rely heavily on traffic control and schedule data. The module performs the calculations from this. If the following restrictive conditions are met, the passenger's needs will be met.

Conditions examined during the START protocol:

- if $\overline{AHD}^j_{act}(START)$ alighting stop included the $\overline{SCH}^j_0$,
- if $\overline{AHD}^j_{act}(START)$ the stopping time associated with the request does not exceed $\overline{SCH}^j_0$ the latest scheduled arrival time at the endstop.

The START protocol has simpler conditions, since the alighting location is known, so the travel time increment inferred from the travel data only must be calculated for the alighting stops.

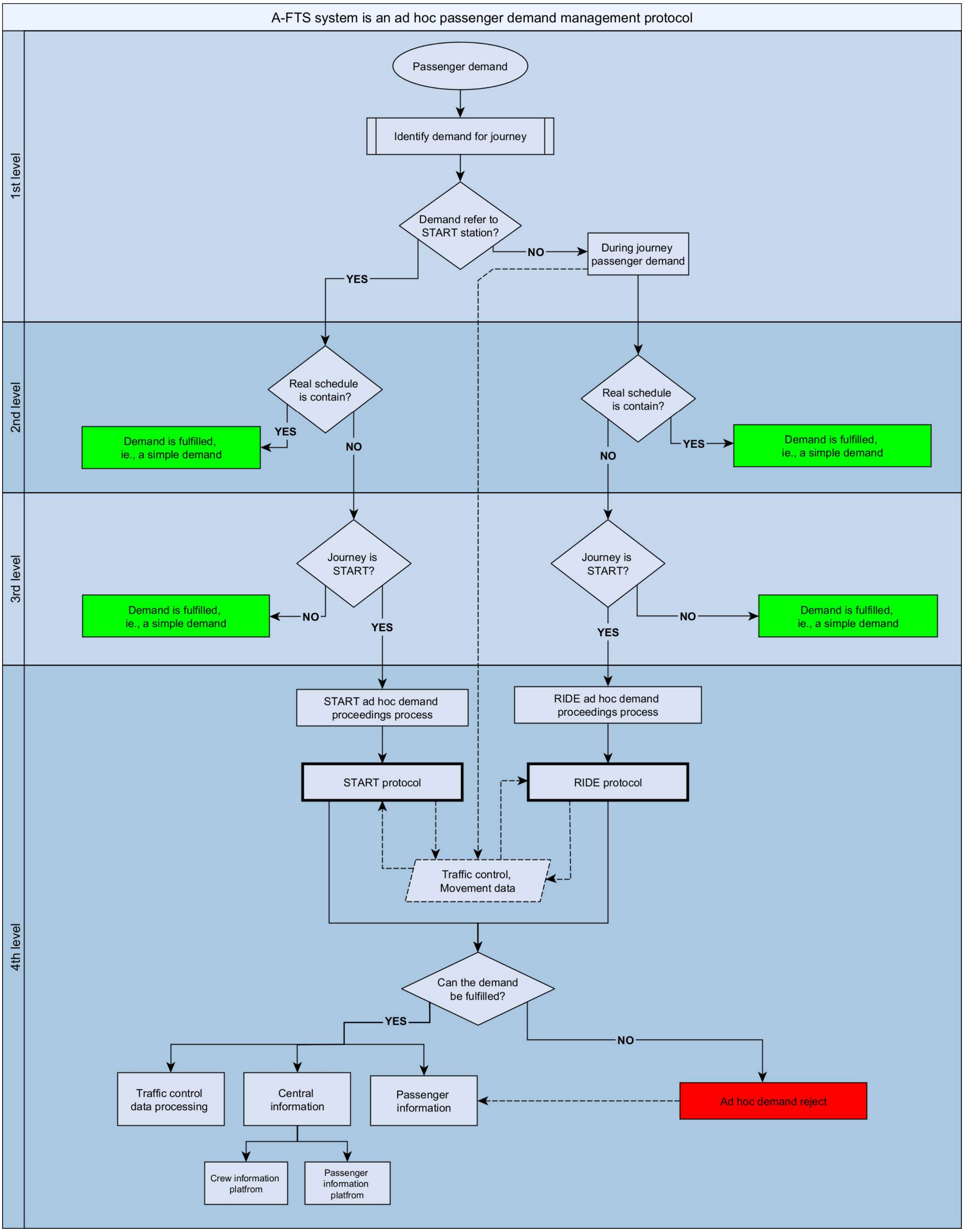

Figure 8. Logical operation of an ad hoc passenger demand management module (authors' own).

Conditions examined during the RIDE protocol:

- if $\overline{AHD}^{j}_{act}(RIDE)$ boarding and alighting stop included the $\overline{SCH}^{j}_{0}$,
- if $\overline{AHD}^{j}_{act}(RIDE)$ stop (boarding and alighting) extra time to demand does not exceed $\overline{SCH}^{j}_{0}$ the latest scheduled arrival time at the end stop.

In the case of the RIDE protocol, the increase in time that can be spent on alighting and boarding stops must be considered. In this case, the mathematical chance of fulfilling the ad hoc demand is lower. If one of the boarding and alighting stops was included in $\overline{SCH}^{j}_{real}$, in the best case, there is a higher chance of a positive evaluation of the ad hoc demand.

Ad hoc demands are handled individually, so the earliest received requests have a higher chance of being fulfilled. The time available to serve ad hoc passenger demand is the difference between the travel times in the $\overline{SCH}^{j}_{0}$ és az $\overline{SCH}^{j}_{real}$ schedules. This is a uniformly applied limiting condition for both protocols. The $\overline{SCH}^{j}_{0}$ schedule provides a wider framework, in which the $\overline{SCH}^{j}_{real}$ is trained before departure, but a flexible framework is provided to satisfy ad hoc passenger demands. Exceeding the travel time of $\overline{SCH}^{j}_{0}$ represents the quality limit of the announced PuTservice and cannot be overridden by the PDMS subsystem module under any circumstances. Based on this information, it must be stated in the $\overline{SCH}^{j}_{0}$ schedule that this schedule may change to a minimal extent due to the management of short-term and ad hoc demands, but that the journey times indicated there are the maximum, which may not be exceeded under any circumstances.

The START or RIDE protocols provide the information to the decision branch at the fourth level. The passenger will be notified directly of the result of the ad hoc demand evaluation via the reservation system. If $\overline{AHD}^{j}$ can be fulfilled, the information must be provided at several levels. The changes in travel time that have occurred must be published on the central information platforms. These are extended on service communication interfaces and passenger information platforms (displays on board and at stops). Furthermore, changes to the $\overline{SCH}_{act}$ schedule must also be recorded for the traffic management, so that the information concerning the infrastructure is up-to-date.

5. A-FTS Case Study

The A-FTS concept will be demonstrated through the passenger demand management described above and the START protocol ad hoc demand fulfillment test through a case study (in following figures and equation notation only: *cs*). First of all, the system boundaries must be clarified, as the full A-FTS model would require the development of additional operational methods and protocols, which will be developed in later research phases. Therefore, the system boundaries of the case study only refer to the management of passenger demand depending on the specific dynamic characteristics of the travel path. The grouping of the A-FTS concept passenger demands by stops described in the previous chapters, the temporal variation of travel time data, and the assessment of the free time capacity available to satisfy ad hoc passenger demands are shown as a function of the input parameters.

The case study-examined travel path contains the stops of a real Hungarian railway line (between Budapest and Miskolc).

Properties and parameters of the examined travel path [58]:

- 182 km;
- A total of 28 pieces intermediate stations and stops (different distance between stops);
- Maximum speed 120 km/h;
- The travel times (acceleration and deceleration) from the stops were determined during on-site (own) measurements (Table 2).

Table 2. Extra time from acceleration and deceleration.

	Speed Change	Distance	Time
Acceleration	0 → 120	2.9 km	165 s
Deceleration	120 → 0	2.35 km	140 s

The two edge states that arise during flexible route planning are first illustrated on a sample travel-time graph. Subsequently, a travel-time graph of the journey based on generated passenger demand is plotted based on A-FTS trip planning principles. The presentation is complemented by an examination of the possibility of incorporating ad hoc passenger demand based on the decision logic introduced in the previous chapter. After that, conclusions are drawn, and further design practices are identified.

5.1. Time Gap Illustration

Figure 9 illustrates the time gap that can occur at each stop for the two types of travel times: the train runs along the travel path without stopping (TT_{min}); it stops at each stations/stops (TT_{max}).

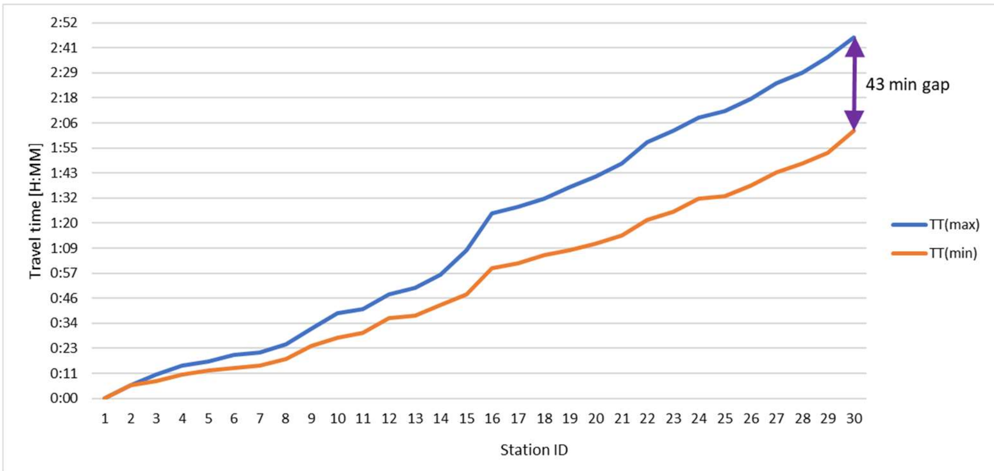

Figure 9. Travel time variation between different flexible journey plans (authors' own based on MÁV-START public dataset).

As may be observed, after a common starting point, time gaps increase over a 180 km travel path. This shows that the size of the resulting windows varies proportionally with the length of the track segment and the number of stations/stops.

5.2. A-FTS Railway Journey Planning

Before presenting the case study, it is necessary to clarify the driving dynamics parameters that have an impact on the calculation of real travel times.

The dataset in the above table was created by averaging five acceleration and deceleration curves. These curves in the table above were measured with a GPS tracking sensor with an accuracy of 1 s [59]. Between two stops, the vehicle's journey path at a speed of 120 km/h is delimited by acceleration/deceleration sections. Acceleration and deceleration periods increase the travel time at each station/stop by the times in the table above. Furthermore, each stop must add +1 min of waiting time to the journey time due to boarding and alighting. The waiting time used in the railway is 1 min [60]. From these considerations, it can be concluded that the total travel time is increased by the time increments t(brake), t(fast), and t(wait) of the stops generated by the passenger demand. If the train is not required to stop at the station/stop, then only the time of the journey path at maximum speed needs to be counted.

According to the schedule-planning principles of the railway line presented in the introduction of the chapter, based on the A-FTS flexible transportation concept, the $\overline{SCH}_0^{cs}$ schedule must first be defined. Long-term passenger demand in this case includes the stops affected by the current "sebes" train journey (Equation (6) set and orange line in Figure 10).

$$\overline{ST}^{cs} = \{1;\ldots;i;\ldots;n\},\ \text{where } n = 30 \tag{5}$$

$$\overline{SCH}_0^{cs} = \{1;8;10;12;15;16;21;22;24;27;29;30\} \tag{6}$$

$$\overline{SCH}_{real}^{cs} = \left(\overline{PD}_0^{cs} \setminus \overline{SCH}_0^{cs}\right) = \{1;10;15;24;30\} \tag{7}$$

In the $\overline{SCH}_{real}^{cs}$ schedule, stations/stops are now only assigned to stops for which there are requests for boarding ((7) correlation). These demands are contained in the set $\overline{PD}_0^{cs}$, in which passengers can make demands on stations/stops in the sets $\overline{SCH}_0^{cs}$ and $\overline{ST}^{cs}$. Its shape is shown by the grey line in the Figure 10.

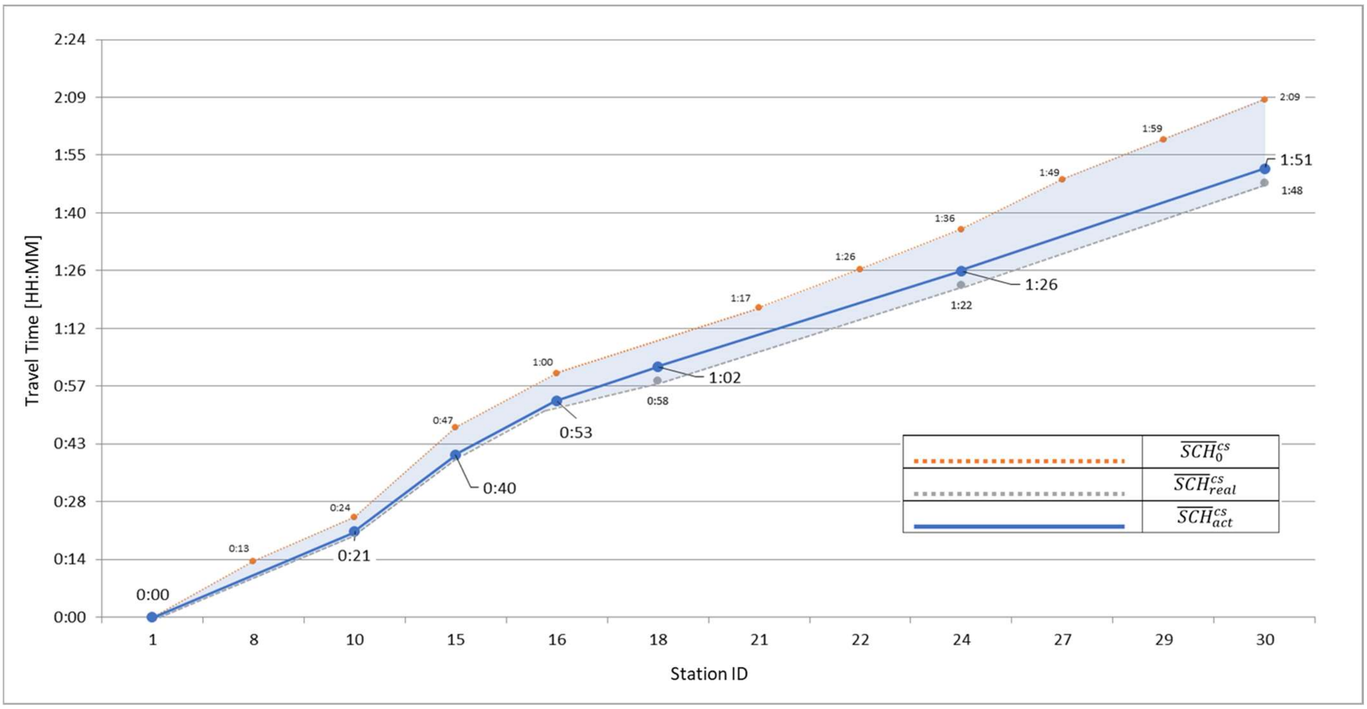

Figure 10. Case study $\overline{SCH}_0^{cs}$ and $\overline{SCH}_{real}^{cs}$ schedule structure based on passenger demand (authors' own based on calculated data of schedule plan).

Figure 10 shows how the characteristics of the $\overline{SCH}_0^{cs}$ schedule can change based on the incoming passenger demand and how the travel time varies along the journey route.

Before the immediate departure of the journey, it is possible to receive ad hoc passenger demands by START protocol. If no ad hoc passenger demands are received, the vehicle will follow the schedule indicated by the grey line. For ad hoc demand handling currently, as stated above, only the START protocol procedure is used in the case study, as shown to the left side of Figure 8 (Section 4.2).

START ad hoc passenger demand $\overline{AHD}_{act}^{cs}(START)$ is only considered to be a demand that arrived 10 min before the departure of the journey or if the $\overline{SCH}_{real}^{cs}$ does not include this station/stop. Then, the ad hoc management module of the PDMS subsystem calculates the amount of extra time that can be spent to serve $\overline{AHD}_{act}^{cs}(START;16)$ (given journey 16th station/stop). If this extra time does not exceed the arrival time predicted in the $\overline{SCH}_0^{cs}$ schedule for the final destination, the ad hoc passenger demand can be fulfilled. The $\overline{SCH}_{act}^{cs}$ schedule contains the ad hoc passenger demand. The ad hoc passenger demand shown in

Figure 10 illustrates the satisfaction of the demand for station/stop ID16 (blue line). It can be observed that before the ID16 stop, the $\overline{SCH}_{real}^{cs}$ and $\overline{SCH}_{act}^{cs}$ travel time curves separate into separate curves, which remain proportionally different until the final destination.

Figure 11 illustrates on a timeline the departure intervals of each demand and the corresponding schedules in relation to the departure time of the given journey. The scales are not proportional, as the indicative nature of the $\overline{SCH}_{0}^{cs}$ schedule can cover several months, while $\overline{SCH}_{real}^{cs}$ and $\overline{SCH}_{act}^{cs}$ cover a few hours. Grey boxes refer to actual passenger demand and actual timetables, and blue boxes refer to ad hoc passenger demand and actual schedule.

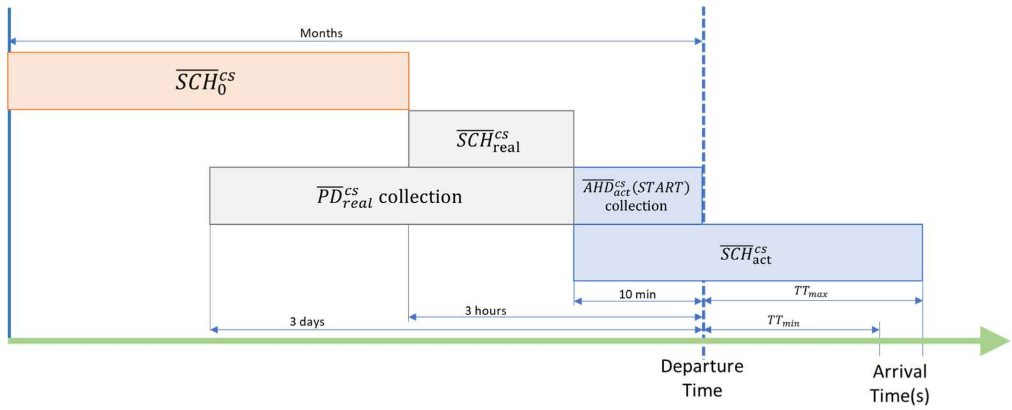

Figure 11. Temporal distribution of the A-FTS timetable variants by processing the collected passenger demand against the departure time of the given flight (authors' own).

5.3. Case Study Summary

The journey used in the case study, which serves a low-traffic period, currently has passenger vehicles stopping at all stations and stops. Stops are made even if there are no passengers boarding or alighting at the station/stop. The case study showed how flexible transportation management can eliminate non-value-adding processes in conventional transport. A-FTS development is containing new and innovative flexible service methods in PuT. The FTS concepts presented in this article also address the inflexible elements of PuT based on a new type of approach. If these solutions can make PuT more efficient, they can be competitive, in addition to meeting the mobility demands of low-traffic periods. In the A-FTS concept, which is based on a thorough identification of passenger demands, no energy is lost during the movement of the transportation vehicle due to unnecessary stops and accelerations. At the same time, an optimal vehicle capacity can be adapted to the known number of passengers, which also results in lower energy consumption.

A basic example is the A-FTS level, where passenger demand can only change the transportation vehicle schedule in time. This paper also demonstrates that even a simpler A-FTS system description is extremely complex and that there are many parameters and management systems working together to make it work efficiently. The main outcome of the case study is that by managing passenger demand and connecting it to stations/stops, the efficiency of the transportation system can be increased on both the passenger and service provider side. The case study presented in this article has already shown promising results compared to the system currently in use. Flexible passenger transportation systems are seen as a mode of mobility towards sustainability. There is great potential for future research in the development of A-FTS and other FTS systems, as transportation innovations have started their global conquests with similar potential.

6. Conclusions

PuT management is a difficult issue due to the unpredictability of passenger demands. The FTS systems presented in this article (such as A-FTS) are designed to fully and comprehensively assess changing passenger demands and make decisions based on these. The literature review has shown that there are no realistic and generic examples of how to manage travel demands. Therefore, this gap had to be filled for the FTS systems presented. In the A-FTS system concept presented in detail, it is possible to adapt the organization and management of fixed-route PuT to passenger demands. A complex digitalization system for receiving passenger demands must be set up, fully integrated into the existing traffic, train control, and management systems. The description of the layout architecture of the A-FTS subsystems has been so detailed because the calculations in the case study are also based on elementary motion data, and the architecture of the communication systems is also elementary data reception and transmission. The A-FTS example shows that passenger demands can be collected and tracked, and each demand can be assigned to specific stations/stops. Furthermore, the integration of the ad hoc passenger demand management model with the A-FTS system was necessary to declare the current case study and further research.

The research has broadened existing knowledge and has presented a flexible transport solution in a way that is understandable to many. Despite research gaps, the case study was abridged.

The use of the A-FTS system in real life can provide time gains on the passenger side and cost rationalization on the operator side. Acceleration and deceleration phases can be identified from the unscheduled stopping. The energy loss from these phases can be minimized, and in the long-term, brake wear and service provider costs can be reduced. These are quite significant benefits of social and service providers.

Further research directions for the A-FTS subsystem (and other FTS systems):

- Take more accurate account of dynamic data, speed restrictions, and the specific characteristics of railway lines for real schedule planning.
- Examine multimodal transport connections for A-FTS.Develop passenger demand reporting periods (time) for intermediate stations/stops.
- Develop a buffer time management module to limit overly wide schedule time windows. The basis for correct passenger information must be determined at intermediate stations/stops.
- The buffer time management logic for the RIDE protocol of the ad hoc passenger demand response module must be developed. In any case, this can be done based on further research results.
- Determine the optimal vehicle acceleration curve based on the distance between two stations/stops (as a function of schedules) and the energy consumption of each acceleration phase.
- Measure brake wear from stopping/braking. Calculate the achievable cost savings per service cycle from brake wear for operational A-FTS systems.

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References

1. Mollenkopf, H.; Ruoppila, I.; Marcellini, F. Always on the go? older people's outdoor mobility today and tomorrow: Findings from three european countries. In *New Dynamics in Old Age: Individual, Environmental and Societal Perspectives*; Routledge: New York, NY, USA, 2017; pp. 175–198. [CrossRef]

2. Sierpiński, G.; Ahmadian, S. The Impact of Utilizing Shared Electric Vehicles on The Energy, Environmental pollution and Transportation. Presented at the World Congress on New Technologies, Online, 5–7 August 2021. [CrossRef]
3. Elias, P.; Macko, M.; Sedmidubsky, J.; Zezula, P. Tracking subjects and detecting relationships in crowded city videos. *Multimed. Tools Appl.* **2022**, 1–23. [CrossRef]
4. Ku, A.Y.; Greig, C.; Larson, E. Traffic ahead: Navigating the road to carbon neutrality. *Energy Res. Soc. Sci.* **2022**, *91*, 102686. [CrossRef]
5. Erdei, L.; Illés, B.; Tamás, P. Selection method of DRT systems. In Proceedings of the 14th International Doctoral Students Workshop on Logistics Magdeburg, Deutschland Otto-von-Guericke-Universität Magdeburg, Magdeburg, Germany, 22 June 2021.
6. Teodorović, D.; Janić, M. Transportation engineering: Theory, practice, and modeling. In *Transportation Engineering: Theory, Practice, and Modeling*; Butterworth-Heinemann: Oxford, UK, 2022; pp. 1–984. [CrossRef]
7. Tamás, P. Application of simulation modeling for formation of pull-principled production control system. *J. Prod. Eng.* **2016**, *19*, 99–102.
8. Maas, B. Literature Review of Mobility as a Service. *Sustainability* **2022**, *14*, 8962. [CrossRef]
9. Hamerska, M.; Ziółko, M.; Stawiarski, P. A Sustainable Transport System—The MMQUAL Model of Shared Micromobility Service Quality Assessment. *Sustainability* **2022**, *14*, 4168. [CrossRef]
10. Andrejszki, T. Intelligens Rugalmas Közforgalmú Közösségi Közlekedési Rendszerek Komplex Gazdasági Hatékonyságértékelő Módszereinek Matematikai Modellezése. Ph.D. Dissertation, Budapest University of Technology and Economics, Budapest, Hungary, 2017. Available online: https://repozitorium.omikk.bme.hu/bitstream/handle/10890/5425/ertekezes.pdf?sequence=2&isAllowed=y (accessed on 12 October 2022).
11. Brendel, A.B.; Lichtenberg, S.; Prinz, C.; Herrenkind, B. Increasing the value of shared vehicles: Insights from an imple-mentation of user-based relocation in station-based one-way carsharing. *Sustainability* **2020**, *12*, 8800. [CrossRef]
12. Lee, J.; Baig, F.; Talpur, M.; Shaikh, S. Public Intentions to Purchase Electric Vehicles in Pakistan. *Sustainability* **2021**, *13*, 5523. [CrossRef]
13. Javid, M.A.; Abdullah, M.; Ali, N.; Shah, S.A.H.; Joyklad, P.; Hussain, Q.; Chaiyasarn, K. Extracting Travelers' Preferences toward Electric Vehicles Using the Theory of Planned Behavior in Lahore, Pakistan. *Sustainability* **2022**, *14*, 1909. [CrossRef]
14. Talpur, M.A.H.; Napiah, M.; Chandio, I.A.; Khahro, S.H. Transportation Planning Survey Methodologies for the Proposed Study of Physical and Socio-economic Development of Deprived Rural Regions: A Review. *Mod. Appl. Sci.* **2012**, *6*, 1. [CrossRef]
15. Talpur, M.A.H.; Khahro, S.H.; Ali, T.H.; Bin Waseem, H.; Napiah, M. Computing travel impendences using trip generation regression model: A phenomenon of travel decision-making process of rural households. *Environ. Dev. Sustain.* **2022**, 1–24. [CrossRef]
16. Li, S.-W.; Li, Y.; Yang, J.-F.; Cao, C.-T.; Yang, J.; Song, J.-H.; Huang, L. Flexible Bus Route Setting and Scheduling Optimization Adapted to Spatial-temporal Variation of Passenger Flow. *Sens. Mater.* **2020**, *32*, 1293. [CrossRef]
17. Tao, Y.; Jun, Z.; Zhi-Hao, Z.; Yi, Z.; Fu-Qiang, Z.; Xiao-Zhi, G. Fault detection of train mechanical parts using multi-mode aggregation feature enhanced convolution neural network. *Int. J. Mach. Learn. Cybern.* **2022**, *13*, 1781–1794. [CrossRef]
18. Rahmani, A.; Seyed-Hosseini, S.M. Evaluation of railway track structural conditions using a fuzzy-logic method: A case study. *Jordan J. Civ. Eng.* **2021**, *15*, 102–115.
19. Li, C.; Wang, J.; Shan, J.; Lanzon, A.; Petersen, I.R. Robust Cooperative Control of Networked Train Platoons: A Negative-Imaginary Systems' Perspective. *IEEE Trans. Control. Netw. Syst.* **2021**, *8*, 1743–1753. [CrossRef]
20. Luan, X.; Corman, F. Passenger-oriented traffic control for rail networks: An optimization model considering crowding effects on passenger choices and train operations. *Transp. Res. Part B Methodol.* **2022**, *158*, 239–272. [CrossRef]
21. Pencheva, E.; Trifonov, V.; Atanasov, I. Towards intelligent train control systems. Presented at the Conference of Open Innovation Association, Helsinki, Finland, 27–29 April 2022; pp. 229–236. [CrossRef]
22. Li, C.; Niu, H.; Shabaz, M.; Kajal, K. Design and implementation of intelligent monitoring system for platform security gate based on wireless communication technology using ML. *Int. J. Syst. Assur. Eng. Manag.* **2021**, *13*, 298–304. [CrossRef]
23. Coppola, P.; Silvestri, F. Assessing travelers' safety and security perception in railway stations. *Case Stud. Transp. Policy* **2020**, *8*, 1127–1136. [CrossRef]
24. Yan, Z.; Zhang, J.; Han, B.; Li, X.; Cao, J. Research on optimization of high-speed rail ticket allocation with flexible tickets. *Tiedao Xuebao/J. China Railw. Soc.* **2022**, *44*, 17–25. [CrossRef]
25. Wang, H.; Zhao, Q.; Lin, S.; Cui, D.; Luo, C.; Zhu, L.; Wang, X.; Tang, T. A Reinforcement Learning Empowered Cooperative Control Approach for IIoT-Based Virtually Coupled Train Sets. *IEEE Trans. Ind. Inform.* **2020**, *17*, 4935–4945. [CrossRef]
26. Sarma, S.P.; Mazumder, S.K.; De La Fuente, E.P. Cost-reducing optimization strategies of electrical trains. Presented at the 2019 4th IEEE Workshop on the Electronic Grid, Xiamen, China, 11–14 November 2019. [CrossRef]
27. Andrejszki, T.; Török, Á. New pricing theory of intelligent flexible transportation. *Transport* **2015**, *33*, 69–76. [CrossRef]
28. Cao, C.; Feng, Z. Optimal capacity allocation under random passenger demands in the high-speed rail network. *Eng. Appl. Artif. Intell.* **2020**, *88*, 103363. [CrossRef]
29. Saleh, W.; Justin, S.; Alsawah, G.; Al Ghamdi, T.; Lashin, M.M.A. Control Strategies for Energy Efficiency at PNU's Metro System. *Energies* **2021**, *14*, 6660. [CrossRef]

30. Nemati, M.; Moaveni, B.; Khosrosereshki, F. Design optimal velocity profile for energy saving in metro system using classical optimization method. Presented at the 2017 25th Iranian Conference on Electrical Engineering, Tehran, Iran, 2–4 May 2017; pp. 859–864. [CrossRef]
31. Erdei, L.; Illés, B.; Tamás, P. Analysis of flexibility on the FTS. In Proceedings of the 15th International Doctoral Students Workshop on Logistics Magdeburg, Deutschland Otto-von-Guericke-Universität Magdeburg, Magdeburg, Germany, 23 June 2022. [CrossRef]
32. Li, C.; Bai, L.; Liu, W.; Yao, L.; Waller, S.T. A multi-task memory network with knowledge adaptation for multimodal demand forecasting. *Transp. Res. Part C Emerg. Technol.* **2021**, *131*, 103352. [CrossRef]
33. Steele, H.; Roberts, C. *Towards a Sustainable Digital Railway*; Emerald Publishing Limited: Bingley, UK, 2022; Volume 14, pp. 239–263. [CrossRef]
34. Gong, C.; Shi, J.; Wang, Y.; Zhou, H.; Yang, L.; Chen, D.; Pan, H. Train timetabling with dynamic and random passenger demand: A stochastic optimization method. *Transp. Res. Part C: Emerg. Technol.* **2021**, *123*, 102963. [CrossRef]
35. Chen, L.-W.; Hu, T.-Y.; Wu, Y.-W. A bi-objective model for eco-efficient dial-a-ride problems. *Asia Pac. Manag. Rev.* **2022**, *27*, 163–172. [CrossRef]
36. Saghian, Z.; Esfahanipour, A.; Karimi, B. A novel kumaraswamy interval type-2 TSK fuzzy logic system for subway pas-senger demand prediction. *Iran. J. Fuzzy Syst.* **2022**, *19*, 69–87.
37. Zhou, S.; Song, C.; Wang, T.; Pan, X.; Chang, W.; Yang, L. A Short-Term Hybrid TCN-GRU Prediction Model of Bike-Sharing Demand Based on Travel Characteristics Mining. *Entropy* **2022**, *24*, 1193. [CrossRef]
38. Xu, X.; Zhang, L.; Kong, Q.; Gui, C.; Zhang, X. Enhanced-historical average for long-term prediction. Presented at the 2022 2nd International Conference on Computer, Control and Robotics, Paris, France, 18–20 August 2022; pp. 115–119. [CrossRef]
39. Cao, Y.; Guan, H.; Li, T.; Han, Y.; Zhu, J. Research on a Prediction Method for Passenger Waiting-Area Demand in High-Speed Railway Stations. *Sustainability* **2022**, *14*, 1245. [CrossRef]
40. Shen, H.; Zheng, L.; Zhang, K.; Li, C. Joint prediction of zone-based and OD-based passenger demands with a novel generative adversarial network. *Phys. A Stat. Mech. Appl.* **2022**, *600*, 127550. [CrossRef]
41. Yamada, Y.; Uchiyama, A.; Hiromori, A.; Yamaguchi, H.; Higashino, T. Travel estimation using control signal records in cellular networks and geographical information. Presented at the 2016 9th IFIP Wireless and Mobile Networking Conference, Colmar, France, 11–13 July 2016; pp. 138–144. [CrossRef]
42. Bali, R.S.; Kumar, N.; Rodrigues, J.J. An efficient energy-aware predictive clustering approach for vehicular ad hoc networks. *Int. J. Commun. Syst.* **2015**, *30*, e2924. [CrossRef]
43. Nayak, A.M.; Ladha, A.; Chaubey, N.K. A Comprehensive Comparative Analysis of Passenger Demand Prediction for Improving the Urban Bus Transportation System (UBTS). *Int. J. Eng. Trends Technol.* **2022**, *70*, 269–279. [CrossRef]
44. Rahmatulloh, A.; Nursuwars, F.M.S.; Darmawan, I.; Febrizki, G. Applied internet of things (IoT): The prototype bus passenger monitoring system using PIR sensor. Presented at the 2020 8th International Conference on Information and Communication Technology, Yogyakarta, Indonesia, 24–26 June 2020. [CrossRef]
45. Huang, C.-M.; Lin, S.-Y. An early collision warning algorithm for vehicles based on V2V communication. *Int. J. Commun. Syst.* **2011**, *25*, 779–795. [CrossRef]
46. Kapoor, R.; Goel, R.; Sharma, A. An intelligent railway surveillance framework based on recognition of object and railway track using deep learning. *Multimed. Tools Appl.* **2022**, *81*, 21083–21109. [CrossRef]
47. Lin, J.; Min, X. Quantitative safety analysis of train control system based on statatistical model checking. *Arch. Transp.* **2022**, *1*, 7–19. [CrossRef]
48. Sameni, M.K.; Moradi, A. Railway capacity: A review of analysis methods. *J. Rail Transp. Plan. Manag.* **2022**, *24*, 100357. [CrossRef]
49. Juhász, J.; Bányai, T.D. Understanding the purchasing portfolio model: A just-in-sequence approach increasing manufacturing efficiency. *J. Appl. Eng. Sci.* **2021**, *19*, 926–933. [CrossRef]
50. Nachtigall, P.; Široký, J.; Tischer, E. Assessing the Efficiency of Increasing the Track Speed in the Line Section Rokycany–Plzeň hl. n. *Sustainability* **2020**, *12*, 7415. [CrossRef]
51. Wang, K.; Li, H.; Zhang, Q. Parallel Redundancy Protocol for Railway Wireless Data Communication Network. *Wirel. Commun. Mob. Comput.* **2022**, *2022*, 1–13. [CrossRef]
52. Kazanskiy, N.L.; Popov, S.B. The distributed vision system of the registration of the railway train. *Comput. Opt.* **2012**, *36*, 419–428.
53. Lin, P.; Tian, Y.; Gui, G.; Yang, C. Cooperative control for multiple train systems: Self-adjusting zones, collision avoidance and constraints. *Automatica* **2022**, *144*, 110470. [CrossRef]
54. Zhang, Y.; Liu, L. Research on the train control system based on virtual coupling. *J. Railw. Eng. Soc.* **2022**, *39*, 94–100.
55. Neufeld, J.S.; Scheffler, M.; Tamke, F.; Hoffmann, K.; Buscher, U. An efficient column generation approach for practical railway crew scheduling with attendance rates. *Eur. J. Oper. Res.* **2021**, *293*, 1113–1130. [CrossRef]
56. Zhang, W.; Wang, Z.; Jia, Z.; Wang, H. Multiple regression method of daily average mileage to predict the overhaul plan of china railway high-speed electric motor unit. Presented at the 2021 International Conference on Big Data Analysis and Computer Science, Kunming, China, 25–27 June 2021; pp. 74–79. [CrossRef]
57. Čamaj, J.; Brumerčíková, E.; Hranický, M. Information System and Technology Optimization as a Tool for Ensuring the Competitiveness of a Railway Undertaking—Case Study. *Sustainability* **2020**, *12*, 8915. [CrossRef]

58. Railway Network of Hungary. Available online: https://www.mavcsoport.hu/sites/default/files/upload/page/trkp_mav_palyahalozat_2023_a0_1211_web.pdf (accessed on 8 January 2023).
59. László, E. Egy„ÚJ" ETCS vonatbefolyásolási szint. *Multidiszcip. Tudományok* **2018**, *8*, 9–15.
60. Brännlund, U.; Lindberg, P.O.; Nõu, A.; Nilsson, J. Railway Timetabling Using Lagrangian Relaxation. *Transp. Sci.* **1998**, *32*, 358–369. [CrossRef]