Chapter 1
Review of Automatic Passenger Counting Systems in Public Urban Transport

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1.1 Introduction

The assessment of the number of passengers in public urban transport (PUT) is of crucial importance for the organization of public transport in urban environments, which is of special assistance in planning and managing the transport services. Currently, there are diverse implementations of technologies and methods for the counting of persons/people, with the aim of collecting data for the optimization of operation. The counting of persons, that is, passengers as a method of optimizing the provision of transport services in PPT is infallible as part of the passenger transport logistics. The passenger transport logistics is focused on creating the transport demand in accordance with the requirements and needs of the PPT users. Therefore, it is important for the information to be accurate and timely since PPT should be the primary transport mode in urban environments because it has numerous advantages such as economy, ecological acceptability, reduction in the number of road vehicles, realizing a reduction in traffic congestion, and so on. Special attention while planning the transport services is added to PPT services and urban planning also has to be taken into consideration. For efficient planning as well as the realization of the service, accurate, precise and reliable as well as timely information must be provided, which includes the service area—wider urban area (which does not always coincide with the city limits), population density [inhabitants/km^2]—ratio of the number of inhabitants to the number of km^2 and the population—number of inhabitants in the area of PPT service [1].

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L. Knapčiková et al. (eds.), *5th EAI International Conference on Management of Manufacturing Systems*, EAI/Springer Innovations in Communication and Computing, https://doi.org/10.1007/978-3-030-67241-6_1

Passenger counting determines the flow in the vehicles (buses, trams, etc.) according to single PPT lines, and it is carried out on several predefined points along each line and the busiest lines have to be taken into special consideration. The basic form of passenger counting is performed by observers at defined locations or it is carried out based on the methods that depend on the number of tickets sold. Neither of the two methods can give accurate data due to the traffic dynamics as well as the large number of passengers since they depend on the factors such as the fatigue of the observer, their expertise and experience, engagement, weather conditions, part of the day, and so on. Errors occur, thus, for various reasons and vary from observer to observer. In order to maximally reduce the human factor, automatic passenger counting systems are increasingly used [2].

Automatic passenger counting (APC) systems are increasingly used in order to avoid the human influence on the results, reducing thus the error to a minimum and eliminating the variations in the results. This paper studies the different used methods in the APC system and presents an overview of the existing studies, their results, that is, measurements that are presented in a table for better clarity (Sect. 1.4, Table 1.1). The motive for researching this topic arose during previous research of wireless telecommunication networks on board vehicles of public urban passenger transport in the city of Zagreb [3]. The problem of determining the number of passengers in tram traffic at all levels (daily, weekly, monthly, and yearly) was observed, and one of the ways that was then considered was counting of passengers via a wireless telecommunication network (Wi-Fi based systems). In addition to the above, the paper analyses various independent and integrated automatic passenger counting systems.

1.2 Automatic Passenger Counting Systems

As already mentioned, proper planning is needed when developing and optimizing the PPT resource allocation strategy. Also, as with any other strategy, it is necessary to set rational goals defined by S.M.A.R.T. (Specific, Measurable, Attainable, Relevant and Time-Bound) methodology. For these goals to be achieved, one of the items that must be implemented is the passenger counting. The automatic passenger counting systems provide numerous advantages in relation to manual passenger counting and are a desirable substitution when passenger counting is done on board PPT vehicles. Figure 1.1 shows a flowchart of a simplified presentation of the automatic passenger counting (APC) operation.

Automatic Passenger Counting (APC), although a relative novelty on the market, is available for sale and use in the form of various designs that will be explained in more detail in the paper. APC thus helps in route planning and in the optimization of resources and represents a backbone for the integration into the modern Smart City concept. The main advantages offered by the APC systems include:

- elimination of human error factors when counting passengers

Table 1.1 Overview of studies related to the designs and methods of automatic passenger counting

Paper title	Authors	Used technology	Design and methods	Transport means (vehicle)	Accuracy
Novel vehicle mass-based automated passenger counter for transit applications; Minnesota; 2015 [10]	Kotz, A.J., Kittelson, D.B., Northrop, W.F.	IR sensors and on-board cameras with measuring pressure inside the vehicle suspension system	Measurement was carried out using IR sensors and the existing cameras on board vehicles in combination with the already installed sensors on suspensions. The data about the pressure from the vehicle suspension are gathered in order to calculate the additional vehicle mass, thus assuming the number of passengers.	Bus	Just IR and cameras 82.50%
					Just pressure 71.70%
					Combination 97.62%
1-6 An echo state network-based pedestrian counting system using wireless sensor networks; Sankt Augustin; 2008 [11]	Mathews, E., Poign, A.	IR sensors	It is designed and implemented in the form of hardware and software components that apply novel machine learning techniques. It is used for learning motion patterns and claims to excel other counters in price (except simple ones using beam breaking principles).	–	80.4%
Concept validation of an automatic passenger counting system for trams; Budapest; 2009 [13]	Kovács, R., Nádai, L., Horváth, G.	Measuring pressure inside the vehicle suspension system	The estimate of the passenger number according to the mass in trams with a large number of passengers and uncoordinated entry/exit from the tram. The mass of a single passenger is taken as an average value per gender (in kilograms). The concept is that the total mass of the vehicle is calculated via dynamic ride, haul and vehicle energy data. This makes it possible to calculate the passenger mass and to accurately estimate their number.	Tram	–

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Table 1.1 (continued)

Paper title	Authors	Used technology	Design and methods	Transport means (vehicle)	Accuracy
Estimating passenger numbers in trains using existing weighing capabilities; Copenhagen; 2014 [14]	Nielsena, B.F., Frølicha, L., Nielsenb, O.A., Filgesc, D.	Measuring pressure inside the vehicle breaks system	Passenger counting by means of the already existing system of measuring pressure in the railway vehicles' braking system. The method compares the obtained results with the results of manual counting and IR system.	Train	–
Research on counting method of bus passenger flow based on kinematics of the human body and SVM; Tianjin; 2018 [15]	Zhu, F., Gu, J., Yang, R., Zhao, Z.	Kinematics of the human body and support vector machine (SVM)	The system analyses continuous kinematic characteristics at the entry of passengers into the vehicle in the form of pressure between the floor and the foot and processes them using SVC (*Support-Vector Machines*).	Bus	93.98%
Clustering method for counting passengers getting in a bus with a single camera; Xi'an; 2010 [16]	Yang, T., Zhang, Y., Shao, D., Li, Y.	RGB video where RGB colour model is an additive colour model in which red, green blue lights are used together to reproduce a broad array of colours	One camera by using KLT (*Kanade-Lucas-Tomasi*) monitoring mode.	Bus	96.5%
Real-time passenger counting in buses using dense stereovision; Paris; 2013 [17]	Yahiaoui, T., Khoudour, L., Meurie, C.	"*Stereo vision*"	Counting of persons passing beneath the camera where the first image creates a block for calculating the disproportion, then the segmentation block identifies the height of the person's head via round shapes with the constant height value. The paper uses modules that reconstruct the head trajectories by means of stereo pairs.	Bus	97%

iABACUS: a Wi-Fi-based automatic bus passenger counting system; Cagliari; 2020 [21]	Nitti, M., Pinna, F., Pintor, L., Pilloni, V., Barabino, B.	Passenger tracking via Wi-Fi	Observation and analysis of mobility in the urban environment following passengers during their travel in PPT, not needing any intervention apart from Wi-Fi on board vehicle (bus).	Bus	94%
Robust people counting system based on sensor fusion; Seoul; 2012 [23]	Dan, B.-K., Kim, Y.-S., Suryanto, J.-Y.J., Ko, S.-J.	"V*ideo-plus-depth*"	First, the image of the depth is processed via a morphological operator for the elimination of the optical noise. Then human objects are drawn out using the already processed image. Finally, the trajectory of the detected object is determined by the application of the two-way overlapping algorithm.	–	90.57%
Automatic passenger counting system for bus based on RGB-D video; Beijing; 2016 [24]	Li, F., Yang, F.-W., Liang, H.-W., Yang, W.-M.	RGB-depth video	Combination of RGB and the depth of the image in order to determine the size of the passenger's head.	Bus	95.4%
Automatic passenger counting system using image processing based on skin colour detection approach; Padang Besar; 2018 [25]	Nasir, A.S.A., Gharib, N.K.A., Jaafar, H.	RGB video	RGB in hue, saturation, value (HSV) coloured image, segmentation by means of threshold method, and elimination of noise and/or unwanted items for passenger counting.	Bus	90.64%
Measuring bus passenger load by monitoring Wi-Fi transmissions from mobile devices; Warsaw; 2014 [26]	Oransirikul, T., Nishide, R., Piumarta, I., Takada, H.	Passenger tracking via Wi-Fi	The system collects periodically "*probe*" requests and data about mobile devices that are located in the AP environment. According to the performed survey, Wi-Fi activity is in correlation with the number of waiting passengers, as well as the number of riding passengers.	Bus	–

(continued)

Table 1.1 (continued)

Paper title	Authors	Used technology	Design and methods	Transport means (vehicle)	Accuracy
Counting public transport passenger using Wi-Fi signatures of mobile devices; Trondheim; 2017 [27]	Myrvoll, T.A., Håkegård, J.E., Matsui, T., Septier, F.	Passenger tracking via Wi-Fi	It is based on discovering Wi-Fi signatures in 2.4 GHz spectrum by collecting "*probe*" requests broadcast for all APs within the area. According to the survey, Wi-Fi activity is in correlation with the results of manual passenger counting.	Bus	–
People counting by means of Wi-Fi; Prague; 2017 [28]	Kalikova, J., Krcal, J.	Passenger tracking via Wi-Fi	An approach to the detection of mobile devices by recording the version of the operating system and producer with other important information about the device (MAC, RSSI, etc.). The device should be detected immediately upon entry into the observed area.	–	73% (for 180 s)
Occupancy estimation using Wi-Fi: a case study for counting passengers on buses; Melbourne; 2019 [29]	Mehmood, U., Moser, I., Jayaraman, P.P., Banerjee, A.	Passenger tracking via Wi-Fi	Wi-Fi system for assuming the occupancy of PPT vehicles which is proposed by the algorithm for the estimation of occupancy with the aim of reducing overestimation in the estimates (based on Wi-Fi).	Bus	67%
Mobile device detection through Wi-Fi probe request analysis; Rio de Janeiro; 2019 [30]	Oliveira, L., Schneider, D., De Souza, J., Shen, W.	Passenger tracking via Wi-Fi	The proposition is to use a technique for estimating the number of mobile devices through analysis of Wi-Fi probe requests. The goal is a solution that is immune to media access control (MAC) address randomization strategies by using information propagated in the environment, without the need to know the real MAC addresses of the devices.	–	Sherlock method 0.087
					Linear regression method 0.383
					Support vector regression method 0.0298; where results value are expressed in mean relative error form.

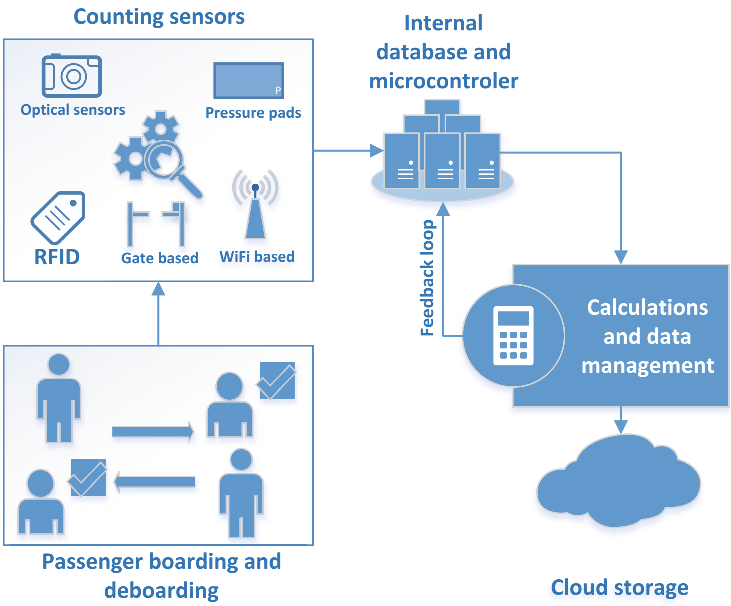

Fig. 1.1 Flowchart of simplified general presentation of APC operation

- fast and up-to-date data collection and processing
- constant accuracy and reliability of results compared to manual counting where the accuracy/reliability varies
- allows work in all weather conditions
- possibility of consecutive counting for several days in a row on the same line and
- gathering information and making conclusions for the optimization of PPT [4].

In spite of numerous advantages offered by the automatic passenger counting systems, there are also many drawbacks that can make it impossible or difficult to use:

- a large initial investment is required when integrating the APC system into the PPT vehicles
- accuracy is not 100%—it often happens that the number of boardings and deboardings of passengers does not match and
- APC systems cannot identify the emergencies [4].

There is no universal APC solution, and for passenger counting on board PPT vehicles, it is necessary to select an appropriate technology and methodology taking into consideration the possibilities and paying attention to the possibilities and limitations of (traffic) infrastructure. Figure 1.2 shows the distribution of APC systems.

The presented breakdown of the APC system (Fig. 1.2) can be divided in the first step into integrated systems, where there is direct interaction with passengers

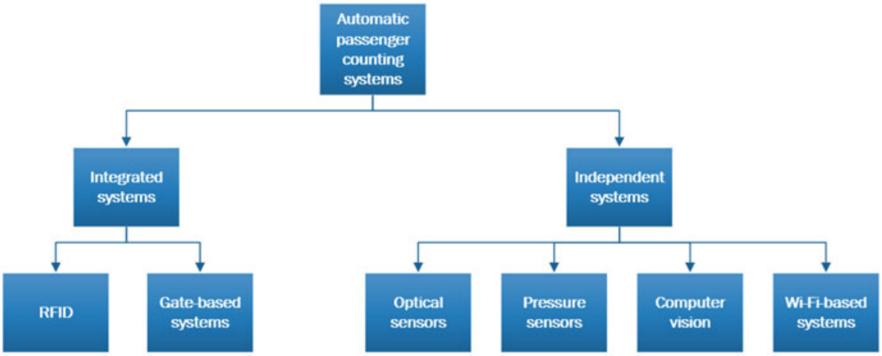

Fig. 1.2 APC system breakdown

and independent systems or independent passenger counting, where there is no direct interaction with passengers. Before introducing the mentioned systems, one should make an analysis of the possibility of implementation as part of the existing infrastructure and technology with the aim of reducing the costs. Therefore, it is necessary to make an overview of the technologies that can be integrated into the already existing system of PPT vehicles' validation. Therefore, in the system for integrated passenger counting the system of verifying the passenger tickets or some other types of identifiers are used in order to determine the number of passengers who accessed the traffic infrastructure or the PPT vehicles. The advantage of RFID in relation to other technologies is that it does not have any mobile parts and it is easily maintainable. RFID device uses radio signals that are sent to the transponder—RFID tag, which gives feedback in the form of identification code and/or a series of data that are stored in the transponder memory [5–7].

In the papers [5–8], the authors use RFID technology as the base for the validation system. Regular tickets are substituted by smart cards that contain data about the user of a certain PPT service. Smart cards contain data about the passengers and based on these data one can follow the movement of single passengers, as well as a group of passengers according to different demographic data (gender, age, education, profession, material status, etc.). Demographic data are often used as the basis for the segmentation of the market and/or users. After studying various demographic factors, the demographic profiles of users can be created, on the basis of which attractive transport alternatives for single groups of users can be determined. The system of smart cards functions so that after boarding the vehicle, the passenger registers and based on the number of passenger registrations the number of passengers on board the vehicle is determined, as well as the number of free places. The research described in the paper [9] has been carried out in controlled conditions (experiment); 40 volunteers carried RFID tags in backpacks, banknotes, pockets, and so on, through the vehicle door model with four antennas installed. Volunteers passed through the model in pairs and individually. The authors showed accuracy for various scenarios depending on where the RFID tag was located (backpack, pocket, in the hand, etc.). The average value of recognition for four scenarios amounted to 91% for single-tag cards and 82% for dual-tag cards, and single-tag cards are the size of credit cards that contain an Electronic Program Guide (EPG) Generation 2 tag whereas dual-tag cards contain MIFARE tags which are common for contactless smart cards [9].

The "Gate-based" methodology is integrated and connected with the validation system, and as a rule, it is used in subways and at airports. The advantage is the ticket validation with simultaneous passenger counting. The main advantage is accurate and reliable information about the actual number of passengers on the PPT infrastructure except in emergencies. This is because passengers have to go through a physical barrier located at the entrance and/or exit on PPT infrastructure (vehicle door, to the station, etc.) where they are validated. The main drawback is the impossibility of boarding passengers without previous validation at the planned "gate checkpoint". This greatly reduces the possibility of implementation in a more dynamic environment of the traffic system, such as bus and tram traffic. However, there are systems that practice a similar approach in public surface traffic (bus and tram), but it refers to fenced passenger stops, and this method in this environment is very inconvenient for passengers because of the waiting queues and requires large financial investments by public urban transport operator, that is, city administration.

Therefore, in the case of integrated APC in a dynamic traffic environment, it is difficult to avoid non-registering of passengers without applying a kind of "gate" technology, but this requires large financial investments, and the mentality and behaviour of passengers who are not used to it is always questionable. For this reason, the integrated APC systems in case of no "gate" are very unreliable, so there is a need to implement some of the technologies of automatic passenger counting on board vehicles, independent of passenger validation.

1.3 Independent Passenger Counting

The ticket validation systems that are integrated into the infrastructure are often not a real indicator of the condition in the traffic so that other direct methods of passenger counting are sought. Independent passenger counting is unrelated to the validation, and contains various counting technologies and methods and serves to find an adequate and unobtrusive way to monitor the number of passengers on board vehicles due to the optimization of traffic processes. In order to take into account the dynamic behaviour of the traffic system and passengers, the counting methods can be divided as shown in Fig. 1.2.

1.3.1 Optical Sensors

The most used optical sensor is infrared (IR), and it is the simplest in the context of the APC system. The main advantages are affordable price and simple implementation, and the IR sensor design requires a minimum of two sensors in order to avoid intersecting of IR beams. Two designs can be highlighted, the active and the passive one. Active IR sensors include in their design a receiver and a transmitter, where the transmitter generates the IR beam that has the purpose of detecting the passing through the cross section of the counter. The main characteristic of passive IR sensors is pyroelectricity, which understands that they are designed so as to emit one IR beam which is divided into beams. Detection occurs when a passenger passes through the beam and during implementation in the vehicle; the receiver/transmitter is installed at the entry and/or exit parallel to one another. The reason is to avoid interrupting the beam only from one side and to reduce errors. IR sensors are often used in combination with some other types in order to raise the level of accuracy as done by the authors of the paper [10].

The authors of the paper [11] tested the APC system which uses Passive Infrared Sensors (PIR) sensors, and they reported an accuracy of 80.4%, but the biggest advantage is the low costs and price of implementation. The authors of the paper [12] used the passenger counting system at airports, and the presented deviations are 3.6% for a 5-min interval when there is no passing of passengers in both directions. In papers [10, 12], IR sensors are used in combination with other types of sensors in order to increase the level of accuracy in passenger counting.

1.3.2 Pressure Sensors

Pressure sensors are often very easy to implement and use, and are divided into several different types. Two types have been singled out in this paper, and the first is the simplest and uses a pressure sensor in the form of a mat to determine the number of passengers. The mat is most often used in the PPT for the purpose of checking passengers when entering/exiting the vehicle so that the door can be closed, and to a much lesser extent for counting. It reacts every time a passenger steps on it and must be made of durable materials to be resistant to mechanical wear and vibration. Thus, it is usually metal and covered with rubber, but when installing it should be taken into account that the edge parts do not have the ability to detect and it is necessary to act accordingly in order to reduce erroneous readings. It is not optimal to use in heavy traffic jams because some of the passengers usually stay standing on the sensor. This causes erroneous readings and thus affects the final results. In such situations, it is advisable to use other technologies to reduce the possibility of error, as was done in [10].

The second type is more complex and expensive and refers to the calculation of mass in motion and can be used in two ways. The first method is integrated and does not require large investments outside the purchase and implementation of sensors. This method has various versions, and each of them brings different results as seen in papers [13–15]. The second way is the implementation in the infrastructure and requires large investments and significant interventions during the implementation. The conducted research determined that there are few papers on this topic, and the assumption is that this is precisely because of the need for large investments.

1.3.3 Computer Vision

Computer vision uses optical sensors as the main component, and according to the characteristics offered, this technology is almost equally or more accurate than some of the already mentioned technologies and does not usually require any additional investments. Computer vision has no mobile parts nor does it require any special maintenance, and the installation can be done with only one sensor. The biggest drawback of optical visual counting is the implementation of software support since the operation method is very simple. It starts by identifying the shape of the passenger and their distinction from the background and other elements in the environment. It can detect their direction of movement, and thus, whether they are entering or exiting the vehicle.

A potential problem is security, that is, from the passenger's perspective, since any visual "software" for detection in public causes fear that results from ignorance and lack of understanding. Thus, during implementation, it is necessary to pay additional attention to the psychological aspect of the passengers. The basic technical design uses one or two cameras, which can be or do not have to be stereoscopic. The cameras are usually installed above the entry and/or exit of the PPT vehicle and an integrated LED is used which enables visibility in almost all ambient light powers. The possibilities depend most on the software support and artificial intelligence which is used in a certain case. Papers [16, 17] provide descriptions of certain simpler technical designs.

1.3.4 Wi-Fi-Based Systems

APC systems that use Wi-Fi methods are based on the number of detected mobile terminal devices within the Access Point (AP) radius or based on the number of connected mobile devices to the access point. These methods can be used on board PPT vehicles if the vehicles are equipped with a wireless access point. In this way, a frame estimate of the number of passengers on board PPT vehicles can be made according to the number of active mobile terminal devices.

However, there is a problem when determining the exact number of mobile terminal devices, and the reason lies in the fact that the access point on board vehicles will detect also the devices that are outside the vehicle, and this will produce inaccurate, that is, unreliable results. One of the problems is the number of mobile terminal devices per passenger also, since there is an increasing trend in persons having 1–2 mobile devices, and this will continue, especially in the context of the development of the 5G mobile telephony, IoT artificial intelligence (AI) in the context of the Society 5.0 environment. The research in paper [18], is based on the increasing number, that is, penetration of mobile terminal devices, and refers to the young people and their need to be connected at every moment. The authors of papers [19, 20] connect the increase with the ever larger number of available smart mobile terminal devices as well as the reducing prices. The most frequent design of Wi-Fi APC systems greatly depends on whether the passengers have the Wi-Fi component on their devices switched on during the ride. Besides, there is yet another problem that affects the reliability of this method and occurs in the form of randomisation of "Media Access Control" or MAC address [21]. Wi-Fi on board vehicles in the future is inevitable, so this method will certainly be used more and more frequently despite its drawbacks.

1.4 Analysis of the Results of Existing Research

Accuracy, that is, precision of the system is frequently checked by manual counting as a preliminary counting method, but this method brings along its problems due to various factors such as the time of implementation, reliability, that is, experience of the examiner, greater possibility of error due to human factor, and so on [22]. By developing various new APC systems, their accuracy (and precision) of measurement results is increasing, that is, it is about 95% in some designs and excludes the influence of human factor in performing the passenger counting.

Conceptually, the principle of using various technologies in the function of automatic passenger counting does not differ a lot between the analysed available relevant papers presented and quoted in Table 1.1. However, the application and the used methodology are not the same due to the different needs of public urban carriers as well as the possibility of the traffic infrastructure in a certain area, and the financial power of the transport service provider. This means that there is no unique solution since different PPT service providers have different challenges that have to be approached in different ways. Therefore, for the sake of clarity, Table 1.1 shows relevant papers on the topic of automatic passenger counting, their authors, used technologies, designs and methods, types of transport means in which the measurement has been performed and the precision percentage indicated in the analysed paper.

It is obvious that in a large number of carried out research the determined measurement accuracy is greater than 90%. Of course, this is not the only important factor, but the used technology, method or design are very important information, as well as the conditions in which the measurement was carried out. A large number of papers use bus subsystem of public urban transport, that is, bus as a reference vehicle for the implementation of a certain automatic passenger counting system, and the reason is the outspread and numerous use of this type of transport means in urban environments. Light-rail—metro, has not been present to such an extent, and it often uses some kind of integrated verification methods (usually "gate-based"), whereas tram traffic is the least present in the presented analysed studies (Table 1.1), but it is possible to apply similar, if not equal, technologies and methods as with buses.

During the research process, apart from the papers mentioned in Table 1.1, a large number of other papers/studies have been analysed, which performed a series of measurements using various technologies and methods of automatic passenger counting but have not been listed due to the lack of relevant data about the quality of the performed measurements, such as accuracy, precision, and finally the reliability of the obtained measurement results. Also, some measurements have been carried out in laboratory conditions on very small samples, so that as such they fail to be comparable without performing additional measurements in the real PPT environment.

According to the carried out research, it can be seen that there is a wide spectrum of APC technologies and methods, and the criteria for selecting a certain technology and method depend on the possibilities of the investor (public urban carrier), available financial means, and the desired level of accuracy and precision of the obtained results.

1.5 Conclusion

According to the set item of research and with the analysis of available relevant scientific papers, it can be concluded that the need for passenger counting in PPT is a universal problem and the solutions are different and numerous. Many authors have performed their research on PPT of a certain city and the results are various and depend on the type of transport means (bus, tram, light-rail—metro, etc.) as well as on the already existing technologies on board vehicles that may be used, in order to reduce the costs of implementation. Although passenger counting is a universal problem, there is no universal technology or method of automatic passenger counting. This paper provides an overview of the most frequent modern passenger counting methods, with the aim of defining a comparison according to the obtained measurement results related to the accuracy, that is, precision of passenger counting and the values of the results of analysed papers range even up to 97%. With the development of innovative information and communication services related to the development and implementation of different IoT devices, it will make possible the detection of events, objects and passengers, real-time data transfer, and being linked to various information and communication systems and devices. The expected implementation of such IoT service in Society 5.0 environment is very large and it will refer to numerous automations and simplifications apart from living also of traffic processes. For instance, activation of numerous measuring devices by detection of movements, temperature and other conditions, surveillance on demand, and real-time presentation, as well as optimization of traffic processes based on the collected analytical data. This leads to the expectation of fast development of the automatic passenger counting systems in various PPT vehicles.

Future expectations of the authors' research will include the development of an initial passenger counter by using the possibility of Arduino platform and the trial testing will be done in closed spaces (entry into a certain facility or building) and public urban transport vehicles, mainly trams. The tests, in terms of counting persons entering a certain facility or building, are expected to use at least three different counting methods, and the determination of the level of accuracy, that is, precision.

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