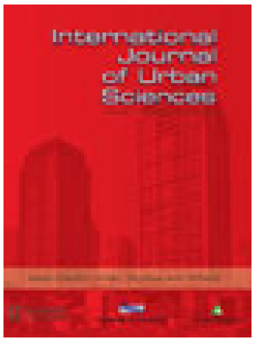

International Journal of Urban Sciences

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rjus20

Urban mobility and public transport: future perspectives and review

Avishai (Avi) Ceder

INTERNATIONAL JOURNAL OF URBAN SCIENCES
https://doi.org/10.1080/12265934.2020.1799846

Routledge
Taylor & Francis Group

REVIEW ARTICLE

Urban mobility and public transport: future perspectives and review

Avishai (Avi) Ceder[a,b]

[a]Transportation Research Institute, Technion – Israel Institute of Technology, Haifa, Israel; [b]Transportation Research Centre, Faculty of Engineering, University of Auckland, Auckland, New Zealand

ABSTRACT
The purpose of this work is to review urban transportation likely to be offered in the future. Trip-making behaviour has already changed considerably as lifestyles change and they will continue to change in the future. This work reflects and places emphasis on profound thinking about the possibilities, rather than predicting them. Thoughts about possibilities for the future draw upon imagination, perceived and justified feasibility, and lessons gained from the past. This work attempts to capture the possibilities, logistics and travel modes of future urban transportation. A visionary, feasibility-related approach grounded in a realist perspective is proposed, only conceptually, to explore plausible visions for the future. In addition, this work shows the inefficiency of using private cars (PCs) and argues that in the development of autonomous and electric vehicles, PCs cannot provide a solution competitive with the potential that urban transportation systems have for the future. Hence, the solutions for the future must be based on public transport (PT) modes of travel, regardless of whether they are metro, bus, light rail, tram, ridesharing services, an ordinary taxi, personal rapid transit, or any other PT-based future mode. The key principal of operation for the mobility of a smart city will be the ability to optimize the connectivity of movement in order to approach a seamless move, while endowing the phrase door-to-door travel with new meaning. Finally, it would be remiss not to mention the unforeseeable implications of the Covid-19 pandemic for future mobility, more controllable by automation of non-privately owned vehicle, and with the prospect of people demonstrating a greater inclination towards changing their habits, behaviour, and thinking paradigms.

ARTICLE HISTORY
Received 2 March 2019
Accepted 16 July 2020

KEYWORDS
Future urban mobility; public transport; private car; innovative travel modes; mode shift

Highlights

- Discussing the evolution of automated vehicles characterized by excessive confusion
- Review of decisions, trends, automated transit networks, modelling and technologies
- Importance of developing sustainable mobility based on public transit vehicles
- Visionary, feasibility-related and realist perspective-based conceptual approach
- Future mobility implications of Covid-19 using automation of non-private vehicles

CONTACT Avishai (Avi) Ceder ceder@technion.ac.il Transportation Research Institute, Technion – Israel Institute of Technology, Haifa 32000, Israel; Transportation Research Centre, Faculty of Engineering, University of Auckland, Auckland, New Zealand
This article has been republished with minor changes. These changes do not impact the academic content of the article.

This work reflects and places emphasis on profound thinking about the possibilities of future urban mobility for people, rather than presuming to predict. Without a doubt, we are on the verge of a dramatic change in urban mobility. However, the evolution of automated/autonomous vehicles (AVs) currently reflects tremendous confusion. Thus, moving in any particular research direction is like moving in a maze. Precisely, for this reason, it is important to think of possibilities for the future, and thereby shed some light on further directions for research. These possibilities, naturally, are the product of a mix of imagination, perceived and justified feasibility, and lessons gained from the past. These ingredients serve the purpose of this work. Another distinct theme is the future of urban transportation of goods. Although they may both have a share in the future infrastructure, the movement of goods will not be addressed in this study. Nonetheless, the implications of the Covid-19 pandemic for future mobility beg mentioning. Certainly, they will have to address mobility of goods and freight. Yet, this is a subject for another study. Nevertheless, previously existing options for future passenger mobility may contribute, under the Covid-19 pandemic, to rethinking, with a window of opportunity in which people may become more inclined to changing their habits, behaviour, and thinking paradigms, and to accepting new, automated, healthier, and improved means of urban mobility.

The work is fivefold. The first section presents thoughts and elements which led to the selection of the themes presented in this work. They are the major themes required, in the author's view, to portray the possible logistics and modes of future urban trips. The second section relates to the major players expected to have an impact on future urban mobility. The third section reviews and discusses four themes of recent studies. The fourth section conceptually proposes, three perspectives for studies on future urban mobility, and the fifth section highlights economic perspectives of future urban transportation, from the user, operator and community/government viewpoints. The work ends with concluding remarks.

1. Overview of future mobility-related aspects of transportation

Information of interest on future mobility appeared in the Business Insider (Tech) (2016) in which BI Intelligence reported that 10 million self-driving cars will be on the road by 2020. There are two different types of self-driving cars: semi-autonomous and fully autonomous. A semi-autonomous vehicle can accelerate, brake, and steer a car's course with limited driver interaction. A fully autonomous vehicle can drive between two points and encounter the entire range of on-road scenarios without any driver interaction. Is this figure of 10 million realistic? The same question is asked by Piper (2020) with the comment that the year 2020 is here, and the self-driving cars are not. Certainly, there is good cause for introducing autonomous vehicles to reduce car accidents. The rhetorical question, however remains – will this help reduce urban traffic congestion, pollution, waste of time, noise, and inefficiencies in terms of capacity and space consumption?

1.1. Urbanization trends

The world population has grown from 1 billion people in 1804 to 7.8 billion people in 2020. It is predicted that by 2050 the world population will rise to 9.8 billion, an increase of 2 billion people compared to 2020, according to the United Nations (2014) Report. The time needed for an increase of 1 billion people will be rapidly reduced. Moreover, according to this report, more than half the world's population already resides in cities. It also shows that there are presently, approximately 3 billion people in rural areas, and that number is expected to remain the same in 2050. Growth is expected to take place almost exclusively in cities. As a means of comparison, it is notable that in 1950, there were 1.8 billion people in rural areas vs. 0.8 billion in urban areas. Half of the population of Asia, is predicted to live in cities by 2020. While there are currently 28 cities in the world with more than 10 million people, that number is expected to reach 56 around 2050 (United Nations, 2014).

Urban transportation has a long history. The first metro system was established in 1890 in London. Metro is also referred to as subway, underground and U-Bahn. Today there are metro systems in approximately 150 cities in 55 countries.. Contemporary urban mobility is characterized by traffic congestion, pollution, waste of time, noise, and considerable inefficiency in terms of capacity and space consumption on the scale required to enable a modern urban economy to function productively. The utilization of cars in urban areas accounts for only less than 5% of a car's lifespan. This indicates that 95% of the time, the car is parked while consuming precious urban space. This can be further observed in Figure 3 of a report (Growth within, 2015) describing the waste of the mobility system, which also appears in Foth (2018). Accordingly, it is unquestionable that urban mobility solutions will gain more and more attention.

From the human perspective, there is no doubt that people, by nature, seek to improve their quality of life. Encyclopedia Britannica defines quality of life (QoL) as the degree to which an individual is healthy, comfortable, and able to participate in, or enjoy life events. In other words, QoL of individuals or groups is directly related to satisfaction resulting from improvement of social, economic, psychological, and health conditions. Schneider, Guo, and Schroeder (2013) investigated the component of transportation within QoL and found that it plays an important and consistent role. More specifically, seven important areas were identified which are indicative of a connection to QoL-related satisfaction. These are: (i) access to destination; (ii) physical layout of the transportation system; (iii) mobility of people from one place to another; (iv) transparency in terms of communication, finances and planning; (v) safety in terms of physical conditions and human behaviour; (vi) environmental issues related to air and light; and (vii) implications of maintenance outcomes, in terms of repairs and surface conditions.

As opposed to riding in rural areas, the increasing rhythm of urban life causes people to appreciate time saved, reduced fares, and increased convenience, or succinctly put, the value of *time, fare,* and *convenience* (TFC). In the use of public transport, regardless of whether it is metro, bus, light rail, tram, ridesharing services, or an ordinary taxi, the customer is not interested in the routing as much as in the TFC. Consequently, future urban transportation will be attractive and successful if delivering a satisfactory TFC related travel system.

1.2. Innovations and technologies

The past several decades have been witness to revolutions which have dramatically altered all prior practices, especially in communications, and have forged a whole new culture, including changes in language and behaviour. New players are entering the mobility market and people are increasingly inclined to consider their mobility options. The Internet and cellular phones have altered the way we live. These two revolutions have far reaching consequences, especially for the rapid development of technologies supporting them, such as: fast switching, mobile broadband, smartphone penetration, self-healing distributed wireless and mobile networks, proximity and location technologies, nanotechnologies, motion control, mobile and miniscule power supplies, new user interfaces and experiences. These developments are all seeping into the world of urban transportation.

The United Nations Report (2014) indicates that over 70% of the land for which urban use is projected by 2040, remains to be built. Among the major questions this raises is how to serve people's needs for mobility in these foreseeable developments, while considering the wellbeing of individuals and societies. To that end, one can think of the need for innovative travel systems while recalling that the car was not invented by improving animal-drawn carriages.

The year 1886 is regarded as the year in which the modern car by the German inventor Karl Benz was born. Its mass production started in the 1920s, some 40 years later. The high speed rail service at 250 km/h introduced in 1964 in Japan was called the bullet train. Many countries have since developed high speed rail including: Austria, Belgium, China, France, Germany, Italy, Japan, Poland, Portugal, Russia, South Korea, Spain, Sweden, Turkey, UK, U.S.A., and Uzbekistan. It is interesting to note that today, in 2020, high speed rail lines (minimum of 200 km/h) exist only in Asia and Europe, but not in the U.S.A. The fastest train in the US is Amtrak's Acela Express that can attain 240 km/h, but only for some parts of the lines, with an average speed less than 150 km/h. Currently, there are approximately 30,000 km of high speed rail throughout the world, two-thirds of which are in China. High speed rail crosses international borders only in Europe. Nonetheless, high speed rail is unlikely to serve urban transportation needs, and thus other mobility solutions will be required.

It is likely that new mobility urban transport solutions will combine mobility components with the following list of technologies:

- Machine-to-Machine (M2M) global, always-on connectivity platform, including robust real time billing, engine rating, and a cloud based management framework.
- Networked computer control systems using real time technology and advanced safety.
- Real time traffic information system connected to driver services in vehicles, mobile and online devices.
- Software-as-a-Service, (SaaS)-based platform for intelligent integration of location technology, information and services.
- Real time machine learning technologies applied to the Internet of Things (IoT) and in M2M.
- Human–computer interaction technologies based on natural language talk, and using integrated intelligent voice command systems.
- Social, online ridesharing communities with intelligent matching technologies between travel requests and available seats.
- Sensors and machine vision technology for automated driving technology.
- Advanced wireless sensor technologies and software for Vehicle-to-Everything (V2X) environments to support intelligent transportation services.

Future developments for urban transportation needs are already reflected in a vast quantity of articles. Although we cannot change the direction of the wind (evolution of lifestyles, land use patterns), we can adjust the sails (create attractive TFC-based systems that will naturally shift people from the automobile to other forms of travel). This sail adjustment will rely heavily on the ongoing development of new technologies. Generally speaking, innovative urban travel technologies will be based on three major objectives:

- Increasing the productivity of urban transport, particularly through the introduction of automation.
- Improving safety, performance and service capabilities, and achieving this in a cost-effective manner.
- Supporting priorities such as energy conservation, safety, central city revitalization, and environmental protection at the national level.

1.3. Definition and importance of urban public transport

The shifts we need in order to respond to increased adverse effects of private cars should include new public transport modes with enhanced TFC satisfaction (Camacho, Foth, & Rakotonirainy, 2013). For instance, perhaps all cars inside cities should be electric and driverless, owned and operated by an assets company. City residents could page a car to take them wherever they choose. Driverless buses of different sizes will move efficiently, and automatically charge low fares. No cars will be parked on city streets. There will be no noise generated by horns and engines. Small rapid transit vehicles will serve city dwellers, enabling merged arrangements which will be considered as modular. Furthermore, the vehicles will draw power from an electromagnetic grid that will line every street, and extend up the sides of buildings. The infrastructure will bring new meaning to *door-to-door travel*. This is a feasible example of how urban transportation may operate in the future.

Table 1 contains the definitions for public transport (PT) and private cars (PCs) based on leading web dictionaries. This provides some insight into the vast connotations that may be applied in different contexts, when defining two comparable, yet different modes of travel. It should contribute to comprehending the slightly different perspectives and variations on people's understanding these two modes of travel. By relaxing PT definitions and dropping fixed routes, we claim that any travel system available for public use, for both ordinary vehicles and AVs, is public transport service (also referred to as PT, public transportation, public transit, mass transit, or just transit). If we avoid allowing conventional systems to obstruct our imagination, elevators are also a sort of PT, moving vertically, with mostly zero fare. By the same token, we can certainly include future, on-demand, computerized, driverless, electrical family vehicles within the PT. These future PT modes can carry individuals or groups of people and will be available for the public with a fare charged electronically. Almost certainly, all of the definitions in Table 1 will have to be revised and adapted to accommodate all of the members of the PT family including the use of automated/autonomous public transport vehicles (APTVs). Accordingly, the foreseeable future modes of urban transportation will rely on PT modes as is also explained by Currie (2018).

Table 1. Web definitions of public transport, private cars, and their variants.

Definition of Public Transport/ Transit/ Public Transportation/ Mass Transit

Cambridge English Dictionary:

A system of vehicles such as buses and trains that operate at regular times on fixed routes and are used by the public.

Dictionary.com

Any form of transportation that charges set fares, runs fixed routes, and are available to the public such as buses, subways, ferries, and trains.

Merriam-Webster Dictionary:

The system that is used for moving large numbers of people on buses, trains, etc.

Collins Dictionary:

A system of buses, trains, etc. running on fixed routes, on which the public may travel.

Oxford Dictionary:

Buses, trains, and other forms of transport that are available to the public, charge set fares, and run on fixed routes.

Oxford Advanced Learner's Dictionary:

A system of buses, trains, etc. provided by the government or by companies, which people use to travel from one place to another.

Definition of Private Car/ Private Passenger Automobile/Private Passenger Car/ Private Transport

Merriam-Webster Dictionary:

A passenger car assigned for private use.

Oxford Dictionary:

A motor car owned and used privately.

BusinessDictionary.com:

Any kind of automobile used to transport private passengers, including a van, which has been approved for use on public motorways.

Insurance*opedia*:

A private passenger car, in the context of insurance, is an automobile used for private needs as opposed to business uses. These vehicles are generally defined as having only four wheels, and they do not carry passengers for money.

The Law Dictionary:

The transportation of private individuals is undertaken in private passenger automobiles.

1.4. Smart cities

Urban growth acceleration should enable healthier and more productive lives than in rural locations. It should also encourage economic growth. This trend towards urban population concentration needs to be recognized by society and governments.

Undoubtedly, an important element of smart cities is to have a sustainable urban mobility system. Understanding the future composition of smart cities ought to consider a perspective in which environment, society, and economics are integrated (James, Magee, Scerri, & Steger, 2015). Yigitcanlar, Foth, and Kamruzzaman (2019a) discuss the built-up generations of advanced cities by indicating first generation as intelligent cities, second generation as smart cities, third generation as responsive cities, and claims the fourth generation to be combined smart and sustainable cities. The authors believe that the future will change the shape of cities, societies, and the environment with humans and non-humans in a sustainable manner, in what they call 'post-anthropocentric cities of tomorrow'. Yigitcanlar, Kamruzzaman, Foth, and da Costa (2019b) reviewed the literature on smart cities and sustainable cities, and based on the literature, point out the direction of cities towards becoming firstly sustainable, before secondly becoming sustainable and smart.

Cities have already begun to benefit from the impact of advanced communication technology. In addition to travel by vehicles, the lifestyle of mobility in future smart cities will also involve walking and cycling. New urban mobility services, such as innovative ride-selling and ridesharing apps, will appear and merge. The key principle of mobility operations for a smart city will be the ability to optimize the connectivity of movement, on in order to approach a seamless move (Ceder, 2016; Wolff, Heller, Corwin, Bansal, & Pankratz, 2020) while investing new meaning into the expression *door-to-door travel*.

The approach to seamless travel (Wolff et al., 2020) will presumably rely on modelling and optimization techniques. Contemporary and foreseeable technologies, with the help of robotics and real time control schemes will enable this seamless travel. This will undoubtedly enhance TFC travel satisfaction.

2. Essential elements to impact future urban transportation

Today's urban transportation systems are surrounded with various new and innovative elements, such as social media and networks, big data, artificial intelligence, biotechnology, robotics, visual reality, smart infrastructure, electrical vehicles, solar vehicles, autonomous vehicles, modularity integration. All of these emerging new technologies will have an important impact on the shaping of next generation, urban transportation systems.

This section identifies and provides an initial understanding of the emerging, major, essential elements which will play an important role in developing future urban transportation. According to their characteristics, these major essential elements are classified into five layers: intelligent technologies, social networking, travel modes, economy and integration as graphically illustrated in Figure 1.

2.1. Intelligent technologies

The application of intelligent technologies, especially intelligent transportation systems (ITS) technologies, in transportation planning, operations, and AVs can significantly improve operation efficiency and level of service of existing transportation systems.

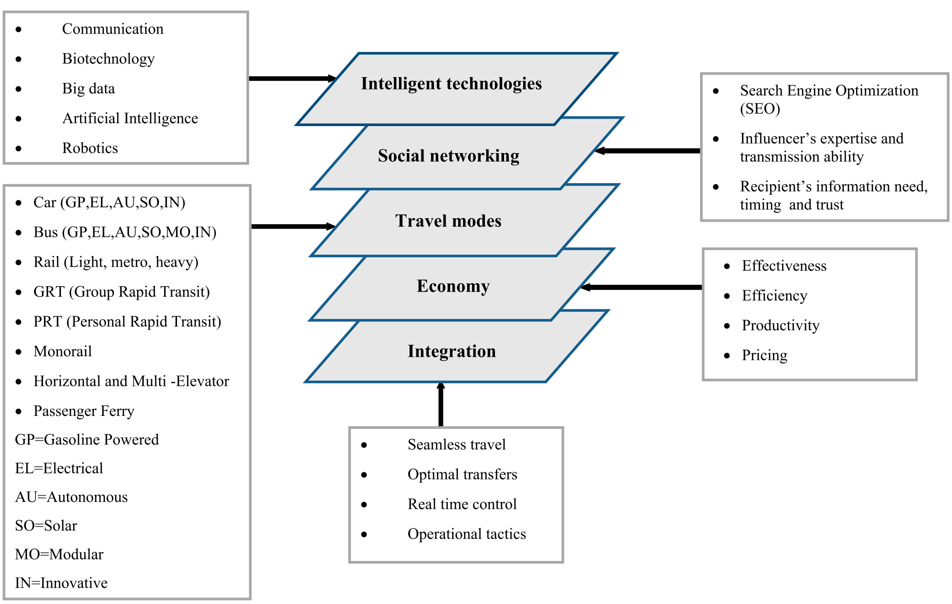

Figure 1. Five layers of elements essential for having an impact on future urban transportation.

This can be attained by increased connectivity, synchronization, and far more attractive, user-oriented, system optimal, smart and sustainable, next generation, urban transportation systems.

Essentially, the new technologies should pursue the goal of a prudent, well connected PT system. The rapid development of information and communication technology (ICT) modernizes the image of traditional transportation systems and opens the door to dispatch vehicles, ordinary or AV, dynamically and in a communication based, connected vehicle environment. Vehicle-to-Vehicle (V2V) communication is an emerging technology. It is recognized as an important component of ITS and is already widely used in the transportation field. V2V communication technology is based on Vehicular Ad-Hoc Network (VANET) technology, which can improve the communication capacity and operations of vehicles by treating each vehicle as a mobile node in a communication network.

V2V communication technology enables drivers, using ordinary vehicles, to share their vehicle location, speed, direction, and passenger information with their peers in the same communication group. One earlier application of this intelligent technology is the Communication Based Train Control (CBTC) system that is employed to increase the train line capacity by safely reducing the headway between trains travelling along a given line (Pascoe & Eichorn, 2009 Zeng, Wang, & Zhang, 2007). Transfer based vehicle-to-vehicle communication architecture has been proposed by Liu, Ceder, Ma, and Guan (2014) for increasing PT service reliability.

With the advancement of computer technology, biotechnology and big data, Artificial Intelligence (AI) and advanced computing techniques will have extended applications for transportation. New AI techniques, such as data driven computing, cloud computation, Internet of Things, can be applied to solve large scale, complex and real world transportation planning, management, control problems. Robotics and visual reality in transportation are also promising application areas for AI techniques. The use of these AI-based intelligent technologies is part of AV development.

2.2. Social networking

Emerging social networking technologies, both those being implemented now and those to be implemented in the near future, are surrounding us at an increased pace. The social media and smartphone app revolutions are creating a technological breakaway from conventional practices affecting every aspect of life. It is an implacably progressive revolution and so affects PT planning and operations, as well. Social media have been shown to have particular advantages compared to conventional information systems in providing real time information. New tools, such as Facebook, Twitter and LinkedIn, enable and enhance real time, two-way communication between large groups of people and agencies, which can help to reduce passenger anxiety and allow informed choices. In order to effectively meet the ever-increasing and diversified mobility needs of citizens, some interactive social networking information platforms, such as Internet websites, telephone and smartphone apps, can be used to provide new and innovative modes of advanced, personalized and flexible demand-interactive PT service.

An important feature of social media is the use of apps for communication with PT operators (Camacho et al., 2013). Ceder and Jiang (2019) show how to have a combined system of seamless mobility with human preferences based on well-designed apps interacting with the PT operator in terms of sending preferences, receiving tailored information, and optimally adjusting system operation and synchronization.

2.3. Travel modes

Travel mode is a term used to distinguish substantially different methods of transport. There are many different kinds of travel modes which can be classified into three main categories: air transport, water transport and land transport. Each category can be further divided into sub-systems. There are also other special travel modes, such as pipeline transport, cable transport, and space transport.

The basic elements of PT systems that define different PT modes include Right-of-Way (ROW), vehicle guidance, guided vehicle support, propulsion, driving and control, service-type network and operations (Vuchic, 2005). The ROW element has different types: street – fully separated, street – partially separated, and street with mixed traffic. The ROW type is the most important element because it interacts with other elements. Different service types of network structures and operations tactics have an important impact on the service provided. The major operational tactics are: holding the vehicle (at terminal or at mid-route point), skip-stop operation, changes in speed (within the lawful speed limit), deadheading operation, short-turn operation, shortcut operation, adding a reserve vehicle, and leapfrogging operation with the vehicle ahead of the one under consideration. The working principles of each of the operational tactics are described in detail by Ceder (2016).

With the rapid development of new technologies, such as information and telecommunication technology (ICT), vehicle technology and propulsion technology, there are some new travel modes. For example, maglev trains, which use magnetic levitation to move vehicles without touching the ground, has already been tested in China, Germany and Japan. The maglev trains in operation are currently found in: Shanghai Maglev, Linimo (Tobu Kyuryo Line, Japan), Incheon Airport Maglev, and Changsha Maglev.

2.4. Economy

The design and implementation of a new mode of transportation system should consider various economic factors, such as effectiveness, efficiency, productivity, pricing and equity. In a PT system, these factors should simultaneously be considered from three perspectives: the passenger perspective, the agency/operator perspective, and the community/municipality/government perspective. These three perspectives emanate from the broad spectrum of PT activities, including online demand collection, network route design, timetable development and vehicle and crew scheduling (for ordinary vehicles, not AVs).

2.5. Integration

The integration of these major essential elements in the PT operations planning process can produce more advanced, attractive and reliable PT services. The need to transfer between routes is a major cause of discomfort for PT users. Improving PT connectivity is one of the most vital tasks in transit operations planning. A poor connection can cause some passengers to stop using the transit service. Synchronized PT timetables are created to enable passengers to enjoy seamless, direct transfers, and thus improve the level of PT systems' service.. However, due to the dynamic, stochastic, and uncertain nature of traffic, planned synchronized PT transfers do not always materialize. Missed direct transfers will not only frustrate existing passengers, but result in a loss of potential PT users. Service design criteria always contain postulates to improve routing and scheduling coordination (intra-agency and interagency transfer centers/points and synchronized/timed transfers). Ostensibly, the lack of well-defined connectivity measures precludes weighing and quantifying the result of any coordination effort.

A study by Chowdhury and Ceder (2013) identified the attributes that can define a connection as a planned transfer. According to their study, five attributes: network integration, integrated timed-transfer, integrated physical connection of transfers, information integration, and fare and ticketing integration are recognized to be the essential elements of the definition of a planned transfer. On the contrary, an unplanned transfer is defined as a connection that has been created without any guidance on how to make the connection. One possible definition (Ceder, 2016) of a prudent, well-connected transit path is: *an advanced, attractive transit system that operates reliably and relatively rapidly, with smooth (ease of) synchronized transfers, part of the door-to-door passenger chain.*

3. Literature review

Recent years have witnessed intensive discussion in the literature about various issues relating to future mobility and the future of PT. Naturally, much of this discussion concerns technological development, whereas for other themes the discussion and research were, and are, characterized by some confusion and lack of clarity about its relevancy. Four themes in the literature review are applied to the attempt to attain a clearer picture of recent research and discussion associated with future urban mobility and PT. The following brief summary includes discussion of each study of these four themes and a summary table is included at the end of this section.

3.1. Confusion about policy-making processes on future urban mobility

Foth (2018) raises the issue of lack of backing by political leadership in Australia for more proactivism in significant decision-making processes on urban mobility. The author observes that there is a belief that technological advances and innovations, e.g. of AVs and ride sharing service, can independently resolve transport-related problems. However, Foth (2018) emphasizes that there is a strong need for regulatory intervention without which there is no guarantee for making mobility more sustainable and economical.

Straub and Schaefer (2019) describe in a recent work an approach to deal with the issue of the interaction between policy makers and the technological advance of AVs. The authors raise the problematic perspectives of making policies for an unknown yet automated system, and the development of new AV technologies to adjust to yet unknown policies. Accordingly, there are two players, the policy makers and the technology developers. Straub and Schaefer (2019) suggest thinking of a way with real time feedback on each player, similar to two dancers who need to modify their moves according to what the other is doing. Generally speaking, this is an interesting analogy, but lacks substantiation from the testing of scenarios required for decisions on optimal developments. Questions, such as *what if*, produce multiple options for interpretation and subsequent responses.

Legacy, Ashmore, Scheurer, Stone, and Curtis (2019) use intelligent arguments, review and interview-based, in a search of how future urban area will consist of AV technology. The authors draw a possible conclusion that the private sector, considerably more than the public sector, will outline things to be done. In their study, Legacy et al. (2019) raise questions regarding whether urban planning can help in eliminating the undesirable impact of AVs on the environment. However, this unknown umbrella of anticipated urban-planning prospects leaves us with open-ended possibilities.

Cohen and Cavoli (2019) discuss whether or not governments should interfere in the economic affairs of AVs. The authors suggest that the do-nothing approach may produce less productive results than planned government intervention. Without real proof, Cohen and Cavoli (2019) believe that the lack of government involvement will result in an increasednumber of AVs with a higher chance of adding traffic congestion, and a decline in accessibility for future mobility systems. This study proposes a set of categories for government interference comprised of planning and land use, regulations and policy, infrastructure and technology, service provision and economic instruments. However, there is no indication of the interactions between these categories and the need for a research framework to connect these conceivable government initiatives and progress of technology for the benefit of urban dwellers. Questions remain unanswered and unanswerable for the present.

Bagloee, Ceder, Sarvi, and Asadi (2019) use a counterintuitive phenomenon called Braess Paradox for considering the introduction of no-car zones in urban developed areas. In effect, the authors show that by closing some roads, traffic circulation can be improved by reduction of total travel time. Certainly, such initiatives can be combined with the reduction of PC use, especially for the time of AV service availability. Bagloee et al. (2019) formulated this problem of finding which roads to close, as a bilevel, math programming problem. Their upper level formulation aims at selecting the number of roads to be closed, and the lower level formulation uses the solution of a traffic assignment problem. Because of the complexity of this problem, the authors developed an efficient surrogate-based methodology for large-sized networks, and tested it with real data of the road network of Winnipeg. The results favour this idea of a no-car zone in major developed cities. Nonetheless, this study does not consider the possibility of AV or APTV zones only in comparison to no-car zones, nor the mixture of the two.

Singleton (2019) discusses the outcome of a few studies, by academia and industry, about the expected reduction of the value of travel time, partly because of the increase of travel time when using AVs. The author argues that this reduction of the value of travel time will arrive not so much because of the extension of travel time, but because of other, what he calls 'positive utilities'. Singleton (2019) believes that AV users will have less stress and a more relaxing atmosphere than those driving cars. Unquestionably, these arguments will have to be examined and investigated before any operative conclusion can be drawn. Meanwhile, a lack of clarity about this (and other) issues prevails.

3.2. Confusion about behavioural trends for future urban mobility

Carleton (2016a, 2016b) presents two profound studies about the fear of the unknown and intolerance for uncertainty using emotion models. These theoretical and empirical studies of human emotion show that fear of the unknown is a strong, basic fear forming the foundation of anxiety and thus neuroticism. With this in mind, we can ask ourselves whether the unknowns for future mobility may, or may not introduce some fears, or anxiety, related to emotion in general. The subsequent question which begs asking is what research should be conducted, and what decisions should be made to enable significantly improved mobility for future smart cities.

Haboucha, Ishaq, and Shiftan (2017) studied the reaction of people to the appearance of AVs. This is done by a stated preference survey in which 721 individuals were asked their future choice given the availability of a mixture of ordinary (human driven), automated, and shared, automated vehicles. In other words, they were asked to indicate their preference for commuting by continuing to use privately owned cars or for a new, privately owned AV, or a shared AV. Interestingly, results show that 44% of them prefer to continue driving their ordinary cars, representing a significant hesitation to move to AVs. Do people fear the unknown, and thus resist change?

Herb, Xiao, Circella, Mokhtarian, and Walker (2018) seek to project changes in traveller behaviour upon travellers using AVs. In contrast to stated preferences' survey studies, the authors propose the use of an imitated self-driving system by a free, 7-day chauffeur service in the San Francisco Bay area. In other words, instead of driving, the traveller has someone available to make the desired trips. Herb et al. (2018) observed the characteristics of these free-of-driving-task trips and found that in comparison to the usual trips made, the number and mileage of trips increased as did the number of single-occupancy trips, particularly in the evening. Thus, the question remains as to whether an increase of mobility in the era of AVs and APTVs can be expected, and if so, what the consequences will be.

Nair, Astroza, Baht, Khoeini, and Pendyala (2018) are developing a rank ordered model for ranked data usually collected in a stated preference survey. As a model, it should best represent survey results when asked to rank hypotetical alternatives. The authors are using this model to attainthe results which contribute to their conclusions Nair et al. (2018) are applying their model to a survey about alternative configurations of AVs and found differences in responses across certain socioeconomic and sociodemographic characteristics. Thus, they draw the conclusion that ranked and preference-based choices made are not so determined. In other words, people are not sure what to prefer, possibly because of the unknown future of AVs and APTVs.

Stromberg, Karlsson, and Sochor (2018) examine a PT service, as inferred from the user perspective, as a Mobility-as-a-Service (MaaS) system in Gothenburg, Sweden, using four users groups based on sociodemographic characteristics. The MaaS system used is called UbiGo. With a sample of 195 individuals, the authors found that there are positive indications allowing for reducing the use of privately owned cars, given that travellers will obtain certain features from the service. Among the most important features found are flexibility of service, and user need for it. The mode of service was not found to be a key feature. This study, however, seems to be both site-specific, and system-specific. Thus, these features cannot be trusted, in general, as strong incentives to make users switch from PCs to PT.

Feigon and Murphy (2018) attempt to investigate how the introduction of transportation network companies (TNCs) such as Uber and Lyft in the U.S.A. will affect changes in PT services, use of single-occupancy vehicles, and traffic congestion. The authors report on a study with more than 10,000 users of PT and shared mobility. Feigon and Murphy's (2018) main results are: most TNC trips are in the evening and on weekends, for short distances in the heart of the city; while PT users and users of single-occupancy vehicles make their trips routinely. TNC users travel more irregularly. The main reasons for ordinary PT users, e.g. bus, rail, to switch to TNCs are travel and wait times. TNC users can be distinguished by income level, and correlated with the reduction of car ownership. This is a typical result from a state-of-preference questionnaire. It raises doubts because it fails to test real decisions by users. Indeed, even for a large sample of 10,000 people, it is not surprising that travel time and waiting time are considered important factors. Yet, it still remains to see what will induce them to give up their PCs entirely.

3.3. Confusion regarding continuing development of automated transit networks (ATN)

ATN systems have a long history, starting with PRT in Morgantown, West Virginia in the U.S.A., in 1975. The basic concept is similar to that of APTVs, but instead of being flexible and running on roadways, the ATN are rail based. Schweizer, Mantecchini, and Greenwood (2011) provide detailed comparisons and summaries of capacity estimations and size characteristics for serial-type and *sawtooth* – type PRT stations. Station characteristics have been modelled as a complex function by incorporating geometry, vehicle dynamics, boarding strategies and user behaviour. Comparisons have been made between capacity and space-efficiency with various load assumptions, using analytical and microsimulation techniques. The subsequent results of this study will be useful for selecting the most suitable PRT station for a given space constraint and demand scenario. Nonetheless, the question remains as to whether it is sensible to continue with this type of PT service.

McDonald (2013) has presented a comprehensive overview of PRT systems. This study traces early PRT explorations through to the first implementation for public use of the complete paradigm change for PT. The complex interrelationship between innovative thinking in technology, communication systems, hardware, architecture, transportation, and urban design/planning spanning the globe, has been discussed with specific examples from various cities. However, over its 40-years, the ATN has yet to flourish due to cost and difficulties in integrating with other PT modes. These difficulties seem to hold today as well, and given the progress of APTVs, it is questionable if there is still room for continuing to develop ATN.

Furman, Fabian, Ellis, Muller, and Swenson (2014) discuss and present the concept of ATN in the context of urban planning/design and public policy. Also, subsequent projects on this concept have been suggested for decision makers, in order to move forward to sustainable urban transportation. The comprehensive report of Furman et al. (2014) outlines and discusses unique features of ATN: (i) its ability to provide direct origin to destination services without the need for transfers or stops at intermediate stations, (ii) small vehicle size which can cater exclusively to an individual or a small group, (iii) demand driven service functionality (as opposed to fixed service schedules), (iv) fully automated nature of service, and (v) other aspects relating to vehicle guideways and stations within a fully connected network. The authors assert that ATN implementations require close cooperation from many kinds of local officials, and most probably will be implemented through a carefully negotiated Public-Private Partnership (PPP). Furthermore, the existing niche applications of ATN, for example, at Heathrow Airport, has been presented, and the extent to which the capabilities of these existing technologies can be expanded, has been discussed. Future work has been recommended to identify the ultimate capabilities of high-speed/high-capacity ATN. Doubts about ATN are still integral to the discussion of this type of PT among decision makers, and there are still more questions than answers.

Another important aspect of ATN is the research on in-vehicle activities. Camacho, Foth, Rakotonirainy, and Rittenbruch (2017) studied rail in-vehicle activities using a theoretical framework consisting of the dynamics of the activities and the passengers' perspective on ways these activities can be improved. The authors found that the activities are affected by circumstantial elements, including sociocultural elements, making their theory more complex and challenging.

3.4. Confusion regarding development of modelling and technologies for future PT

Villagra, Milanés, Pérez, and Godoy (2012) present a novel approach to planning smooth paths and speed profiles for APTVs in unstructured environments. The proposed approach deals explicitly with efficiency and comfort of automated PT systems by developing a planning algorithm. This algorithm is comprised of three layers: (i) an optimal local continuous curvature planner for obstacle-free situations; (ii) a global planner that finds intermediate points to connect the configuration space to the desired degree, taking obstacles into account; and (iii) a speed planner that uses the set of curves of the previous layer to compute analytically a comfort-constrained profile of velocities and accelerations. This system will therefore provide the APTV system with *a priori* knowledge on the shortest path within a selected area that guarantees lateral accelerations and steering wheel speeds below given pre-set thresholds. Furthermore, the speed-profiler can utilize semantic information from the path planner to set a continuous velocity reference, which considers bounds on lateral and longitudinal accelerations consistent with comfort, and a bound on longitudinal jerk. Real -life applications of the above features have been undertaken and the results of the algorithms were found to be satisfactory in an APTV when compared with real driving maneuvers performed by human drivers. Future work has been proposed by the authors in order to include the path planner in an overall control scheme in which an adapted, robust control algorithm can be used to track both the planned path and the planned speed as closely as possible. This is an example of a proper analytical development, yet to some extent, it is limited here to an isolated system. Smart urban mobility is expected to be synchronized and coordinated with all PT-related vehicles, and not built upon separate systems, similar to current, non-coordinated, distinct and separate bus companies operating in the same city.

Cuddy et al. (2014) describe smart cities and discuss their potential for interfacing with the emerging connected transportation environment. The authors aim to provide a well-defined foundation for the U.S. Department of Transportation's connected-vehicle programme, in order to identify and exploit opportunities to help ensure that connected vehicles and connected transportation fulfil their potential to improve safety, mobility and environmental outcomes in a complexly interdependent and multimodal environment. Furthermore, in order to understand the potential benefits of such a concept, this report explains in detail the definition of a smart and connected city. The *intelligent infrastructure* utilized by smart cities, such as devices and equipment which can sense the environment and/or their own status, send data, and often, receive commands, along with their potential transportation implications, has been reviewed and outlined. While the connected intelligent infrastructure is indeed required, the lack of clarity regarding types of APTVs and AVs using it, is an obstacle to defining a coherent plan supported by decision makers. It is therefore left aside until the unknown should become known.

With the advancement of technologies, AVs and APTVs can be expected to operate on the roads sometime in the future. VANET technologies can help to connect AVs so that they can respond cooperatively to instantaneous situations. Lam, Leung, and Chu (2014) and Lam, Leung, and Chu (2016) proposed a new, intelligent APTV system that can manage a fleet of AVs to accommodate a set of travel requests and offer point-to-point services with ridesharing. The APTV scheduling problem was formulated as a mixed integer, linear programming problem, and the admission control problem was formulated as a bi-level optimization problem. The scheduling problem was solved by existing commercial optimizers, e.g. YALMIP and CPLEX. A genetic algorithm-based method was proposed to solve the bi-level admission control problem. Taxi data collected from Boston, MA were used to validate the performance of the solution methods. The study results show that the new, intelligent APTV system with ridesharing can effectively reduce total operational cost, and an increase of vehicular capacity can further enhance system performance. This is another example of optimization of routing with shared APTVs, but as an isolated fleet problem, without comparing with PCs and without coordination with other APTVs.

Lam (2016) further studied the pricing issues for the multitenant APTV system considering benefits to PT users. Three types of services, including the splittable, non-splittable, and private services, were investigated. The pricing process was modelled as combinatorial auctions, where operators bid for providing the service requested by a customer. The winner of the auction was determined by solving an integer linear programming problem. A strategy-proof Vickrey-Clarke-Groves-based charging scheme was proposed to settle the final charges for PT users. Extensive simulations were conducted to verify the analytical results and evaluate the performance of the charging mechanism. This study assumes user preference is to minimize cost where preferences change dynamically among different people and all concerned, as well as for the same person, and for different times for all involved. Thus, further analysis is required for applying it to smart cities.

Vazifeh, Santi, Resta, Strogatz, and Ratti (2018) show a potential saving of shared APTVs with the use of novel network-based modelling. The authors introduced a new concept of a vehicle-sharing network with an optimization procedure to minimize the number of shared APTVs required for an on-demand service with no-waiting time/ Vazifeh et al. (2018) tested their modelling on extensive real taxi data for New York City and found an impressive reduction of 30% of their fleet size. Certainly, as the number of APTVs increases, the control of vehicles, with less variance on their travel time, improves. In turn, this increases success in implementing advanced modelling. This is intelligent modelling which can be used in simulation to check *what if* questions about different future mobility scenarios in order to provide some insight into the volume of vehicles that should be able to accommodate future smart cities.

Finally, it is interesting to observe that in September 2015, the world's first autonomous bus (APTV) completed its trial operation on the intercity road from Zhengzhou to Kaifeng in China. This APTV was designed by Yutong, China's leading bus manufacturer, and produced after three years of hard work. Covering a distance of 20 miles (32.6 km), the intercity route from Zhengzhou to Kaifeng includes a total of 26 traffic lights. Despite this, and heavy traffic, Yutong's autonomous bus completed a series of highly complex driving maneuvers, including automatic lane changes, overtaking and responding to traffic signals. The APTV arrived at its destination without any human assistance, with its highest speed reaching 42mph (68 km/h). The vehicle's intelligent sensing system boasts laser radar and cameras on four sides of the vehicle, which forms a panoramic 360-degree view and provides a response for driving information needs subject to various complex road conditions. In addition, the vehicle's driving system is operated by its master controller, which issues orders for acceleration, deceleration, or coming to a complete stop before it reaches a traffic light, depending on the colour of signal displayed. This is an example of a technologically feasible APTV that continuous to arrive, but without a clear idea on how to be integrated with intelligent infrastructure.

3.5. Summary table of literature review

Table 2 contains a broad view of the 21 articles reviewed in this section, for each of the four themes. The last column of Table 2 refers to the general questions remaining regarding the creation of a profound plan or consolidation of directions for development for future urban mobility. Unfortunately, many uncertainties about the direction to take in securing advanced smart cities with attractive, comfortable and effective APTVs systems oblige all the four themes start with the words 'confusion about'.

4. Visionary, feasibility related and realist (VFR) perspectives

The literature review of the four themes is characterized by lack of clarity about the best way to prepare the ground for future urban mobility. As a result, this review only conceptually proposes Visionary, Feasibility-related and Realist (VFR) perspectives as the basis for exploring plausible scenarios, based on feasibility evidence. This is done while attempting to realistically consider the imminent gap between progress and current struggles. Table 3 illustrates several breakthrough inventions and innovations using this VFR concept. The core input parameters of this concept combine empirical analyses of world population growth (described in section 1.1), individual car growth, and the future of PCs as compared with PT, including consideration of AVs and APTVs. Clearly, the result of what we see in Table 3 is dependent on global developments and occurrences for which these three input parameters are relevant to our quest for potential alternatives for creating magnificent, future urban mobility. Nonetheless, these VFR perspectives are only outlined in this section, with the intention of marking the door to further research of this notion. It is believed that the examination of future urban mobility options depends on the strength of all three types of professionals: those who have clear and strong vision, those who can test and examine new ideas and technologies, and those

Table 2. Overall view of some of the characteristics covered by the literature review.

Theme	Source	AVs or APTVs	Technological advance	Math modelling	Empirical	Questions remaining unanswered
Confusion about policy	Straub and Schaefer (2019)	AVs	√ vs. policy makers	–	–	What if?
	Foth (2018)	AVs	√	–	–	Lack of regulations
	Legacy et al. (2019)	AVs	√	–	√	Open-ended possibilities
	Cohen and Cavoli (2019)	AVs	√	–	–	Lack of connection between government and researchers
	Bagloee et al. (2019)	Both	–	√	√	Zones for AVs and APTVs only?
	Singleton (2019)	AVs	√	–	√	Lack of clarity
Confusion about behavioural trends	Carleton (2016a, 2016b)	–	–	–	√	How to overcome the anxiety?
	Haboucha et al. (2017)	AVs	–	–	√	Fear of the unknown
	Herb et al. (2018)	AVs	–	–	√	Consequences of more trips?
	Nair et al. (2018)	Both	–	√	√	People's preferences
	Stromberg et al. (2018)	APTVs	–	–	√	Can features found be trusted?
	Feigon and Murphy (2018)	APTVs	–	–	√	What is needed to give up PCs?
Confusion about continued ATN	Schweizer et al. (2011)	APTVs	√	–	√	Continue with PRT?
	McDonald (2013)	APTVs	√	–	√	Continue with ATN?
	Furman et al. (2014)	APTVs	√	–	√	Lack of clarity about ATN
	Camacho et al. (2017)	APTVs	√	–	–	Challenged in-vehicle activities
Confusion about modelling and technologies	Villagra et al. (2012)	APTVs	√	√	–	What about integration?
	Cuddy et al. (2014)	Both	√	–	√	Lack of coherent plan
	Lam et al. (2014, 2016)	Both	√	√	√	Lack of coordination
	Lam (2016)	APTVs	√	√	–	Why is only cost considered?
	Vazifeh et al. (2018)	APTVs	√	√	√	What if?

who can see clearly and consider the constraints inherent in implementation of the new ideas and technologies. Following is a brief description of the three input parameters.

4.1. Individual car growth

The total number of motor vehicles on the planet in 2020 is approximately 1.3 billion vehicles. It is estimated that the number of motor vehicles in use in the world will reach 2 billion by 2035, with PCs representing at least 50% of all vehicles. By some estimates, the total number of vehicles worldwide could reach 2.5 billion by 2050. From 2010 to 2015, an increase of 21% was evident in the number of registered vehicles in

Table 3. Examples of the development stages of inventions and innovations.

Invention^/ innovation*type	Invention^/ innovation*	Stages of invention^/Innovation* Events: Visionary's event(s)	Feasibility-related event(s)	Realist's event(s)
Hardware type	Airplane	People tried to navigate the air by imitating birds	The Wright Flyer on 17 December 1903	Mass production started during World War II (1939-1945)
	Automobile	Steam car designed by Verbiest in 1672	Karl Benz built the Benz patent Motorwagen in 1886	Mass production started by Ford 1913–1914
	Ship	Dates back about 10,000 years (vessels)	Circa 4,000 BCE, the ancient Egyptians were making wooden sailboats	Mass production of ocean ships started in 1940
	Telephone	Early acoustic devices for transmitting speech and music	Invented by Johann Philipp Reis in 1860, first success by A. Graham Bell 1876	Mass production started after 1877
	Maglev	Late 1940s, linear motor by British engineer E. Laithwaite	First maglev between the airport and railway station of Birmingham, 1984–1995	Expected to be widely available in the 2030s
	Quantum computer	Quantum computer with spins in 1968; Quantum computing, in 1980 by *P.* Benioff and Y. Manin	First quantum computer introduced by D-wave company in 2011	As of 2016, the development of actual quantum computers is still in its infancy
Softwaretype	Film	Huygens in the 1650s (magic lantern)	By the end of the 1880s (motion picture cameras)	Mass production started after 1910
	Internet	Visions into packet switching started in the early 1960s	ARPANET created in 1969	The creation of the Hypertext Transfer Protocol (HTTP) in 1991
	Smartphone	First conceptualized by Nikola Tesla in 1909 and Theodore Paraskevakos in 1971	First mobile phone with PDA features was an IBM prototype developed in 1992	Mass production of iPhone with multi-touch capabilities from January 2007
	Wireless communication	The use of telegraph before 1600s	Heinrich Hertz in 1888 demonstrated the underlying base of wireless technology	Mass production from 1980s with the use of cellular communication

^ In its purest sense, ***invention*** can be defined as the creation of a product or introduction of a process for the first time.
* ***Innovation*** on the other hand, occurs if someone improves or makes a significant contribution to an existing product, process or service.

the world (Statisa, 2018). This reflects numbers for 2010 showing 775,573 passenger cars and 280,127 commercial vehicles registered whereas in 2015, there were 947,080 passenger cars and 335,190 commercial vehicles registered. Motorization has an impact upon road traffic injuries, as well as upon congestion, air pollution, and mobility. In many countries, the rapid pace of motorization has taken place in a void of measures to ensure that all road users, notably pedestrians and cyclists, remain safe.

4.2. Private cars (PCs) or public transport (PT)

Cities in the future will become more compact, making it prohibitive to use more and more of the earth's surface for low-density, resource-intensive settlements in which mobility depends almost wholly on PCs. The combination of rapid urbanization and motorization has been placing a progressively increasing amount of pressure on the current transportation infrastructure throughout the world, resulting in such widespread problems as traffic congestion, traffic fatalities and injuries, traffic pollution and increased energy consumption. Because land and road resources are finite and subject to competing uses, government resources are constrained and PCs cannot meet progressively increasing, diversified, urban mobility needs. The PT systems, especially those involving APTVs with innovative, shared, customized, and modular modes, should be considered the best choice for solving these problems. The following section highlights the major elements of all PT systems.

5. PT effectiveness, efficiency, productivity, pricing and equity

Morris (2016) found that cars, on the average, are parked 95% of the timeHe used three extrapolated approaches to confirm that cars are actually in use only 5% or less of the time. The three approximations used are: (i) using data on the number of car trips and their average time, (ii) a survey of time spent driving and (iii) reports on the distance and speeds at which cars travel. This observation alone demonstrates the inefficiency of using PCs. This inefficiency shows that AV-based PCs cannot be the solution for future urban transportation systems.

From the literature review presented above, there are no clear-cut, practical, or measurable criteria for evaluating how good existing and new urban transportation systems are. The only comprehensible matter is that the evaluation of PT systems should be looked at simultaneously from three perspectives: that of the passenger, that of the agency/operator and that of the community/municipality/government. These three perspectives emanate from the broad spectrum of PT activities. The three key players of the PT system and their processes are graphically illustrated in Figure 2. The operations planning process of each player can be further divided into four parts: input, output, activity and impact. For PT users, with the main inputs of information, cost and social class, the outputs will be reliability, satisfaction and comprehension. PT users' activities include waiting, riding and transferring between different travel modes. The outputs are discrepancy of/agreement with information provided/expectations. Operator inputs include estimated passenger (pax) demand, fleet size available, cost components, etc., and the outputs are veh/km, veh/hr, pax-km, pax-hr, revenue, reliability and safety level. The main operations planning activities are providing scheduled/flex service, sending updated info, assigning vehicles and drivers, handling real time control. These activities will have an impact on time and safety performance, discrepancy of/agreement with expected pax demand. The inputs by the community/municipality/government are fixed/flex routes and stops, interchanges, priority schemes, safety measures. The main operation planning involves activating priority schemes, encouraging PT users, and restricting car movement. These inputs and activities result in less/more unused capacity on priority segments, less/more PT-related accidents and less/more PT use in modal split.

Quality of service reflects passenger perception of PT performance. The Transportation Research Board (TRB) defines quality of service as the overall measured or perceived performance of transit service from the passenger's point of view. Camacho, Foth, Rakotonirainy, Rittenbruch, and Bunker (2016) further highlight a passenger-centric approach in the pursuit of improvement and an extended definition of PT quality of service. Quality of service depends, to a great extent, on the operating decisions made by a transit

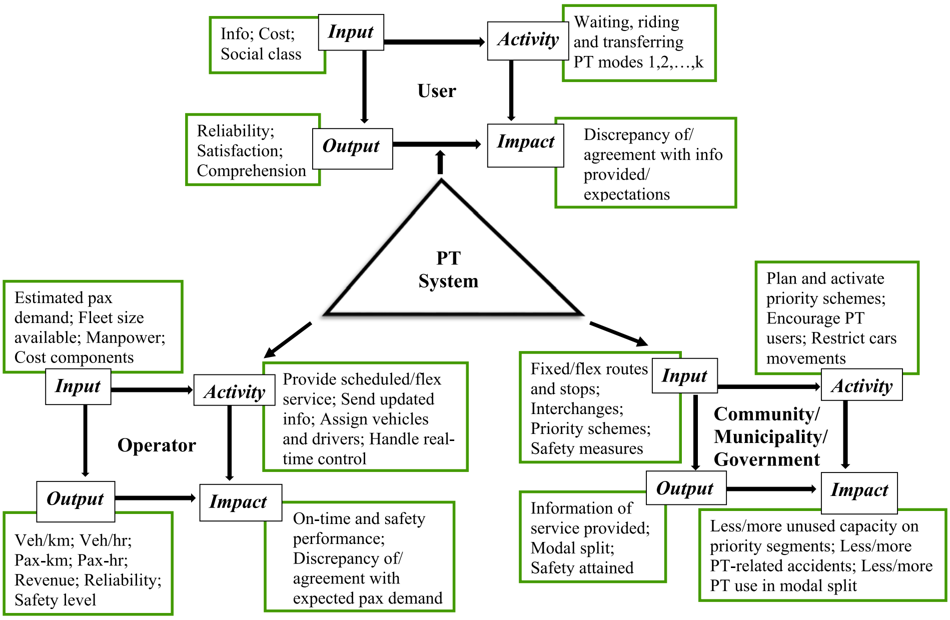

Figure 2. The three key players of the PT system and their processes.

system within its budget constraints, particularly decisions on where transit service should be provided, how often and how long it is provided, and the kind of service provided. Quality of service also measures how successful an agency is in providing service to its customers, which has ridership implications (TRB, 2013).

Four criteria can be considered when measuring the quality of a PT system: (1) minimum passenger waiting time, (2) minimum empty seat/space time, (3) minimum time difference from shortest path and (4) minimum fleet size. The first three criteria are measured in passenger hours, and the last in number of vehicles. Clearly, the first criterion represents passenger perspective. The second and fourth criteria represent the agency's perspective, and criterion 3 represents both passenger and community perspectives. When the purpose of measuring is to compare sets of existing PT systems or proposed future PT systems, monetary weights can be introduced to the four criteria. Optionally, criterion 3 can be replaced by the total monetary loss (or saving, if it is negative) if all PT passengers are switched to the shortest path.

Further to the aforementioned criteria for measuring PT system quality, it is noteworthy that in PT service, *tremendous* and *monotonous* can be understood as synonymous. It is best to have a monotonous, automated PT system that will always be there for the passenger, e.g. a modularized PRT system conducted like a horizontal elevator. This observation serves as an introduction to the need for PT service standards and guidelines. On the one hand, standards involve maintaining and improving existing service levels. On the other hand, they are often a source of fiscal pressure for PT agencies.

Service standards are also linked to any evaluation effort aimed at improving the efficiency, effectiveness and productivity of PT services. The greater these measures, the higher the level of service that can be offered. While efficiency refers to how well something is done, effectiveness refers to how useful something is. For example, a car is an effective form of transportation, able to move people across long distances, to specific places, but a car may not be efficient because of its use of fuel.

The need for dynamically updated standards in the PT industry warrants our attention, especially in light of the rapid introduction of advanced technologies in bus and rail transit and services. While standards, regulations and best practices are justified for supporting safety and security applications, they are also crucial for creating satisfactory PT service. The main standards currently utilized can be divided into two categories: (i) route design and (ii) service design. These can be further divided into route level and network level standards, and into planning level and monitoring level standards.

An assessment of ridership productivity and financial performance of any PT agency largely relies on five variables determined on a route basis: (i) vehicle hours, (ii) vehicle km, (iii) passenger measures, (iv) revenue, and (v) operating cost. These five variables form the base for seven economic and productivity standards that are in use in the US and Europe: (i) passengers per vehicle-hour, (ii) passengers per vehicle kilometre, (iii) passengers per trip, (iv) cost per passenger, (v) cost recovery ratio, (vi) subsidy per passenger, and (vii) relative performance. The main evaluation standards currently utilized can be divided into two categories: (i) passenger-based and (ii) cost-based. The former relates to ridership productivity criteria, and the latter to financial criteria.

The application of PT-connectivity measures, with respect to PT, falls in the area of social equity. Recent decades have witnessed a slow but steady paradigm shift from planning mass transit to considering equity and social inclusion as an integral part of the PT planning process (Kaplan, Popoks, Prato, & Ceder, 2014). While equity and social inclusion were initially discussed with respect to fare policies, concessionary fares, and PT subsidies, the perspective has been widened to include population groups with mobility limitations. An interest in considering equity and social inclusion first became apparent during the 90s with discussion of the need to integrate equity as a policy goal in transport provision. Accessibility is broadly defined as the ability and ease of reaching activities, opportunities, services and goods, and accessibility gaps are defined as the differences in accessibility across geographical areas, population groups and time. These accessibility gaps serve as indicators for identifying spatial, vertical, temporal and intergenerational inequities. PT connectivity can be used as a comprehensive impedance measure for the calculation of both location-based and potential accessibility measures which relate to equity assessment within PT planning and evaluation processes. While previous accessibility measures focused on travel time, transit connectivity considers not only travel time, but passenger discomfort associated with waiting, transfer and access/egress times, service reliability and attractiveness, frequency and seamless transfers along multimodal paths with specified travel demand as part of the door-to-door passenger chain (Kaplan et al., 2014). Thus, PT connectivity is free of the aforementioned four limitations and offers a deep and comprehensive understanding of accessibility gaps as equity indicators. In addition, for each origin-destination pair, PT connectivity is calculated for a set of multiple and feasible PT paths, including the three shortest paths and the three most popular paths (i.e. the paths with the maximum demand) in order to account for the probabilistic nature of PT path choice.

6. Concluding remarks

With changes in lifestyles, travel and transportation behaviour has already changed and will continue to change in the future. Clearly, we are on the verge of a dramatic change in urban mobility, but the evolution of automated/autonomous vehicles (AVs) is currently characterized by excessive confusion, causing uncertainty for researchers with respect to the chances that their research will improve future urban mobility. This is why this work emphasizes *thinking profoundly of the possibilities*, rather than *predicting* them. Thoughts of possibilities for the future draw upon imagination. Each of these strains of thought contribute to shedding some light on directions for further research.

This work reviews four themes of studies which are part of the prevalent confusion about best practices as well as the research required for enhancing future urban mobility. The four themes are on research studies related to decisions, behavioural trends, automated transit networks, and modelling and technologies. As the result of this review, this work proposes – only conceptually – a Visionary, Feasibility-related and Realist (VFR) perspective-based approach to exploring plausible visions for the future. This VFR concept combines empirical analysis of world population growth, urbanization, growth in private cars and their future in comparison to the future of public transport (PT) services.

Presently, in 2020, it is evident that more than half the world's population resides in cities, and growth is expected almost exclusively in cities. Accordingly, urban growth acceleration can be expected to result in healthier, more efficient and more productive lives for city dwellers. One observation of this work is that private cars (PCs) are parked approximately 95% of the time, demonstrating the inefficiency of their use. In consideration of this inefficiency and applying it to the development of autonomous and electric vehicles, it is clearly evident that PCs cannot provide a solution competitive with the potential that urban transportation systems have for the future. Hence, the solutions for the future must be based on PT modes of travel, regardless of whether they are metro, bus, light rail, tram, ridesharing services, an ordinary taxi, personal-rapid transit or any other PT-based future mode.

As opposed to rural areas, the increasing rhythm of urban life causes city residents to more highly value time saved, reduced fares, and increased convenience. Succinctly, they appreciate the value of *time*, *fare*, and *convenience* (TFC). When using PT, the customer is not interested in the routing as much as in the TFC. Consequently, future urban transportation will be attractive and successful if it delivers a travel system which is TFC-considerate. Moreover, advanced communication technology has already begun to have notably favourable effects upon cities and their transportation systems. The foreseeable lifestyle of mobility in future smart cities will not only involve travel by vehicles, but also walking and cycling. New urban mobility services, such as current ridesellling and ridesharing apps, will continue to appear, develop and merge. The key principal of operation for the mobility of a smart city will be the ability to optimize the connectivity of movement into a seamless transition, while endowing the phrase *door-to-door travel* with new meaning.

As suggested above, we cannot change the direction of the wind, with respect to evolution of lifestyles or land use patterns, and other phenomena. We can however adjust the sails and create attractive PT systems that will naturally shift people from PCs to PT vehicles. Appropriate adjustment of the sail relies heavily on acknowledging the ongoing development of new technologies. This is especially applicable to the unforeseeable implications of the Covid-19 pandemic for future mobility. However, it is premature to make hypotheses regarding changes that may occur with respect to human mobility needs as new practices evolve in terms of working hours for working from home and social distance implications when using PT services.

Accordingly, we will apply new technologies to more advanced, attractive, connected and customized travel modes for the purpose of encouraging mode shifts. Instead of trying to push people away from already crowded travel modes, we need to lure them away with innovative planning and operational strategies and ensure that transfers across travel modes are seamless. However, much will remain beyond our control, as the systems, like life, will evolve/develop by themselves. In other words, it is reasonable to assume that the evolvement of urban transportation will be as predictable and as unpredictable as the weather, and similarly beyond our control.

Acknowledgements

The author would like to express his sincere thanks to KOTI – Korea Transport Institute for partly supporting this study, and to Dr. Tao Liu, for having good and interesting conversations.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The author would like to express his sincere thanks to KOTI – Korea Transport Institute for partly supporting this study.

References

Bagloee, S. A., Ceder, A., Sarvi, M., & Asadi, M. (2019). Is it time to go for no-car zone policies? Braess Paradox Detection. *Transportation Research Part A*, *121*, 251–264.

Business Insider (Tech). (2016). 10 million self-driving cars will be on the road by 2020. *BI Intelligence report*. Retrieved from: https://www.businessinsider.com/report-10-million-self-driving-cars-will-be-on-the-road-by-2020-2015-5-6

Camacho, T., Foth, M., & Rakotonirainy, A. (2013). Pervasive technology and public transport: Opportunities beyond telematics. *IEEE Pervasive Computing*, *12*(1), 18–25.

Camacho, T., Foth, M., Rakotonirainy, A., & Rittenbruch, M. (2017). Understanding urban rail in-vehicle activities: An activity theory approach. *Transportation Research Part F: Traffic Psychology and Behaviour*, *46*(Part A), 70–86.

Camacho, T., Foth, M., Rakotonirainy, A., Rittenbruch, M., & Bunker, J. (2016). The role of passenger-centric innovation in the future of public transport. *Public Transport*, *8*(3), 453–475.

Carleton, R. N. (2016a). Into the unknown: A review and synthesis of contemporary models involving uncertainty. *Journal of Anxiety Disorders*, *39*, 30–43.

Carleton, R. N. (2016b). Fear of the unknown: One fear to rule them all? *Journal of Anxiety Disorders*, *41*, 5–21.

Ceder, A. (2016). *Public transit planning and operation: Modeling, practice and behavior* (2nd ed.). Boca Raton: CRC Press. This book was translated to Chinese (2017) and Korean (2018).

Ceder, A., & Jiang, Y. (2019). Personalized public transport mobility service: A journey ranking approach for route guidance. *Transp. Res. Proc*, *38*, 935–955.
Chowdhury, S. J., & Ceder, A. (2013). Definition of planned and unplanned transfer of public-transport service and users' decision to use routes with transfers. *Journal of Public Transportation*, *16*(2), 1–20.
Cohen, T., & Cavoli, C. (2019). Automated vehicles: Exploring possible consequences of government (non)intervention for congestion and accessibility. *Transport Review*, *39*(1), 125–151.
Cuddy, M., Epstein, A., Maloney, C., Westrom, R., Hassol, J., Kim, A., … Bettisworth, C. (2014). *The smart/connected city and its implications for connected transportation*, U.S. Department of Transportation, FHWA-JPO-14-148, John A Volpe National Transportation Systems Center, 55 Broadway, Cambridge, MA.
Currie, G. (2018). Lies, damned lies, AVs, shared mobility, and urban transit futures. *Journal of Public Transportation*, *21*(1), 19–30.
Feigon, S., & Murphy, C. (2018). *Broadening understanding of the interplay between public transit, shared mobility and personal automobiles*. TCRP Research Report 195, Transportation Research Board, Washington D.C. USA.
Foth, M. (2018). Smart mobility alone is no substitute for strong policy leadership. *The Conversation*, Cities, Australia. https://theconversation.com/smart-mobility-alone-is-no-substitute-for-strong-policy-leadership-105959
Furman, B., Fabian, L., Ellis, S., Muller, P., & Swenson, R. (2014). *Automated transit networks (ATN): A review of the state of the industry and prospects for the future*, Mineta Transportation Institute, MTI Report 12-31, No.CA-MTI-14-1227. College of Business, San José State University, San José, California.
Growth within. (2015). A circular economy vision for a competitive Europe. https://www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFoundation_Growth-Within_July15.pdf
Haboucha, C. J., Ishaq, R., & Shiftan, Y. (2017). User preferences regarding autonomous vehicles. *Transportation Research Part C*, *78*, 37–49.
Herb, M., Xiao, Y., Circella, G., Mokhtarian, P. L., & Walker, J. L. (2018). Projecting travelers into a world of self-driving vehicles: Estimating travel behavior implications via a a naturalistic experiment. *Transportation*, *45*, 1671–1685.
James, P., Magee, L., Scerri, A., & Steger, M. (2015). *Urban sustainability in theory and practice: Circles of sustainability*. London: Routledge and Earthscan.
Kaplan, S., Popoks, D., Prato, C. G., & Ceder, A. (2014). Using connectivity for measuring equity in transit provision. *Journal of Transport Geography*, *37*, 82–92.
Lam, A. Y. S. (2016). Combinatorial auction-based pricing for multi-tenant autonomous vehicle public transportation system. *IEEE Transactions on Intelligent Transportation Systems*, *17*(3), 859–869.
Lam, A. Y. S., Leung, Y.-W., & Chu, X. (2014). Autonomous vehicle public transportation system, In: *Proc. 3rd Int. Conf. Connected Veh. Expo.*, Vienna, Austria, Nov. 2014, 571–576.
Lam, A. Y. S., Leung, Y.-W., & Chu, X. (2016). Autonomous vehicle public transportation system: Scheduling and admission control. *IEEE Transactions on Intelligent Transportation Systems*, *17*(5), 1210–1226.
Legacy, C., Ashmore, D., Scheurer, J., Stone, J., & Curtis, C. (2019). Planning the driverless city. *Transport Review*, *39*(1), 84–102.
Liu, T., Ceder, A., Ma, J. H., & Guan, W. (2014). Synchronizing public transport transfers by using intervehicle communication scheme: Case study. *Transportation Research Record: Journal of the Transportation Research Board*, *2417*, 78–91.
McDonald, S. S. (2013). Personal rapid transit and its development. In M. Ehsani, F.-Y. Wang, & G. L. Brosch (Eds.), *Transportation technologies for Sustainability* (pp. 831–850). New York: Springer.
Morris, D. Z. (2016). Today's cars are parked 95% of the time. *Fortune Technology*. http://fortune.com/2016/03/13/cars-parked-95-percent-of-time/

Nair, G. S., Astroza, S., Baht, C. R., Khoeini, S., & Pendyala, R. M. (2018). An application of rank ordered probit modeling approach to understanding level of interest in autonomous vehicles. *Transportation*, *45*, 1623–1637.
Pascoe, R. D., & Eichorn, T. N. (2009). What is communication-based train control? *IEEE Vehicular Technology Magazine*, *4*(4), 16–21.
Piper, K. (2020). It's 2020. Where are our self-driving cars? https://www.vox.com/future-perfect/2020/2/14/21063487/self-driving-cars-autonomous-vehicles-waymo-cruise-uber
Schneider, I. E., Guo, T., & Schroeder, S. (2013). *Quality of life: Assessment for transportation performance measures*. Tourism Center & Department of Forest Resources, University of Minnesota. Report MN/RC 2013-05.
Schweizer, J., Mantecchini, L., & Greenwood, J. (2011). Analytical capacity limits of personal rapid transit stations. In: *Automated People Movers and Transit Systems* 2011: *From People Movers to Fully Automated Urban Mass Transit*. 326-338, Reston, Virginia, American Society of Civil Engineers (ASCE), ISBN: 9780784411933, doi: 10.1061/41193(424)30.
Singleton, P. E. (2019). Discussing the "positive utilities" of autonomous vehicles: Will travellers really use their time productively? *Transport Review*, *39*(1), 50–65.
Statista. (2018). https://www.statista.com/statistics/281134/number-of-vehicles-in-use-worldwide/
Straub, E. R., & Schaefer, E. (2019). It takes two to Tango: Automated vehicles and human beings do the dance of driving – four social considerations for policy. *Transportation Research Part A*, *122*, 173–183.
Stromberg, H., Karlsson, I. C. M., & Sochor, J. (2018). Inviting travelers to the smorgasbord of sustainable urban transport: Evidence from a MaaS field trial. *Transportation*, *45*, 1655–1670.
TRB. (2013). Transit capacity and quality of service manual, Third Edition. United Nations, Department of Economic and Social Affairs, Population Division (2014). World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352).
United Nations. (2014). Department of Economic and Social Affairs, Population Division. World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352).
Vazifeh, M. M., Santi, P., Resta, G., Strogatz, S. H., & Ratti, C. (2018). Addressing the minimum fleet problem in on-demand urban mobility. *Nature*, *557*, 534–538.
Villagra, J., Milanés, V., Pérez, J., & Godoy, J. (2012). Smooth path and speed planning for an automated public transport vehicle. *Robotics and Autonomous Systems*, *60*(2), 252–265.
Vuchic, V. R. (2005). *Urban transit: Operations, planning and economics*. New Jersey: John Wiley & Sons.
Wolff, C., Heller, M., Corwin, S., Bansal, M. P., & Pankratz, D. (2020). *Activating a seamless integrated mobility system (SIMSystem): Insights into Leading Global Practices* (World Economic Forum, 2020); https://www.weforum.org/reports/activating-a-seamless-integrated-mobility-system-simsystem-insights-into-leading-global-practices
Yigitcanlar, T., Foth, M., & Kamruzzaman, M. (2019a). Towards post-anthropocentric cities: Reconceptualising smart cities to evade urban ecocide. *Journal of Urban Technology*, *26*(2), 147–152.
Yigitcanlar, T., Kamruzzaman, M., Foth, M., & da Costa, J. S.-M. E. (2019b). Can cities become smart without being sustainable? *A Systematic Review of the Literature. Sustainable Cities and Society*, *45*, 348–365.
Zeng, X. Q., Wang, C. L., & Zhang, S. J. (2007). *Communication-based train operation control for rail transit*. Tongji (in China): Tongji University Press.