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ARTICLE / ARAŞTIRMA

Using Personal Rapid Transit as an Effective Transport Solution in Historical Downtown Areas: A Case from Historic *Kemeraltı*, İzmir

Tarihi Kent Merkezlerinde Bireysel Hızlı Toplu Taşımanın Etkin Bir Ulaşım Çözümü Olarak Kullanımı: İzmir Tarihi Kemeraltı Örneği

Yavuz Duvarcı, Figen Akpınar

Department of City and Regional Planning, İzmir Institute of Technology, Faculty of Architecture, İzmir, Türkiye

ABSTRACT

Many issues related to the conservation of urban heritage are closely related to the transit system and the use of private transportation. Regeneration, revitalization, and/or heritage conservation are not properly managed due to problems arising directly from inconvenient transport solutions that cannot provide or resolve the accessibility and mobility needs of vulnerable groups together with inappropriate space management while indirectly causing economic shrinkage and loss of vitality. Furthermore, even if modern modes of transportation are used, they will cause significant environmental and societal difficulties, making them unsuitable for such sensitive places. This article, using a micro-simulation approach, investigates whether a Personal Rapid Transit system is physically applicable, and whether it can meet existing travel requirements to prove that it is sufficient for the needs of local level mobility, and finally whether other environmental/social impacts such that land use, air pollution, safety, sustainability are positive or negative. As a method, these outputs of the system application are presented as validations of the usefulness of the PRT. Finally, it was found that there is a gain in productivity in terms of mobility as well as other socio-economic benefits besides the physical applicability of the method. The study's goal is to get the information out about how PRT technology may help produce more ecologically friendly and sustainable solutions while also conserving historical assets.

Keywords: Personal rapid transit; smart transportation; sustainable transportation for the heritage areas; sustainable transportation policy.

ÖZ

Kentsel mirasın korunması bağlamında pek çok sorunun temelinde ulaşım sistemi ve özel ulaşım türleri bulunmaktadır. Buna karşın kentsel yenileştirme, yeniden canlandırma, ve/veya kültürel mirasın korunmasında ulaşıma ilişkin konuların yeterince gözetildiğini söylemek zordur. Halbuki ekonomik canlılığın sağlanması sürdürülmesi, ulaşım sistemi ve arazi kullanım ilişkisinin sağlıklı kurulması ve dezavantajlı sosyal grupların erişim, hareketlilik ihtiyaçlarının gözetilmesi için ulaşımın özellikle kentsel koruma alanına entegrasyonu önem taşımaktadır. Üstelik çağdaş ulaşım türleri kullanılsa dahi çok dikkatli müdahale edilmesi gereken miras alanlarında çeşitli çevresel ve sosyal sorunlar ortaya çıkmaktadır. Bu makale mikro-simülasyon yaklaşımıyla Bireysel Hızlı Toplu Taşım (BHT) sisteminin fiziki olarak uygulanabilirliğinin, dezavantajlı grupların yerel düzeydeki ulaşım ihtiyaçlarının karşılanabilirliğinin, ve arazi kullanımı, hava kirliliği, güvenlik, sürdürülebilirlik türünden çevresel ve sosyal etkilerinin araştırılmasını hedeflemektedir. Çalışmada BHT sisteminin mikro-simülasyon yönteminin kullanılmasıyla, anılan tüm bu unsurlara çözüm sağlanmış ve doğrulanabilir kanıtlar biçiminde ortaya konmuştur. Bulgular hareketliliğin BHT teknolojisiyle eşit bir biçimde sağlandığını, sosyoekonomik faydaları olduğunu ve tüm bunların yanısıra fiziki olarak da sistemin uygulanabileceğini göstermiştir. Çalışmada BHT teknolojisinin çevreci ve sürdürülebilir olduğu, kentsel sit alanlarının korunmasında etkin bir çözüm olduğuna dair bilgi sağlanmıştır.

Anahtar sözcükler: Bireysel hızlı toplu taşıma; akıllı ulaşım; miras alanları için sürdürülebilir ulaşım; sürdürülebilir ulaşım politikası.

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Correspondence: Figen Akpınar
e-mail: figenakpinar@iyte.edu.tr

TMMOB
Şehir Plancıları Odası

1. Introduction

Our interest in the historic center of Izmir, namely *Kemeraltı*, stems from the need to retain a viable economic function for the area, which is already in the process of economic decline, repression, loss of character and viability despite all the conservation, revitalization and renovation efforts. It has long been proven that mere physical revitalization is unsustainable and short-lived. However, in order to bring about economic revitalization, transportation issues have not gained much attention among other solutions. Transportation is not only an equalizer among economic classes and eliminates the accessibility problems of needy groups, but also a major driver of development in large and small communities. For this reason, more research is needed to bring together conservation of historic areas and transportation. This paper can be seen as an attempt to address the gap in this area.

Today's conventional transport systems, such as private cars, buses, trains, subways, ferries, etc., have demonstrated their high cost, major safety issues, and high fossil fuel consumption levels. Factors such as the use of advanced technology and the reduction of operating costs are behind the development of ITS. Personal Rapid Transit (PRT) excels among others in the ITS realm. The system is theoretically and practically proven to be highly comfortable and environmentally sustainable, safe and low in management costs (Poojari and Uday 2014, McDonald 2009, Jain et al. 2008, Srivastava et al. 2014, Loyola et al. 2019). PRT also excels in the planning and management of urban spatial development for long-term urban prosperity and resilience. Low energy, no drivers, no railways, no timetables, no delays and emissions, no queues, fair participation and mobility, resilient and regenerative urban management are all examples of social and economic inclusion. That is, even those vulnerable groups such as the elderly, children, disabled, etc. who are not able to drive can use these autonomous systems conveniently. On the other hand, despite the tremendous effectiveness that PRT systems would promise, particularly for historic conservation, it has received little attention due to a lack of interest on the part of local governments, scholars, planners, and policymakers in the major issue that we seek to highlight.

Many problems faced in the conservation of the historic core areas are mainly related with the use of massive transit systems as well as private automobiles that needs to confront the limited space problem. Yet, since there is dense motor traffic intrusion and parking pressures to these areas, most heritage areas have to be closed partially or totally to motorized traffic. But, this brings the problem of accessibility for those needy groups, especially those who are not able to walk to the remote points within these areas. They should be able to reach their destinations without the special aid from other people, or should be assisted by technology. In the meantime, heritage conservation is not realized or adequately managed as a result of huge transportation challenges such as accessibility, mobility, economic shrinkage, and inflexibility of main transit axes, among others.

As a result, the focus of this paper is on questioning the efficiency of any potential PRT in terms of both physical abilities, such as whether it can run in the narrow and winding streets of such historical areas, and meeting existing travel demands, particularly the vehicular travel demand of the needy and people with disabilities. In terms of meeting the main requirement, the looping ability of the guideway network that the PRT requires for passing through a dense pedestrian walkway, which takes about two meters in width, is to be considered.

For the second requirement, pedestrian traffic circulating along the primary axis should be considered for PRT transit. The applicability of the technology will be investigated in a virtual simulation utilizing an actual heritage case location, *Kemeraltı*, in Izmir's historic downtown regions. The system is expected to prove itself in terms of societal needs and environmental outputs, such as a lower rate of accidents, after these basic prerequisites are met.

Basically, this paper shows that even though this is a simulation-based study, the PRT system works well and can help with transporting the needy and disabled travelers, and reduce unnecessary travel even for pedestrian travelers.

2. The Problems Related with the Conventional Transit System and Its Effects in Historical Downtown Areas

The concept of heritage, which is never static and has a tendency to expand its scope as one of the primary topics of sustainable development over time, has gained significant importance in many directions as well as the development of new instruments and attitudes in heritage conservation (Faro Convention, 2005; The Valetta Principles 2011; Fairclough 2009, 125). The traffic around the historic town or urban area should be strictly controlled by regulations (Washington Charter 1987). Historic core areas are usually located in the city's central areas and many traditional activities can be found instead of residential functions. Most of the urban fabric consists of various commercial, miscellaneous services and small-scale manufacturing activities. While many believe that the complete elimination of motor traffic from the historic core areas is a commonly agreed solution, total removal or restriction of all motor traffic is not a realistic solution for economic vitality, accessibility and mobility (Rypkema, 2006; Banister, 2008; Tønnesen et al., 2014). Furthermore, some people in society, such as people with disabilities, the elderly and young people who do not have vehicles, are now forced to walk long distances.[1] Furthermore, transportation interconnectivity will involve full integration into urban planning strategies, which will provide economic prosperity and cures for economic, physical, and social damage to urban space.[2]

On the other hand, large scale development, i.e. large areas consumed for the conventional private and public transit system are extremely harmful and damaging to historical and archaeological sites. Especially, car parking is a troublesome issue demanding more space and eventually causing alteration of the traditional lot sizes that help to define historic urban morphology.[3]

Promoting pedestrian mobility, reducing traffic, and lowering parking spaces necessitate new modes of transportation that provide users with additional information about an environmentally friendly solution. Another difficulty in historic conservation is energy efficiency and noise reduction.

3. About PRT Systems

The idea of sustainable urban development and the internalization of renewable energy have recently become common in urban planning, both in terms of energy savings and the creation of vibrant environments. The advancement of ITS systems displays very promising characteristics such as becoming more environmentally friendly, saving expenses, reducing the risk of a crash, and requiring less space. The elimination of the human driver factor by replacing the drivers with the autonomously driven vehicles operating under human supervision is very effective for achieving a zero-accident rate.

The Information and Communication technology (ICT), which are usually economic, the sustainable output is defined as holistic and comprehensive efficiency: social, environmental and cost effective solutions, so as not to undermine future generations' right to use resources (Bibri and Krogstie 2017, 183; Silva, Khan and Khan, 2018, 705–6). All of the sustainability and comfort-related transportation criteria listed in Table 1 are nearly all crammed into a single PRT system, in contrast to the other traditional systems. This table illustrates how the PRT can meet practically all sustainable mobility challenges.

The quality of urban life and participation in its activities depends on the good quality of the services of urban transport. On the other hand, transport services' success depends on sound transport policies that are sensitive to these vulnerable groups (Heggie and Jones, 1978). Even elderly people living in remote places tend to be dependent on automobiles because of the decentralization process of the urbanization in the era of liberalization. However, excessive distances to transit stops, the time needed to reach destinations, poor reliability of service, etc. have all curtailed the participation of such groups in activities. Most of the time, the elderly defer less important social and leisure trips, or plan and combine strictly into one-end household trips. Family dependence also factors into mobility choices along with car dependence (Duvarci and Yigitcanlar, 2007; Srinavasan and Ferreiras, 2002; Limanond and Niemeie, 2004; Litman and Colman, 2001). There are some partial attempts and paratransit services to help these special groups, but they are separated from the rest of society by special transit systems, and it also creates an inconvenience for these groups to rely heavily on public modes (Hine and Grieco, 2003). Where there is no alternative mode of travel and no special transit to assist the safety needs for the older and vulnerable people, this leads to inequalities in social inclusion and mobility that cannot be sustained. Since PRT systems are thought to be a radical alternative to both public systems and private automobile usage, they can't just be regarded as 'paratransit' services.

In terms of the environment, however, peak hour congestion reduces travel quality and safety while also wasting time, money, and air quality. Today, transport activities are responsible for almost 60% to 90% of all air pollution, and a non-negligible share (40%) is due to private car use (Duvarci et al., 2008).

With the increased motor traffic rate higher than the population growth rate, traffic congestion on urban streets is an overlooked issue. The noise effect on downtown streets is enormous, and drivers tend to look for alternative streets that impede local community access when congestion occurs (Robinson, 1984; Hansen Gillen et al., 1993). The narrow streets of the historic central areas, which were not originally designed for heavy car traffic, are overwhelmed by the heavy volume of traffic.

PRT is essentially a technological solution with a fundamental feature of being autonomous (driverless) and has many advantages, mainly being accessible to the young, elderly and people with disabilities who do not want to risk driving in today's dangerous traffic and road conditions. It is specifically designed for safety (the promise of 0-accident risk), improved energy efficiency and optimal use of resources (Mogge, 2009; NICHES, 2010). The link between smartness and sustainability was redefined in a benchmark study by Debnath and colleagues (2014). Cities were tested for their transportation services according to smartness levels (index), and the city of

[1] The Model Proposal for Izmir Municipality recently published a report that offered the same "private car ban entering the city center" by increasing parking fees etc., without offering any new transit solutions or how to create economic vitality without transit solutions (Tekeli 2018, 88).

[2] The New Charter of Athens, 2003.

[3] In Turkey, especially in fast-growing cities, fires and arson are very common in the historic core areas to create more parking spaces and substantial gains from parking fees.

Table 1. The Comparison of traditional transit with the PRT

Traditional public transportation systems	The PRT system
A vehicle can accommodate large groups of passengers	A pod can only carry a small group of people (between 3–6 passengers)
Destinations and stop points are always the same	Private demand-responsive, and passenger determines the destination
Less privacy, less flexibility, and public	More privacy, as flexible as private automobile, and public for those who do not own cars
Pre-scheduled time-table & tariff, the travel has to endure many stops & writings which increase the travel time. Travel time is longer at peak hours, stressful and uncomfortable	There is no pre-scheduled route and times (no time-table). No loss of time at stops. The service quality is much higher.
Exposure to congestions and usually higher safety risks	More convenient and safe due to the computer-based control mechanisms
Require large infrastructure investments, and have environmental, visual and audial impacts	Requires smaller and not heavy infrastructures. Has lesser visual and audial impact
Construction and operation costs are high	Both construction and operation costs are lower
High emissions and energy consumptions, problems of pollution	Environmentally benign, no emission and very low energy consumption

Source: Duvarci & Akpinar, 2012. PRT: Personal Rapid Transit.

London, England was chosen to have the best smart applications, including the state of the art PRT system at Heathrow Airport although such systems are rare worldwide (Debnath et al., 2014). In the study, smartness is indexed to advanced technology, automated communications and self-corrections; i.e. Internet of Things (IoT) on each subsystem of the city's entire transportation.

Furthermore, PRT offers the most environmentally friendly advantage as compared to conventional systems such as no obligation of travelling with strangers; privacy with non-stop travelling, stations can be spaced far more closely than metro; passengers do not need to transfer between lines, making point-to-point journeys especially easy for the elderly and disabled. And lastly; PRT offers faster and more comfortable travel especially for the vulnerable groups (Duvarci and Akpinar, 2012; Di Bona and Mikosza, 2013) with the least environmental cost (Fig. 1).

Although the current public transport systems are generally introduced as meeting the “public interest” providing equality between urban people, it also causes inequalities between different social groups i.e., for those who could not drive cars, elderly, handicapped or children. In fact, the shift in transit rates from private cars to public modes was not as high as expected (Duvarci and Mizokami, 2009; H. Chapman and M. Chapman, 2011). As a result, current public transportation, which necessitates costly infrastructure in addition to being a vast system, is not as ideal or viable as previously imagined, particularly in heritage sites in urban centers. As a radical solution to urban road safety, the PRT systems have been on the scene since the 1950s as a practical and sustainable solution requiring less energy use (Edelman, 2010).

4. Method

This paper employs a typical what-if case comparison and applies this hypothetical case to the existing situation. If the PRT system were to completely replace the existing motor systems or unnecessary pedestrian trips, then it could:

1. Eliminate the existing motor traffic if needed;
2. Provide better transportation options for the majority of pedestrians that may be disadvantaged, people with disabilities and other vulnerable groups (children or elderly) instead of requiring vehicle usage to reach their destinations beyond an acceptable walking distance;
3. Improve land usage;
4. Provide social and environmental benefits and safety.

Using the current situation data (the case of no PRT, open to partial vehicle access and pedestrian ways) as a reference point, we will compare the situation with the one including the PRT operation. In this paper, the general scheme of the simulation approach proposed for the PRT situation is based primarily on the **operability** of the hypothetical PRT simulation, given the basic requirement to meet travel demands (Fig. 2). The surveyed pedestrian trips at the survey spot on *Anafartalar* Street, supported by other data sources, were therefore the subject of a simulated Origin-Destination (O-D). That is, the O-D data, and the number of pods to be dispatched are generated from the previous surveys made on the major streets for finding pedestrian trips, and other related data. The O-D matrix trips must be distributed (each cell value being the same) to bring the simulated trip values up to the surveyed values (i.e., about

Electric Pod Cars at the Heathrow Airport

Figure 1. Rendering of a PRT images at the *Izmir Institute of Technology Campus* on the left and the London Heathrow Airport's pod cars is on the right https://www.joyenjoys.com/electric-pod-cars-at-the-heathrow-airport/

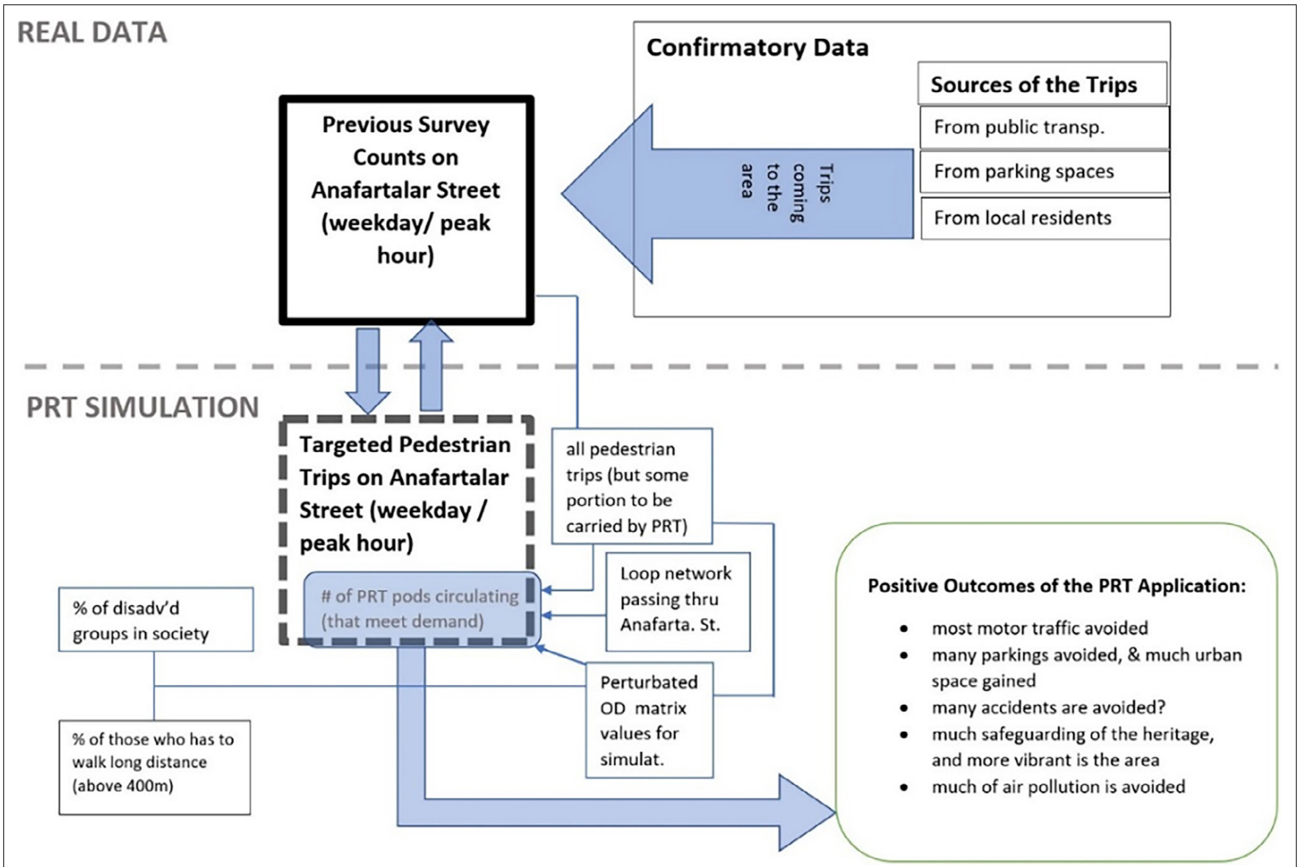

Figure 2. The general method of PRT Simulation to find the PRT fleet size for the trips that would need vehicular transportation.

PRT: Personal Rapid Transit.

500 vehicles/hour on average). This way, the simulated values are to be matched with the real survey values. The dynamic simulation is then tested to see whether it runs smoothly and operates correctly; whether there is an issue with the execution, such as congestions, etc., or not. However, before these requirements can be accomplished, the system must be physically appropriate for the street; most commonly, larger streets are used to build the round ring structure appropriate for one-way running, which is approximately 2 meters for the PRT.

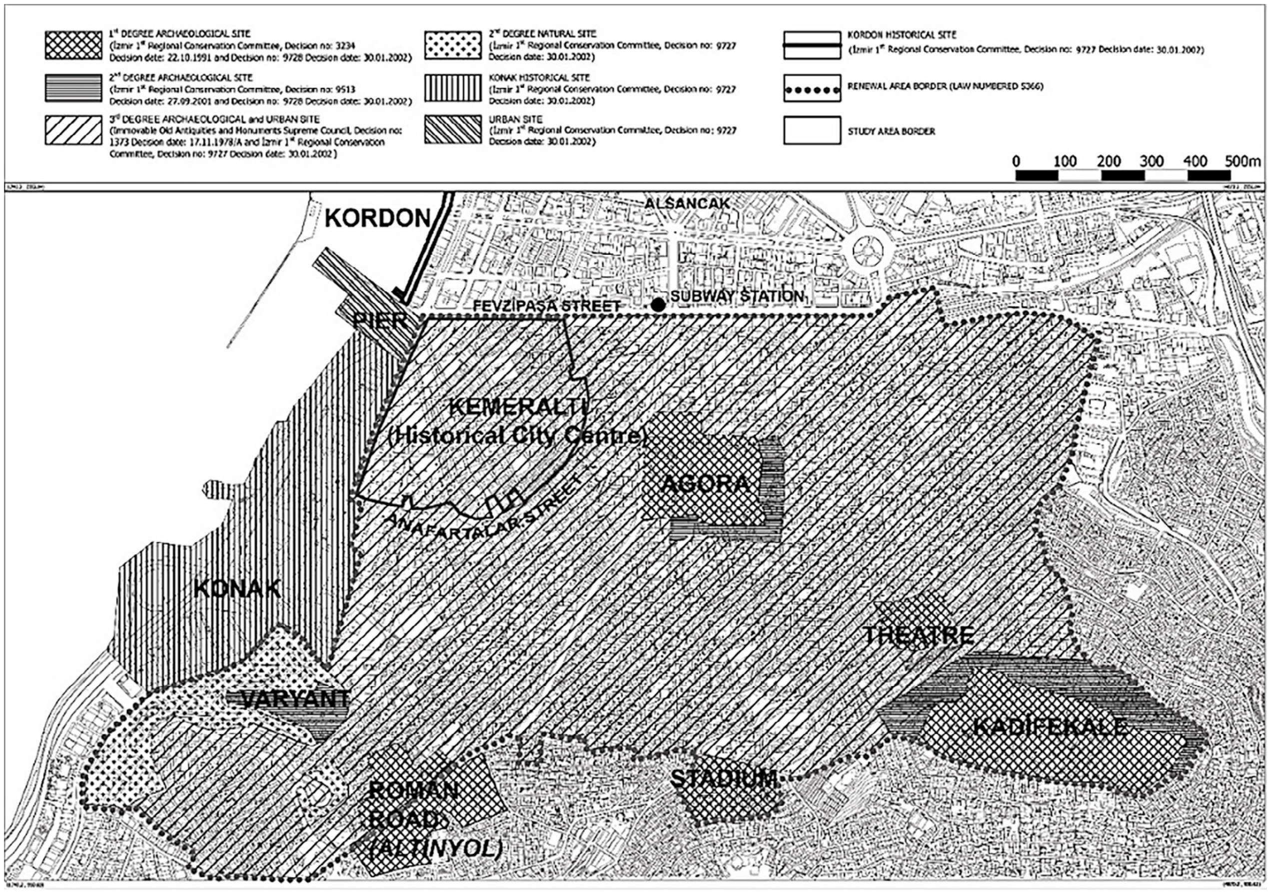

Figure 3. Historic *Kemeraltı* Project Area and the study area (black point indicates the Subway Stop).

Since the study area of the *Kemeraltı* region[4] is already a large pedestrian zone (Fig. 3), most local streets are narrow and not suitable for motor traffic during most of the day (usually access is time-constrained; no vehicle is allowed during daytime). Therefore, traffic circulation is already limited. However, there are still some drivers who want access to the area park in pedestrian zones to avoid the parking fees. Thus, it is assumed that the new PRT system could cover only those pedestrian trips circulating in the area. Further, vehicles delivering and taking cargo will not be taken into consideration because they only stop shortly outside and are not normally allowed into the area. Those delivering cargo from the vehicle to the retail shop will be counted amongst the pedestrians. Moreover, as mentioned earlier, most cargo deliveries are usually during the off peak hours.

Thus, if implemented, the new PRT system should prove its usefulness and feasibility for various reasons (formulated as the *validations after all*) based on the hypothetical aftermath of the simulation results. The method in this paper is based on the evidence relating to transportation problems and the environmental and social sustainability issues that the PRT application will bring many benefits for conservation and management to the historic parts of a city. The method involves three main stages: (a) collecting evidence-based data on the current situation, (b) simulating PRT whether it meets the current travel demands for both vehicles and pedestrians, and (c) calculating the area and environmental gains that could be used for other purposes other than vehicle space requirements.

The validations that are related to transportation are:
First validation is that the PRT proposal can fully meet the area's urban transport needs. The basic method is first to determine the current travel demand on one of the pedestrian axes with which the proposed PRT line (the 'loop') overlaps, and then to define the equivalent number of PRT pods (the fleet size). The demand is assessed from both the off-board-

[4] *Kemeraltı* Bazaar and Khan Area located around the commercial axis of *Anafartalar* Street, is a registered urban and archeological site, where our PRT line is passing through. The whole conservation area, which is about 248 hectares, is being subjected to conservation, renewal and regeneration applications based on *Izmir-History* Project under the guidance of the Municipality of Izmir (Tekeli, 2015). The research area is accessed easily from the subway station on *Fevzipasa* Street. It is also within walking distance to the contemporary commercial center, Konak, and the Republican period development zone, *Alsancak*.

Table 2. The Problems and data types

Transport/access problems	Required data	Method*
Parking (difficulty)	How much parking (as availability and as need)	Replacing parking need for those accessing in by cars
Pedestrian versus motor vehicle confrontations	Difficulty of easy access caused by pedestrian/traffic interactions	Observations, people's opinions
Pedestrian accessibility/mobility/travel demands	Walking Access distances % of needy groups % of travel minutes above 5 minutes (access time) Traffic counts (especially pedestrians)	Especially the percentage of needy groups to be transported by PRT for long distances to walk
Access by motor vehicle (especially for Cargo up/unloading)	Width of streets (both at site and over map)	Search PRT suitable RoW (min. 2 m width required all through the route)

*The research question here is whether the PRT applies to the study area, what methods to be used. PRT: Personal Rapid Transit.

ing of the motor vehicles i.e. public transport, car parking and residents/workers, as well as the survey data conducted by the Municipality of Izmir for the Izmir Sustainable Transportation Project for the area (Oztas et al., 2018). To see if the system is running efficiently, we simply run the PRT simulation. As of the method's main principle, those who are able and willing to walk will be assumed to be a portion of persisting pedestrians, but the others, who cannot walk to distant destinations will be 'rescued' from being compulsory pedestrians and will be transported by the PRT. Also, most pedestrians traveling from other locations by a car are to be served by the system, since the vehicular intrusion to the area is unwanted.

Second validation is that the PRT system can be employed for a considered loop route around the area due to the physical adjustability of street widths. For applicability, only those streets with a width criterion of at least 6–7 meters were considered to close the looping network. The PRT 'ring' is designed so as to tour the whole concerned area to a greater extent. Traffic stops are located at most probable spacious places.

The other validations that are related to environmental considerations:

Third validation is that, with the PRT system, additional space will be gained from the areas once occupied by car or traffic; all parking lots are to be eliminated. The total area of the eliminated lots is the area gained for social recreation purposes.

Fourth validation is that PRT can help vulnerable pedestrians to transport them where appropriate i.e. beyond reasonable walking distances; again, from the ratio of poor population groups to regular population[5] we can derive approximately the number of pedestrian travelers who are especially unable to walk at all and/or who do not need to walk.

Fifth validation is that PRT will help to preserve the historical parts of the cities effectively and will be taken as an effective new instrument for conservation of the historic inner city central core areas.

Sixth validation is that PRT systems are the safest mode in terms of accidents. If crash and fatality data are available, assuming that the PRT system is a zero-accident system, all annually recorded accidents will be eliminated.

As the first step we need to set up the simulation environment and set up the PRT lines as if a representative PRT system were to be implemented in the area; whether it works physically and is applicable. Then, whether the proposed PRT system can meet the current travel requirements and solve the access problem of the needy groups. Finally, positive social/environmental contributions of the system are to be sought. Table 2 and Table 3 summarize the transport problems that the conventional transport system has brought to the heritage areas and the data required to fix the problems and the methods.

5. Data

The traffic related data used in this paper is from the *Izmir Sustainable Transportation Project*[6] conducted by the Municipality of Izmir (Oztas et al., 2018). The survey includes information on travel habits, existing facilities and traffic flows. In summary, the data extracted so far contains the following:

[5] Data from national statistics and local data statistics.

[6] The data retrieved from the survey report of the *Izmir Sustainable Transportation Project* conducted by the Municipality of Izmir (2018). https://wrisehirler.org/sites/default/files/IzmirSurdurulebilirUlasimProjesi_Final.pdf.

Table 3. The Socio-economic and environmental problems

Socio-economic and environmental problems**	Required data	Method
Noise/Resonance/Dust/bad smell	Measurements or, Interviews with passerby and shop owners	Site observations and previous survey data
Loss of spaces/less recreational or green areas due to the road infrastructure, traffic and parking	The necessary amount/area occupied by car parking	Calculation of total parking areas, and circulation roads to be to be removed
Road infrastructure threatening the historical structure	Damage to historical assets, e.g. fountains, buildings, etc. required. But, data not available	Not available
Retailers' need of loading/unloading goods and services	Site survey done by Projects' members	Survey questionnaire results (from previous study)
Urban quality and loss of historical urban texture and values	Site survey done by Projects' members	Site survey, interviews, observations
Safety	Number of accidents (that the existing traffic creates)	Existing traffic accident data (yearly) will be removed, assuming 0–accidents by PRT, replacing motor traffic
Air Pollution and/or Noise	Amount of emission per vehicle that the traffic creates. Air pollution values of nearby districts. Existing noise data are not available	Use of a study's model; decrease of pollution level by certain amount of vehicle use

**These are the problems that have been brought by the conventional transport system. PRT: Personal Rapid Transit.

- General traveler behavior and preferences, opinions, satisfaction, etc.
- Recent traffic flow data; motor vehicles, bicycle, pedestrians, etc.
- Road infrastructure and parking supplies.
- Land usage and planning decisions.

According to the survey report, user satisfaction levels of travelers, neighbors, passer-by, etc., the problems associated with the existing transport system and infrastructures are summarized in Table 4.

On the survey counts of pedestrian and vehicles:[7]

Vehicle access is already limited to a great extent in the area, and for this reason travel demand data consisting mainly of car park capacity will be used in the study area instead of these travel figures in Table 5.

We will basically refer to the weekday counts for the hypothetical PRT application. Weekend travel will not be considered. Trips per hour (for peaks) visiting the area are mainly from three major entry points: West-*Konak* side, North-*Fevzipasa* street and East-*Ikicesmelik* street (Fig. 3).

Pedestrian Trips from parked cars:
There are both regional high capacity multi-story parking facilities near the area as well as private and small parking lots within the area. The high capacity parking facilities operated by the Municipality (Oztas et al., 2018) and other private and/or irregular parking capacity are calculated from the respected sources in the same report (Fig. 4). Accordingly, the total capacity for the car parks operated by the municipality would be around 1,750 and the total capacity for the other car parks are 620.

Since the daily parking occupancy rate is assumed to be 1,5 the former's daily capacity becomes 2,625 and the latter's 940, which makes a total of 3,565 daily. Usually all the capacity is fully utilized. These generate most pedestrian trips from the car parks directly to the area of concern. For peak hours, its contribution becomes roughly 700 car arrivals. With the assumed vehicle occupancy value of 2, it generates around 1,400 passenger trips that make about 350 per peak hour

[7] There are restrictions on vehicle entry to the area: the weekday count for three major points (as a means of five day counts).

Table 4. User satisfaction levels (of travellers, neighbours, passer-by, etc.,) & Problems with the existing transport system and infrastructure

On Parking insufficiency	For all user segments	All segments stated that they were unhappy with the casual and unlawful car parking in the region between 80–90 %
On the noise dissatisfaction	For all user segments	73–83 %
On the types of transport used	Pedestrians	42% use public transit, 24% use privately owned cars, 22% prefer walking 12% are unknown 71% complain about the existence of motor vehicles, and 69% say that pedestrian areas are not enough
	Local employers/employees	28% use public transit, 28% use privately owned cars, 29% prefer walking 15% are unknown 71% complain about the existence of the motor vehicles, and finally 74% say that areas for pedestrians are not enough.
	Local neighbourhood residents	32% public transit 12% use privately owned cars, 46% prefer walking 10% are unknown 80% complain of the existence of the motor vehicles, and 82% say that areas for pedestrians are not enough.
	Bicyclers	47% uses public transit 26% use privately owned cars, 12% walk, 4% use bicycles 11% are unknown 73% complain about the existence of the motor vehicles

(four hours within the peak period, either morning or evening). However, there may still be casual parking along the roads, which can cause the above figure to swell up to 2,400 for the Eastern point. It is not considered to rise above 2,500.

It must be kept in mind that the travel numbers the simulation has to match up with must actually be around 2,000–2,200 trips for the Eastern base point. But, as mentioned before, considering that the PRT will overwhelmingly serve the needy groups and those seeking access with their cars, assuming not all pedestrians are to be transported (since some will prefer walking as in Fig. 5). From the surveys; only 27% can reach their destinations in five minutes' walking time (i.e., 73% cannot and won't have an accessibility problem that the PRT should address). And, around 23% arriving by bicycle, and 37% working in the area, and 30% of the residents living in the area can reach their destination in five minutes. That is, almost 50–60% of people have at least the accessibility, who will need assistance of vehicular transport; nearly 60% of all pedestrians may need PRT transportation. Considering that the occupancy ratio can be around 0.5, the number of PRT pods will be around 650–770 per hour (Fig. 6a, b).

Transportation Issues for the Conservation of Historic *Kemeraltı* and the Possibilities of the PRT

The study area is the historic inner core of the ancient harbor which had been gradually silting up with soil at the time and was transformed into land. Curved *Anafartalar* Street was the coastline that has evolved into the street today (Fig. 3). The main commercial activity of retail trade and traditional khans are concentrated as the oldest settlement area of the city. The elements of the traditional city, mosques, khans and various traditional shops, including organic street patterns,

Table 5. Pedestrian and vehicle count surveys

	Pedestrian count surveys	
	Morning Peak-hour (8–10 a.m.)	**Evening Peak-hour (4–6 p.m.)**
The weekday counts***	Eastern Anafartalar Street count: 716	3280
	Western Konak Square entrance count: 1300	3692
The weekend counts	Eastern Anafartalar Street count: 1192	3500
	Western Konak Square entrance count: 1800	4750
	Vehicle count surveys	
	Morning Peak-hour (8–10 a.m.)	**Evening Peak-hour (4–6 p.m.)**
The weekday counts	Eastern Anafartalar Street count: 24 (west)/18 (east)	19/12
	Western Konak Square entrance count: 15	7
	Southern point (Anafartalar street.) count: 86 (west)/30 (east)	75/35
The weekend counts	Eastern Anafartalar Street count: 6 (west)/5 (east)	8/6
	Western Konak Square entrance count: 2	3
	Southern point (Anafartalar Street) count: 28 (west)/12 (east)	35/16

*** Five-day survey (22 % is of shopping, 30 % is of local residents).

squares and fountains, offer rich potential public use. Vehicles entering traditionally narrow streets that do not adhere to monumental and traditional building structures may cause accidental damage to the historical buildings. The plethora of cars generally blocks the accessibility of the space and obscures the visibility of the monuments (Fig. 7). The site survey also reveals that empty spots used as car parking decrease the quality of space in general. Excessive car parking also damages pedestrian circulation and orientation.

The study area is Izmir's old traditional settlement and business area. Although commercial activities have continued to the extent of their historical significance, economic activities are not as lucrative as they were before. The decreasing profit margin, the loss of significant manufacturing activities, the migration of high-mid-income groups to newly developed areas, being replaced by the low income groups, foster the constant decline in the area (Akpınar et al. 2021). Moreover, the existing transportation system cannot be sufficient, safe and user friendly. For this reason, mere physical revitalization is unsustainable and short-lived. The area also needs a viable economic function and a well-integrated transport network and architecture is the solution.

Safety consideration:

According to the previously recorded data of accidents, there are 11 accident records within the area of concern (Cinar et al., 2011). Besides the number of accidents, there is no information about the type of accident or severity. Interestingly, the *Fevzipasa* Boulevard, which is the upper boundary of the area, was found to be the most dangerous street in the respected investigation. We assumed the street was outside the concerned area. We can interpret the number of accidents as the various trend data in Turkey. According to national data, the 11 previously recorded accidents can be extrapolated to 17–18 (with the annual rate of 10% increase in accidents) as the current figure up to 2017 (TurkSTAT 2018). However, considering reduced fatalities in pedestrian crashes, we will assume that, while most of the crashes are pedestrian-related, they are unlikely to be fatal.

6. The PRT Applicability Simulation Environment

Through simulations, the likely socio-economic and environmental impacts, the pros and cons of the costly, controversial project investments can be evaluated before being applied on the real ground. Furthermore, the impacts of different policies and alterations can be tested, and the outcome compared. In addition to static macro-simulation tools for analyzing long-term effects, real-time and dynamic micro-simulation are more practical (Mokhtarian et al., 2006; Thill, Rogova and Yan, 2004; Pendyala and Bhat, 2006; Peeta and Zhang, 2004). However, real-time micro-simulations are the basic tools for testing the usefulness of policy scenarios, either qualitatively or quantitatively, whether as a result of a single parameter,[8] or as a bundle of policy measures, which are decreasing transit ticket rates, increasing toll rates, and decreasing the availability of car parks together (Duvarci, et al., 2015; Nijkamp

[8] i.e. road capacity expansion, supply elasticity demand.

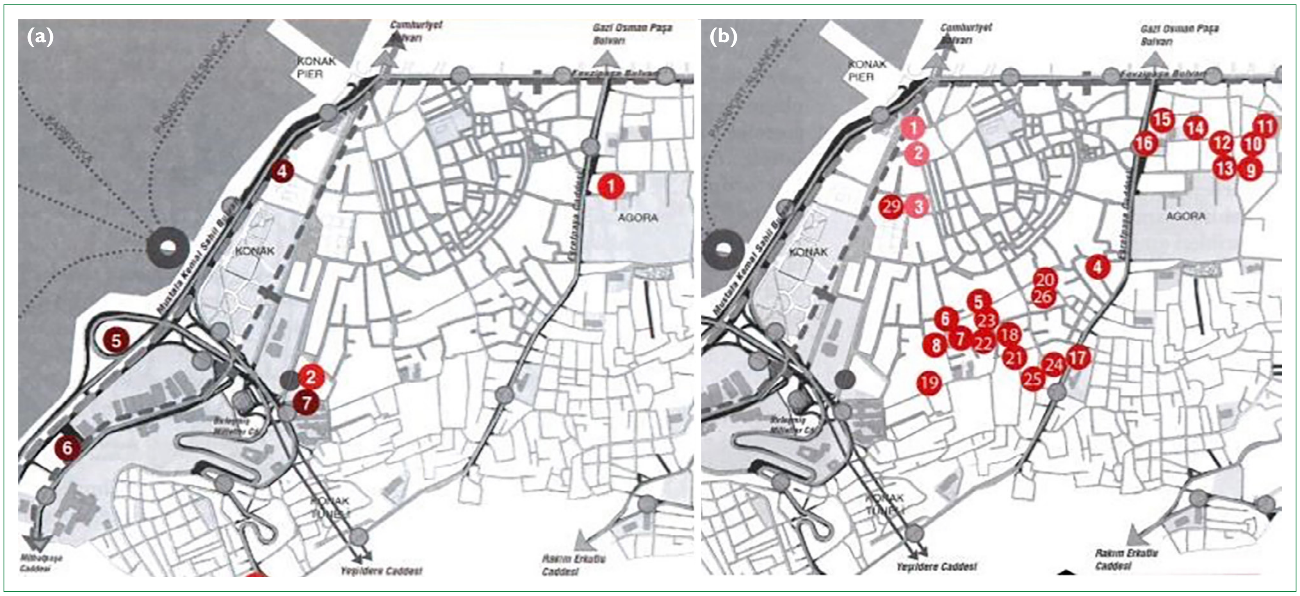

Figure 4. Both high-capacity (multi-storey, no. 1 and 2) car park, no. 4 and 7 **(a)** and small/private (some unlawful) parking (lots) facilities **(b)** (Source: Öztaş et. al., 2018: 46–7).

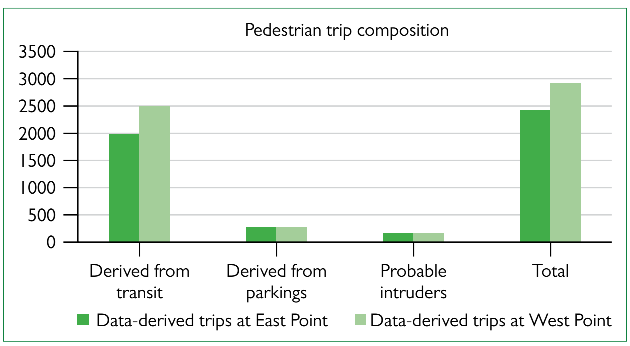

Figure 5. Compositions of walking trips of pedestrian (hr) at both Western and Eastern survey points.

and Blaas, 1994; Hansen et al., 1993; Zhao, 2011). Simulation models provide an opportunity to test the effectiveness of policies before implementing them.

The simplistic free download version of ULTRA GLOBE (ATS CityMobil) was used to simulate the operability of the PRT system. In simulation, the system requires an efficient amount of depot stations to be located anywhere beyond the network, requiring spacious area where the PRT pods can be deposited. In our model, we placed three depots and 10 stations at strategic locations (spots) throughout the study area, covering 75 hectares (Fig. 8, 9). The stations, representing centroid points of zones, also to be located at spacious and focal points, leaving equal distances between them as much as possible. The destination points are the known focal points of the case area.

One station is located near the *Konak* square (the hub of transport systems) at the western entrance point. Another

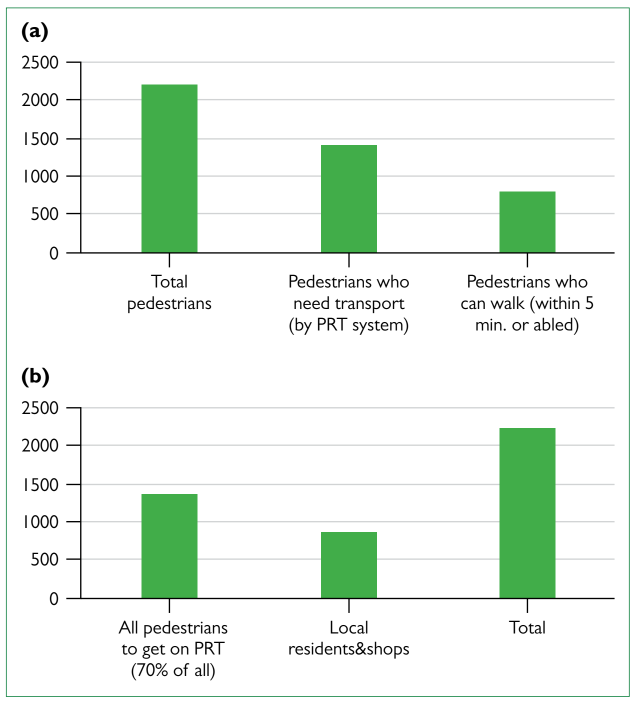

Figure 6. (a) Hourly pedestrian trips in need of PRT transportation, and **(b)** Vehicle pedestrians and local residents (or shopkeepers) for the East survey point.

PRT: Personal Rapid Transit.

is located in the north, which is very close to the metro station and the main axis up to the port of *Alsancak*, and in the east, another station closer to the arterial street (the hub of *İkicesmelik* Street) is located. All are within the major points of access to the area.

Figure 7. Car parking in front of the *Saraçoğlu* Mosque.

As can be noted, when the simulation is running, there are both loaded (indicated in green dots) and empty (indicated in red dots) pods running on the network (Fig. 10). Interestingly, PRT systems also require the use of empty pods as a technical requirement. The station points contain such information at the moment: parked pods, loading, unloading, waiting and freed pods. Only two-pod space is permitted for each station for all situations, due to space limitation. Stations are the places where the passenger gets on and off the PRT pods. The total length of the track is 12.1 km whereas the demand-weighted distance is 4.93 km. Mean demand-weighted passenger travel time is 493 seconds (8.21 minutes). The system

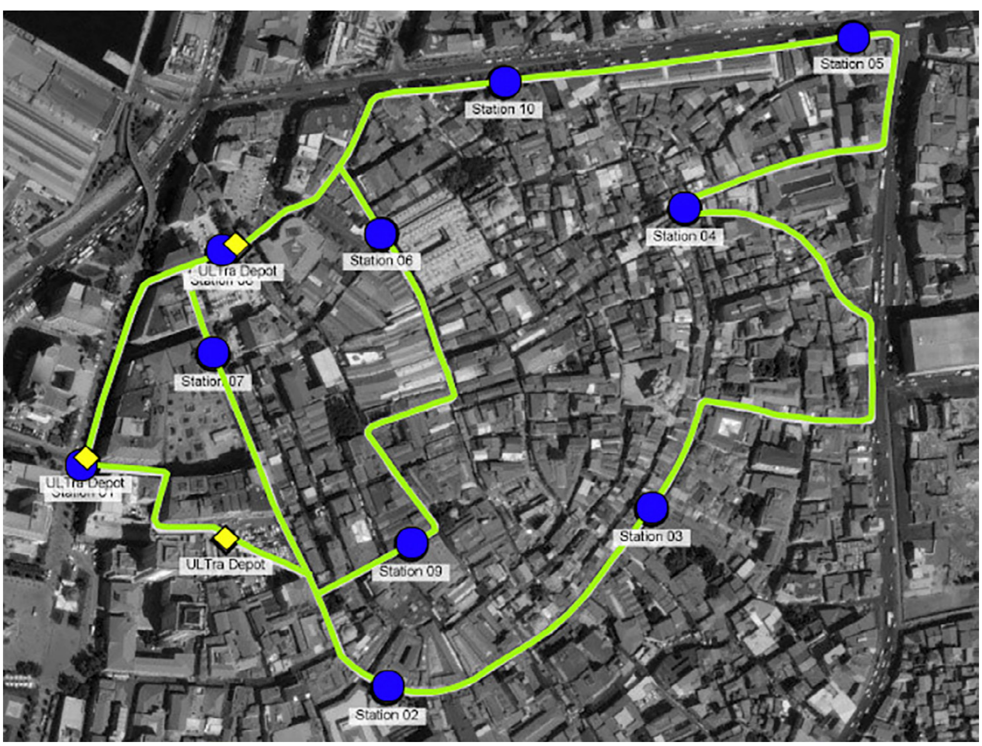

Figure 8. The Case area, its urban texture and the application of the PRT system (yellow dots are the depots, blue dots are the stations).

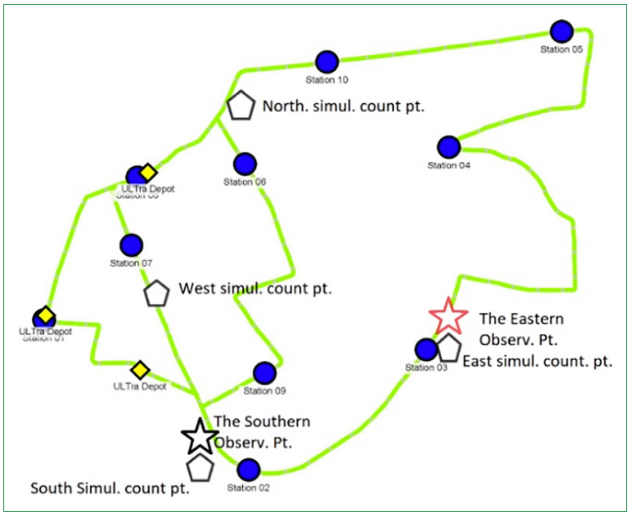

Figure 9. The one-way looping PRT system network, traffic observation and simulation count points.

PRT: Personal Rapid Transit.

requires only 169 pods for the fleet size throughout the system, waiting at depots or running. Stations, as requested by a data input, in a sense represent traffic assignment zones for the trip distributions. However, there is no strict requirement to create zones as required in other static models.

Nonetheless, the simulation should be adjusted in such a way that the PRT flow value per designated time frame (an average peak hour) in the loop network will be the same as the observed traffic values. The O-D trips were equally introduced to each O-D cells in an incremental manner so as to validate the simulated numbers with the observed numbers on the Eastern observation point, though the validation was not specifically aimed here. Finally, through the abridged trial load method ("*tatonman*" in Turkish), it reached the similar numbers (pod numbers multiplied with the occupancy values to catch the pedestrian numbers observed that are supposed to not wishing to walk at the same hour at that point (the simulation view can be seen in Fig. 10). Accordingly, the appropriate network and station locations (representing the 10 locations) were designated to make this agreement.

Appropriately, all the trip distributions between the zones (O-D matrix generation) were adjusted in a homogeneous fashion i.e. sending the same number of trips to each other until the destined trip amounts are provided at the test point (Eastern survey point). This is due to the fact that the inner trip distributions in this heritage zone are unknown.

The trips in each O-D cell were incrementally increased in the same amount to maintain the defined travel demand i.e., the pedestrian trips observed at the Eastern and Western survey points. Finally, until each cell reaches the 8.88 trip value, the system produced the designated flow of pods (i.e., 1,000–1,500 pass/hour trips) per hour at the survey point. This value is congruent with the data of 1,300–1,550 passengers previously identified. With this demand target, the required amount of PRT flow for the fleet at the traffic counts above that *Kemeraltı*'s main axis was determined. Using only 169 pods effectively, this matrix of O-D trips is sufficient to create about 500 PRT vehicle trips where we used pod occupancy ratio of 2 at the Eastern survey base point, which actually means 1000 passengers (but if occupancy is 3, then 1500 passenger/hr.), which was the targeted carriage for vulnerable population

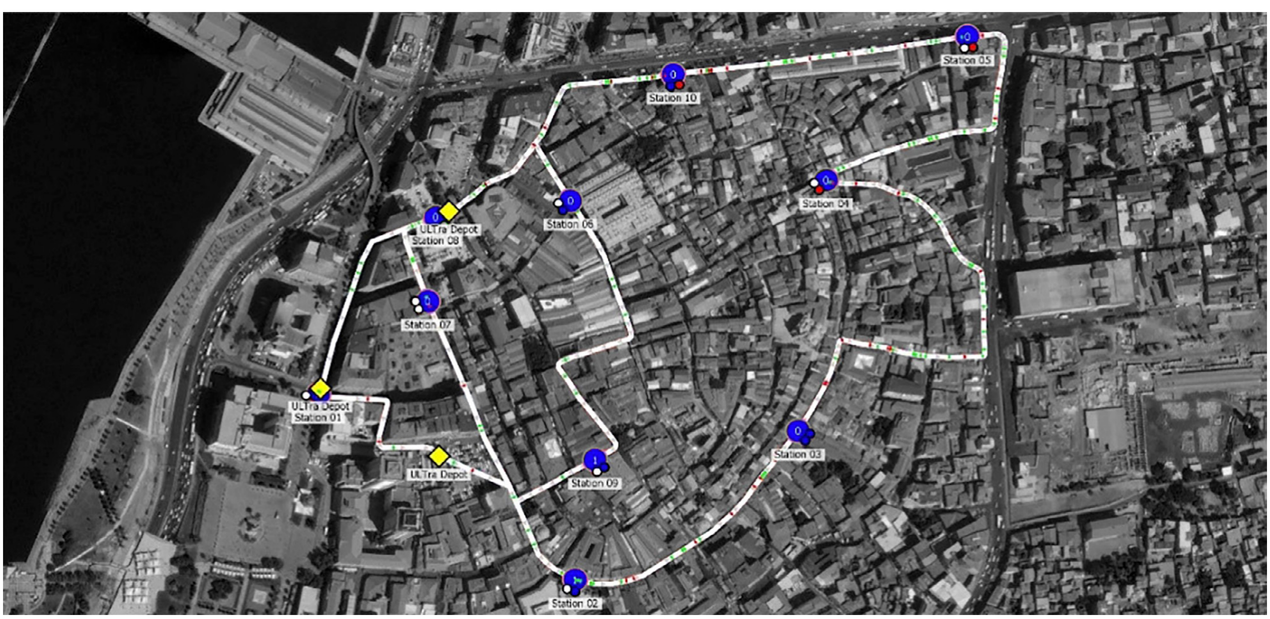

Figure 10. The Software's simulation view that shows dynamic run of pods in the network for the *Kemeraltı* Region.

ranging from 1000 to 1500 and car owners who once wanted to access to their parked cars i.e., intruders at the Eastern survey point. Since about half of the current pedestrians will be removed, the problem of pedestrian overcrowding will be solved to a great extent (from 2200 down to 800).

The average number of peak hour pedestrian counts (morning and evening) for a typical weekday was determined to be 2,200 trips per hour. From a number of simulation runs (24 times), the flow value is determined to be 480 pods/hr. which is close to 500 for possible maximum level of survey outcomes at the major observation point (see Table 6, simulation has generated from traffic counts). The flow is so chaotic that it matches the trip need we set up earlier for travel i.e., 1,000–1,500 trips/hr. Thus, the counts seem consistent at the observation points i.e., the validation of the simulation. Again, if we assume that an average of two or three people use the same pod, that makes roughly between 1,000 and 1,500 trips, which proves that their demand is adequate to a greater extent than we wanted to achieve. Cyclists are not included in these figures.

In the context of this article, we are not interested in measuring this possible future demand, but for the moment only the current one.

7. Outcomes and Discussion of PRT Application

Meeting the travel demand and accessibility problem for those needy groups (first validation): In Turkish society, women make up around 35% of travelers, half of whom are in need, and those with disabilities and obesity make up no more than 10% of travelers, half of whom are women, whilst children make up around 8% of travelers and the elderly make up 7%. (UPI 2030, 2017). Altogether, the total percentage of people in need who can participate in travelling would not be more than 4% of the total number of pedestrians in the area, and the elderly can only walk up to closer destinations (Duvarci and Yigitcanlar 2007; Zhang et al. 2018). These groups are assumed not to have a car and/or to be assisted by motor vehicle drivers. Of all those, however, only 40% can walk up to an acceptable 5-minute walk (Oztas, et al. 2018) and the rest would travel to distant destinations (i.e., beyond 400 m).

The total trips defined so far require a further addition of 600–700 car trips for the peak period i.e., 300–350 trips per hour. Finally, the PRT system will be sufficient to transport about 1000 travelers including locals to which cargo carriers can also be added as part of the needy groups that are willing to travel. The cargo carriers can therefore be neglected. Non-significant system costs and energy demands can also be ignored, as long as the municipality provides it as a pilot project. Ultimately, the proposed level of the PRT program can be assumed to be sufficient for minimum criteria and accessibility needs.

Table 6. The perturbation counts of the simulation and the averages (bold) of the six counts

West point	South point (observation point)	North point	East point (observation point)
249	482	498	479
236	452	493	448
228	448	492	487
265	546	457	517
258	471	483	466
241	489	441	480
246.2	481.3	477.3	479

Transport-related physical adaptability (second validation): The proposed PRT guideways should fit physically within the right of way of the existing streets. When we checked through the widths of the streets, where a width of two meters is supposed to be necessary for the PRT guideway, an almost loop-type route seemed possible. The wider routes, however, generally coincide with the pedestrian-dense axes, such as *Anafartalar* Street. Thus, as shown in Figure 9 a loop-type route has been designated, which operates as a counter-clockwise one-way system.

The one-way operation of the system is the most appropriate for both the restricted width requirement and the loop type route so that it can penetrate into a larger area without requiring a larger width i.e., two way run. Since it will replace most of the pedestrian traffic, the route on the pedestrian axes is also a good decision. Therefore, to apply the network, wider streets were chosen. However, in historical areas such as the *Kemeraltı* region, broader streets are harder to come across. Besides the width of the guideway, there must be an extra width alignment for the pedestrians. Then, if the PRT is allocated one unit of width, at least two units of width must be reserved for the rest of the pedestrian traffic i.e. at least one street about 6–7 m wide. The requirement for width (physical applicability) is met with these considerations for the area. As discussed earlier, the PRT will not only meet the requirement of pedestrian demand, which cannot walk long distances, but also the most inconvenient vehicle journeys. In this way, it solves transport and access problems, including freight, to a greater extent.

Removal of Car parks and Reclaimed Area (third validation): If the high capacity, multi-story car park facilities, which are generally located outside, are assumed to be necessary for car access to the area, we only need to remove the ones inside the area, which are usually private and occupy small lots. Because, after the PRT application, access to the area mostly

Table 7. Travel Information derived from the study of "Sustainable Transportation Project for Izmir History"

Pedestrian travels dropped off from PT*:	2000 pass./hr. at the Eastern count point
	2500 pass./hr. at the Western count point
Trips from Parking: (which generate most pedestrian trips)	3500 daily (350 pedestrians' trips per peak hr.)
Car Parkers' rate:14–15%	(250–300 would pass from the observation point)
Pedestrians generated from Vehicles	[2500–3000] generated pedestrian trips /hr
Pedestrians who would get on PRT:	1350 (if all will board)
	1350+850=2000-2200 (for East point)
(If we accept the finding in Table 4 that 20–22% would be from pedestrian arrivals, then)	
Pedestrians generated from the Public transport: ~60–65%	
Needy groups (old, young, disabled, etc.) that PRT will serve:	1300–1500 pedestrian passengers
(60–70% of all 2000–2200 pedestrians)	
The number of PRT pods (if occupancy rate: 0,5) per hr:	650–770/hr. (with the fleet of 169 pods)

Source: Öztaş et.al., (2018) (Sustainable Transportation Project for İzmir History, Greater Area Municipality of Izmir, EMBARQ, WRI. Retrieved from https://wrisehirler.org/sites/default/files/IzmirSurdurulebilirUlasimProjesi_Final.pdf. *Public Transport; PRT: Personal Rapid Transit.

by car will not be as necessary as envisioned, and they will be removed assuming they are unnecessary. The capacity of the car park was found to be 620. However, there are also casual and unlawful parking usually 'appropriate' on the roadside. Originally, they were assumed to be 300–350. Then it totals up to 950 (on average) parking spots. We usually allocate a gross 20 m^2 per parking stall in planning tradition assuming all vehicles are automobiles. If 950 parking spaces were to be removed, the area could gain an extra **19,000 m^2** area, which is almost two hectares not including access roads and general circulation areas. With this spatial gain (**two hectares**) or more, many other useful public spaces, playgrounds or green areas can be realized for social purposes.

Assisting the needy groups who have access difficulty (fourth validation held in first validation): This evidence is already considered synchronistical together with the first validation, to meet travel demands. Final amount of trips that the PRT system is to serve is deduced briefly as given in Table 7 below.

Conservation of the Urban Historical Parts (fifth validation): This part concerns removing excessive use of cars and space-occupying car parking to leverage effective space management and gaining more space for public use and improving the quality of the space. Transforming car parking into public spaces will increase the quality of the urban space and make the area attractive for all social groups, especially young people as well as older and people with disabilities. As an indirect measure, creating a heterogeneous social mix of new groups and attracting young people to the area is very beneficial for commercial activities and the wealth of daily life in *Kemeraltı*. Transportation, easy access, high mobility by using PRT can contribute to this objective (see the PRT system rendered photos in Fig. 11).

Increasing Safety (sixth validation): The number of accidents within the area of concern was determined to be 17 or 18 in the Data Section. With the introduction of the PRT system, which promises zero accident in the area, we assumed that these accidents would not occur with the reduced intrusion of motor vehicles or, even if not 0, at most, there will be 4–5 accidents. This level of improvement is insurmountable (Table 8).

With these validations shown above it can simply be deduced that, contrary to the general argument, a passive type of vehicle system can still be used in the historical parts of downtown areas, where they are designated as 'should be' pedestrian zones. Furthermore, as we have shown in this paper, most pedestrians and many other vulnerable groups, such as the elderly and the disabled, find it difficult to access urban uses in these areas, particularly when they are not supported by some form of vehicle transport which is an easily accessible issue. If they are not helped, it is evident that they are not encouraged to move in the center of the city. Here, therefore, we have seen the applicability and feasibility of a possible PRT system in a restricted area for motor vehicles as an alternative type, not only as a 'can-replace' vehicle or other means of public transport for its signs of sustainability, but also as a necessary mode for encouraging, assisting and attracting vulnerable groups and even tourists for such larger protected areas. In a sense, it satisfies the transport requirements of heritage areas for their viability. This paper therefore contributes in particular to the literature not in terms of the feasibility of applying an autonomous system in access-challenged areas but in terms of the 'necessity' of such systems. It demonstrates that well-designed or tailor-made PRT systems can be particularly helpful for heritage areas to be protected from the hazardous impacts of motor traffic since the most undesirable or even unnecessary travel seems to be absorbed by the system beyond walking distance.

Figure 11. Two rendering of a PRT at the *Anafartalar* street. On the left picture, PRT is lifted from the ground and flows into the air due to the inefficiencies of road infrastructure, narrow and dense streets. On the right, PRT goes on the ground.

PRT: Personal Rapid Transit.

8. Conclusion

This paper has demonstrated how modern PRT technology may help to produce more ecologically friendly and sustainable solutions while also conserving historical assets. It is proven that PRT systems are highly promising for sustainable urban transportation in the future and contribute to the revival of the economy and equalize both accessibility and management of land use in central urban areas such as *Kemeraltı*. PRT infrastructure contributes positively in comparison with the conventional system in which the maintenance, protection and refurbishment of existing infrastructure places a heavy burden on public finances. It must therefore be conceived as the real sustainable transport system of the 21st century and it deserves close attention and concentration to go further with the issues of conservation of the old, deprived urban areas.

This article reveals that the PRT system itself improves the transport and social/environmental situations of all citizens, but mainly of those mobility and accessibility impaired. In ad-

Table 8. Box of validations

Validation 1:	PRT can meet existing travel requirements when 169 pods are running on the network (500–600 pods/hour).
Validation 2:	A physically applicable network has been defined that makes a loop that serves the area.
Validation 3:	Two hectares of space gained from the eliminated parking lots which can be allocated to more social activities.
Validation 4:	PRT will assist with the transportation of the needy groups (i.e., no. of pass. 1300–1500 hr).
Validation 5:	With the application of the PRT system, it will be very beneficial to create a social mix and eventually increase the profit margin of commercial activity by gaining new social groups. The new groups will also help to compete to attract users of the large-scale shopping malls that ultimately dotted urban areas further away from the city center. These points will also help to strengthen the traditional trade function, which is one of the basic elements of the living heritage. Besides all of them, the use of the area as a safe place creates lively urban life throughout the day and night. Gaining more space (approximately 2 hectares) will also be very beneficial for improving the quality of life and space and provide room for more public use. In the study area, the rendering images including the PRT, were viewed positively and were not taken as being intrusive or obstructing the historical or traditional characteristics, in contrast, traditional elements were enthusiastically approved with such a modern concept (Figure 11).
Validation 6	(Safety evidence): Considering that the annual rate of traffic accidents is around 10 for the area of concern, this will be reduced to 2 or 3 for non-covered areas, if not zero, after the application of the PRT system (with less intrusion of motor traffic for load/unload or parking).

PRT: Personal Rapid Transit.

dition, with the improvement of mobility and accessibility, we can conclude that all of these contribute positively to the economic vitality and dynamism in which the area's basic historical quality and the continuity of all its intrinsic character are retained. We can quantify the other positive social and environmental benefits on heritage areas once the PRT system has been proven to meet people's transport requirements and economic activity while also responding physically to street widths and managing historical issues through land management. Formulated as validations, these basic gains are; sustainable and low-cost infrastructure that fits the historical quality of the area, meeting the demands of all people for travel and greater access for the needy groups, gaining substantial amounts of land for social and cultural purposes that also mark the physical and visual leverage of the historical fabric, etc. Finally, PRT systems promise a more sustainable transportation for communities leading the way to viable, diverse and vital cities around the urban world.

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