

Planning a Park and Ride System: A Literature Review

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Abstract: The Park and Ride (P&R) system is integrated into the transport infrastructure of a city's urban environment. P&R is an intermodal connection point between private vehicles and public transport, and therefore is considered a fundamental element in transport planning. The planning of a P&R system is linked to numerous parameters related to transport planning, such as origin and purpose of travel in the P&R system, P&R location problem, P&R and potential demand, P&R and catchment area, P&R and public transport, and P&R in the future transportation (autonomous, electric vehicles). Thus, the planning process becomes essential for the successful implementation of the P&R system. However, most studies have shown each part of the planning process separately. Therefore, the researchers in this paper have conducted a comprehensive analysis of the available literature on P&R system planning, and studies that consider the planning sections separately are to be part of the complete research. In conclusion, the planning of P&R facilities should not be regarded as a separate mobility design element. Instead, it should be viewed as an essential component integrated into the city's urban environment.



Citation: Ortega, J.; Tóth, J.; Péter, T. Planning a Park and Ride System: A Literature Review. *Future Transp.* **2021**, *1*, 82–98. <https://doi.org/10.3390/futuretransp1010006>

Academic Editor: Antonio Comi

Received: 16 March 2021

Accepted: 6 May 2021

Published: 19 May 2021

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Keywords: Park and Ride; planning; transportation; public transport; smart cities; autonomous; electric vehicles

1. Introduction

The P&R system is a set of facilities distributed throughout the urban environment of a city to establish a connection point or modal interchange to transfer private vehicle users to a more sustainable mode of transport, such as public transport [1]. In other words, the Park and Ride system is closely linked to parameters of private and public transport [2]. Private vehicle users who live in areas outside the urban perimeter (origin of the trip) or where there is few or no direct connection to public transport wish to commute daily to their destination. Their target is generally the central business district (CBD), where they carry out their daily activities, such as work or shopping. This entire trip from origin to destination by private vehicle is inconvenient due to the high traffic in the urban area [3]. For this reason, the P&R system allows modal shift for private transport users to switch to the public transport system in the urban area, where the connection and accessibility of public transport is much better [4] (Figure 1).

Planning of the P&R system emerged in the 1920s in the United States, and began as parking systems independent of the transportation infrastructure. Through the years, P&R systems have been increasingly recognized as necessary in different countries and cities worldwide, for example, in Oxford and Nottingham, UK or in Hungary and its capital Budapest [5] or West-European cities, like Munich, Netherlands, and Belgium [6]. P&R has moved from being an independent system to become part of the transportation infrastructure, as well as the parking policies included in sustainable mobility plans (SUMP) [7,8].

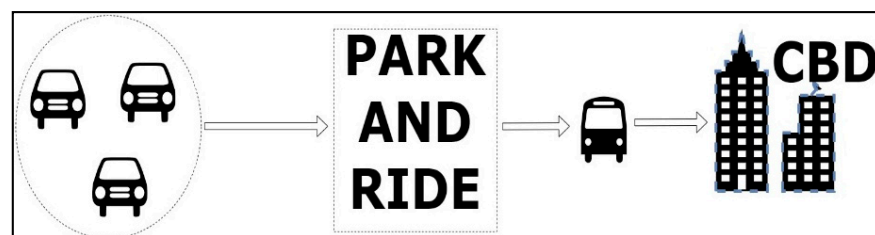


Figure 1. Concept of P&R.

Planning the P&R system is unique in each city. For example, in European cities, the P&R system is undoubtedly difficult to place due to lack of available space, and in many cases, they are already in constructed. Therefore, the planning starts with how to improve the coverage of the second phase of the trip through public transport. However, it is certainly a relatively new system in Latin American cities, where planning starts from determining the place of the future facility. Many cities use this system to reduce private vehicle trips to the city center and thus reduce pollution. P&R system planning is likely to be combined with integrating electric vehicles and autonomous vehicles in smart cities. There is no strict planning to adopt; instead, it depends on the city type and the transport policies to be achieved concerning the P&R system.

Most of the studies on the P&R system have investigated a specific topic of the planning process, such as the origins of trips, location of the facilities, capacity, and the interaction with public and private transport. This paper aims to describe the studies according to their purpose within P&R system planning to provide future researchers and transportation planners a tool to develop studies on the P&R system. Thus, the paper studies in depth the P&R system and its relationship with the different components within planning.

The article is structured as follows: Section 2 is linked to the P&R system and origin and purpose of travel. Section 3 describes the research on the P&R and the location problem. Section 4 describes the potential demand and trips made through the P&R. Section 5 discusses studies related to the catchment area. Section 6 explains the studies that relate to public transport combined with P&R system. Section 7 describes the future of the P&R system and its interaction with autonomous and electric vehicles. Finally, the conclusions section discusses the results obtained and sets directions for future studies.

Figure 2 illustrates each section's components to describe the planning process of the P&R system. Besides, each section includes a table listing the main studies carried out in each area. Additionally, at the end of each section, a paragraph provides an overview of existing and potential future studies.

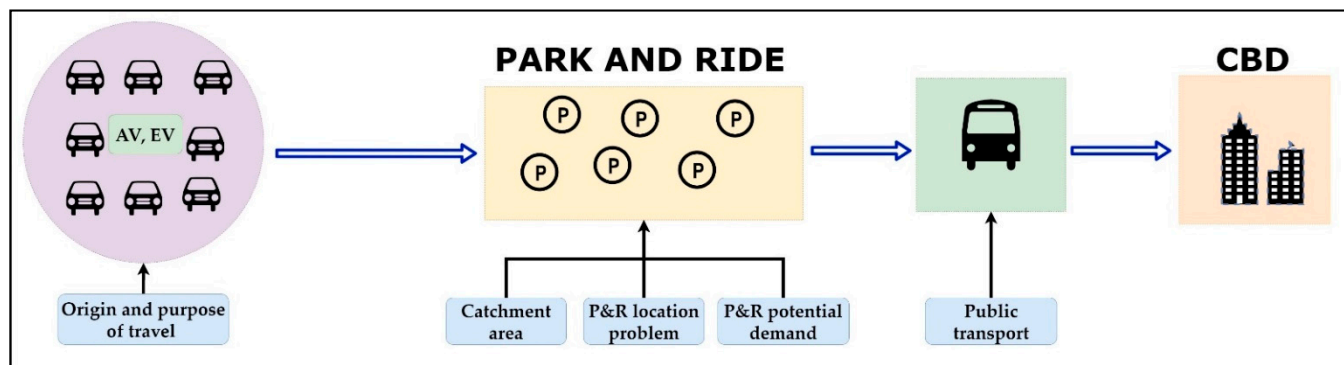


Figure 2. Planning a Park and Ride system.

2. Origin and Purpose of Travel in the P&R System

Cities adopt the P&R system in order to allow more people to access traditional centers for work and shopping, while at the same time avoiding the environmental damage associated with increased highway and parking supply and more car trips [9,10]. Therefore, P&R is a modal interchange point between private vehicles and public transport users; commuters use park and ride system for the purpose of work and commercial travel [11]. These trip origin points of the P&R system are associated with more specific mobility domains such as land use [12]. Therefore, studies have been developed to associate the type of trip origins produced by the P&R system. According to [13], P&R users' main trip purposes are work and shopping.

Furthermore, these trip origins of the P&R system can also be associated with socio-economic aspects to determine the trip purpose of a potential user of the system. The result shows that P&R system users consider aspects such as total travel time, income, trip purpose [14]. A survey can also help to determine the purpose and origins of travel through the P&R system. Thus, a survey was conducted among P&R system users in Putrajaya Sentral city, where the work purpose is predominant for 85% of the users [15]. In the same line of research on P&R and its travel purpose, an interesting result was obtained within the social benefits of the P&R system, as it stipulates that it improves access to jobs through improved travel time [16]. Even in studies that focus on the behavior of potential P&R users, work is already considered as a travel purpose. Thus, a study carried out used home as origin and workplace as the destination for P&R [17]. Researchers have been using the results of previous research on the travel purpose of the P&R system, and thus studies have been carried out only on workdays [18]. In support of this, a study showed that the system utilization rate was 84.5% on workdays, and the duration of parking showed that users were parked for more than 9 h, because they were traveling for work purposes [19]. In this context, a study found that most of them drove alone to the parking lot and made long trips to work, many of them more than 50 km in one direction [20]. Table 1, shows the main studies carried out with respect to origin and purpose of travel in the P&R system.

Table 1. The main studies carried out with respect to origin and purpose of travel in the P&R system.

Category	Key Parameter	Description	Reference
Origin and purpose of travel in the P&R system	–P&R –Work –Shopping	The original rationale for these cities adopting P&R was to enable an increased number of people to access traditional centers for leisure, work, and shopping whilst avoiding the environmental damage associated with increased road and car park provision and more car journeys.	[11]
	–P&R –Work –Shopping	A study of dynamic accessibility on P&R leads to a complete model consisting of a series of elements and steps to analyze travel time under various traffic conditions, and taking as origin points such as work and shopping.	[13]
	–P&R –Work	The type of trip origin points produced by the P&R system are work and shopping activity.	[12]
	–P&R –Work	The type of trip origin points produced by the P&R system are work activity.	[19]
	–P&R –Work	The type of trip origins points produced by the P&R system are work activity.	[20]

Regarding the origin of P&R system trips, research has been conducted showing that private vehicle users make these trips for work and shopping purposes. However, further research on the purpose of P&R system trips is needed since trip purposes may change according to city, land use, and transportation policy.

3. P&R Location Problem

The facilities belonging to the P&R system are a crucial issue in planning and improving the system. The location of the facility depends on whether the potential user is willing to travel through the P&R system [21]. For example, from the users' point of view, if the distance, the travel time from the P&R is too far from the destination, it is not very attractive; or on the other hand, if it is close to the destination, it is not necessary to use it. In contrast, the location of facilities for planners involves much more technical aspects, including travel times, costs, and even availability of land for their construction. For this reason, determining the optimal location involves studying the methods and methodologies applied and the criteria used.

The optimal location of the facilities of the P&R system can be studied through a geographic information system. Thus, planners used a series of potential locations in Delaware City, and based on a set of criteria, such as position relative to the CBD or primary activity center, negative lot competition, travel characteristics to CBD or activity center, maximization of service area population, location relative to transit service, and frequency of transit service, the optimal locations of the facilities belonging to the P&R system were obtained [22]. Multicriteria methods have also been carried out, in which a set of main criteria and sub-criteria have been used to determine the experts' point of view. Thus, the result shows that the main criterion to be taken into consideration for the location of the facilities belonging to the P&R system is the accessibility to public transport. This means that the location of the P&R system should be close to the public transport infrastructure [23,24]. Thus, P&R systems are close to public transport stations. For example, close to railway stations maximize the possibilities of removing private vehicle users from the transport network [25]. Even transportation costs can be included to determine the appropriate location using travel cost per unit distance [26,27]. A transport network with mode mix and P&R provide information in smart cities on the number and location of P&R, including the combined mode choice in different circumstances and the travel time impact due to P&R implementation in a real environment [28]. Besides, multi-objective spatial optimization modeling methods can be applied, including three fundamental criteria in the P&R system: to cover as much potential demand as possible and to locate P&R facilities as close as possible to major roads, and to locate such facilities in the context of an existing system [29].

A parameter for the location of facilities is demand, which can be described as a function of distance and coverage. Thus, a discrete linear model for locating P&R facilities illustrates the flexibility and utility of the modeling approach developed to address a wide range of planning issues [30]. Besides, it is possible to use mode choice according to P&R usage rates and maximize benefits and minimize social costs [31]. Linear models have been used to designate a series of P&R facilities in an average city. The objective is to establish criteria for the model that best approximates reality [32]. A mixed linear programming formulation to determine the location of a fixed number of P&R facilities to maximize their use. The result shows the most commonly used P&R facilities [33]. An evaluation for P&R reliability analysis is used to locate the facilities of a stochastic P&R system, where travelers can complete their trips using two options: car mode or P&R mode. The results show that the reliability of P&R facilities is significantly influenced by parking capacity, frequency, and metro fare [34]. A case study was described in [35]. Thus, the location of the facilities is recommended to be 5–6 km from the city center, with exceptions when there are geographic barriers [36], and reduce the possibility of P&R facilities adding to the congestion problem [37].

The location of P&R system facilities throughout a city's urban environment becomes more complex depending on the number of criteria included, such as demand, connectivity, transportation design, and economic viability [38]. As described above, the location of the P&R system is studied by various methods and methodologies that include the use of mathematical models and computer programs [39,40]. For example, a two-level

programming model for P&R localization can capture the interactions between decision-makers and travelers to maximize total social welfare [41].

On the other hand, the location of the P&R system also depends on the transit service levels serving these facilities [42]. A study on the location of all facilities belonging to a city's urban area has already been considered a planning tool in combination with transportation policies, including minimizing the operating deficit and adding decision variables such as transit and parking fees [43,44]. Besides, combined modal split and traffic assignment models can be established for a two-level mathematical programming model to establish the optimal location and capacity of P&R [45]. Table 2, shows the main studies carried out with respect to P&R location problem.

Table 2. The main studies carried out with respect to P&R location problem.

Category	Method	Description	Reference
P&R location problem	Geographic information system	A hybrid knowledge-based expert system/geographic information system tool was developed to help determine the optimal location for park-and-ride facilities.	[22]
	Multicriteria	A set of six main criteria and 19 sub-criteria were established and through the application of the multi-criteria method to determine the most important criteria for the location of a P&R system. The main criteria result is accessibility to public transport.	[23,24]
	Deterministic mode choice	Transportation costs can be included to determine the appropriate location using travel cost per unit distance	[27]
	Multi-objective spatial optimization modeling	Multi-objective spatial optimization modeling methods can be applied, including three fundamental criteria in the P&R system: to cover as much potential demand as possible and to locate park-and-ride facilities as close as possible to major roads, and to locate such facilities in the context of an existing system	[29]
	Deterministic mode choice	It is possible to use mode choice according to P&R usage rates and maximize benefits and minimize social costs	[31]
	p-Hub approach	A mixed linear programming formulation to determine the location of a fixed number of P&R facilities to maximize their use.	[33]
	Stochastic park-and-ride network	An evaluation for P&R reliability analysis is used to locate the facilities of a stochastic P&R system, where travelers can complete their trips using two options: car mode or P&R mode.	[34]
	Bilevel programming model	A two-level programming model for P&R localization can capture the interactions between decision-makers and travelers to maximize total social welfare.	[41]
	Optimization model	A planning tool in combination with transportation policies. Minimizing the operating deficit and adding decision variables such as transit and parking fees.	[43]

There are many studies on methodologies and methods for determining the location of the P&R system, including a wide range of variables. Rather, it is one of the most researched topics concerning the P&R system. Indeed, studies range from planner experience to the use

of mathematical models based on optimization. Planners must select the most appropriate study depending on the city where the P&R system is to be planned.

4. P&R Potential Demand and Acceptance

The P&R system is entirely linked to future users who drive a private car and want to turn to a more convenient mode of transport; thus, demand is linked to the potential demand of the public transport system.

The P&R system helps to attract private vehicle users who live outside the urban area of a city to transfer to public transport to complete their trip [46]. These restrictions are critical during peak hours [47]. Besides, demand in the P&R system can be influenced by the preference of users to choose the system: costs generally represent this preference. In fact, the methods for estimating demand become more sophisticated with the added criteria [48]. P&R pricing is a useful tool for governments to motivate private vehicle users to use public transport [49]. Even increasing demand for the P&R system is combined with other measures such as increasing entrance and parking fees in the CBD (Central Business District) [50]. The addition of the optimizations in the methods used has helped to increase the accuracy and complexity of the system. For example, a multimodal traffic assignment with combined modes, formulated as a variational inequality problem, generates the demand for transport modes and parking. An algorithm solves the model [51,52]. Travel through the P&R system depends on travelers' travel choices in terms of travel mode, route, and transfer point [53]. In other words, demand is affected depending on the parameters studied when choosing a transportation system, including the P&R system [54]. The choice of a transport mode, including the P&R system, can be made by multimodal equilibrium, and the determination of the spatial equilibrium model along the corridor can be obtained [55]. Besides, the variables belonging to public transport should be studied. Furthermore, the calculation of the demand of the P&R system becomes increasingly complicated. For this reason, algorithms have been used to include the facility's capacity and the criteria for the user to choose the P&R system [56].

Demand is closely related to public transport for those who regularly use the P&R service. The existence of good public transport connectivity is essential when using the P&R system [57–59]. Also, large differences have been found between the impact on the demand of introducing a parking fee and the impact on reducing the use of the parking system [60]. Furthermore, scientific evidence shows that the distribution of individuals' preferences for cars over public transport is the main determinant of the demand for the P&R system. A hypothesis whether private car users increase in the first stage of the trip through the P&R system should be investigated [61]. Therefore, behavioral models allow one to know the potential demand for the P&R system [62]. Based on the principle of a random selection of users, Logit models of parking demand forecasting are built [63]. Introducing models including the Logit, the factors that influence parking choice are such as travelers' attributes, trip characteristics, transfer services [64]. The modal split can also be obtained by introducing the P&R system, which can be considered as a potential demand [65]. A shift in travel habits responded appropriately to changes in the use of the P&R system. The data derived from the surveys allowed for the great proportional prediction of those changes [66]. For example, there is evidence that 29.8% of users used to arrive in the CBD by car, but now use a combination of car and public transport. On the other hand, the number of people who have abandoned public transport for their entire journey now does part of it by car. However, this result is only from one city, so it should be carried out in other cities to verify that the P&R system could encourage the use of private transport by people who live outside the urban area [67]. Ultimately, the theory of planned behavior was able to predict the users' intention to use the P&R facilities [68]. A research to identify and quantify the influencing factors that determine the choice of P&R facility during a journey helps to understand who the potential users of the facility are [69]. A research conducted considered the park and ride system as one of the transportation demand management (TDM) schemes, which is very popular in some congested cities with

a large parking area on the borderline or suburban area. The results showed the potential shift from the use of private vehicles to the user of P&R facilities [70]. Table 3, shows the main studies carried out with respect to P&R demand.

Table 3. The main studies carried out with respect to P&R demand.

Category	Method-Variable	Description	Reference
P&R potential demand and acceptance.	Traffic Choice model	A multimodal traffic assignment issue with mixed transport modes generates demand for modes of transport and parking.	[52]
	Elastic demand	Traveling through the P&R system provides travelers with various travel options in terms of mode of transport, route, and transfer point.	[53]
	Capacities	Factors associated with public transport should be examined. Algorithms were used to incorporate the facility's capacity and the user's selection criteria for the P&R system.	[56]
	Choice behavior	P&R facility selection is influenced by various factors, including the travelers' characteristics, the trip's characteristics, and parking availability.	[64]
	Travel behaviour changes	There is evidence that 29.8% of users used to arrive in the CBD by car but now use a combination of car and public transport. On the other hand, the number of people who have abandoned public transport for their entire journey now does part of it by car.	[67]
	Demand management (TDM) schemes	This study considered the Park and Ride system as one of the transportation demand management (TDM) schemes, which is very popular in some congested cities with a large parking area on the borderline or suburban area. The results showed the potential shift from the use of private vehicles to the user of P&R facilities.	[70]

The demand for the P&R system in some aspects seems easy to determine. However, it is much more complex than it is believed to be, since it is linked to parameters such as the users' decision to take the P&R route or, rather, to use the system. This decision is based on more specific criteria such as the cost of travel and the use of the P&R system. It is also influenced by public transport parameters such as frequency and travel times. This complex demand calculation has been studied by researchers and implemented by transportation planners through the use of mathematical optimizations, surveys, and software. However, at this stage of P&R system planning, the demand calculation must be according to the parameters of the city being studied.

5. P&R and Catchment Area

When planning a P&R system, it is important to identify the catchment area, since it is the first line of potential users' arrival [71]. Thus, in the literature review, one component that is part of the transportation planning of the P&R system is the catchment area [72]. In fact, it is the starting point to get an idea of the potential extent of the catchment area of each facility and maximal coverage [73].

The study and analysis of the catchment area of a P&R system are performed by representing and using geometric shapes such as the circle, parabola, and hyperbola. In order to represent this catchment area in the urban environment, the data are costs, distances, and even travel time [74]. Using a software script within a GIS tool is a comprehensive method to define the P&R catchment area in urban mobility. The result is a perspective on spatial analysis and how catchment areas are part of the GIS component [75]. Although

the catchment area has focused on other studies such as pedestrian facilities and energy expenditure estimates: network grade, pedestrian speed, and pedestrian energy methods, it is helpful to use a similar approach for studying the P&R system [76].

There is a large amount of information on the catchment area that has been applied in healthcare facilities such as hospitals. Thus, the P&R system is a facility in which vehicles arrive to perform a multimodal transfer. It is necessary to study methods already applied in other types of facilities and adapt them to the P&R system [77]. Even a combination of methods can be implemented, such as support for WebGIS technologies or the OpenStreetMap (OSM). A more general approach can also be taken. It is not necessary that studies only focus on P&R system facilities. Instead, it is possible to study methods applied to study the catchment area of any facility [78]. Thus, identifying which method is used to study the catchment area leads to the next step of how to represent this catchment area in the urban environment.

Most of the papers studied have used GIS supported software. However, it depends on the complexity of the data and locations to be visualized [79]. Studies on the P&R system that focused on the catchment area have evolved according to the development of the software for its visualization. For example, by applying geographic information systems (GIS) technology to delimit the catchment areas and calculate the access distances to the respective stations and questionnaires and using MapInfo and ArcView GIS 3.2, the catchment areas of the respective facilities were delimited. The result is the visualization and coverage of the catchment areas of the P&R system [80,81]. Most research on the catchment area of the P&R system has focused on the Parabola method. Since this geometric shape allows to represent a potential demand for the system from residents near the facility, the parabola approach has been used by some researchers to represent the catchment area of the P&R system. As well as potential users by choosing the closest access. Although this method is indeed a precursor, it is still a static type, which leads to the evolution of methods and offers a step to the next level, which is the application of dynamic methods with real traffic [82,83].

Rather, dynamic methods inform how the potential user might access a facility in a more detailed way. In other words, it can be combined with mathematical methods and even optimizations in order to know how the catchment area captures a real number of users [84–88]. Thus, the dynamic methods have been studied using data according to the reality with the combination of geographic information system (GIS) and the users' direction of travel. The result shows that the developed dynamic approach works best according to its detailed description and a real visualization of the facilities in an urban environment [29,30,89]. The representation of the catchment area of the P&R system could be more realistic by including research on the P&R system, such as future demand. In other words, by combining these methods, the catchment area can change either in its extent or in its shape [90]. Even mathematical optimizations can be included, e.g., on the cost related to the use of the P&R system. Including a more realistic approach would also include the catchment area of public transport. In fact, including more criteria for the representation of the catchment area would help to have a more realistic approach. Although mathematical models have been investigated or included, there is little research on the combination with the catchment area [91]. An investigation of the parabola method for representing the catchment area of the P&R system that has been conducted has given a new approach to the traditional parabola method. This study focuses on whether the direction of the parabola is according to the main arrival of the system's potential users. However, it is still necessary to include a set of criteria to make this representation more realistic [92]. Table 4, shows the main studies carried out with respect to P&R catchment area.

The catchment area of the P&R system can be represented in a simple form. As software development has progressed, more complex analyses and representations of the P&R system catchment area have been developed. However, the most common approach is the parabola method. The evolution of these methods has come to provide a realistic representation of the P&R system's catchment area through dynamic methods. Thus, it is

possible to include within the representation parameters inherent to the P&R system, such as costs, travel time, and even the interaction of the catchment areas of other transportation systems. Therefore, the development of dynamic methods to map the catchment area of the P&R system would be a topic for future research.

Table 4. The main studies carried out with respect to P&R catchment area.

Category	Method	Description	Reference
P&R catchment area.	Hyperbola	Potential catchment area and maximum coverage of each facility.	[72]
	Parabola, circle and market	The interpretation of the catchment area of a P&R system is made through geometric shapes, including the circle, parabola, and hyperbola.	[74]
	GIS linkages	While other studies have focused on the catchment area, such as pedestrian facilities, it is beneficial to use a similar approach when examining the P&R framework.	[75]
	GIS-based approach	Geographic information systems (GIS) can be used to delimit catchment areas and calculate access distances to the respective P&R.	[80,81]
	Parabola	Most of the research on the catchment area of the P&R system has used the Parabola method. This method is a preamble to the evolution of the method, and the next step is the application of dynamic methods with real traffic.	[82,83]
	GIS and spatial analysis	Dynamic methods allow for a more detailed understanding of how a potential user might access a facility. It can even be used in combination with optimization methods to determine the efficiency of the catchment area.	[84–88]
	A GIS-Based Approach	Dynamic approaches have been investigated by combining a Geographic Information System (GIS) and user navigation with data derived from the travel experience. The result provides detailed insights into user preference when using the P&R system.	[29,30,89]
	Parabola	A study of the parabola method for describing the P&R system's catchment area revealed a novel approach to the conventional parabola method. This focuses on the parabola direction about the main arrival of potential users.	[92]

6. P&R and Public Transport

Most of the studies described above are closely linked to public transport. In other words, the function of the set of P&R system facilities is to be a point of modal interconnection from the private vehicle to public transport. This section details the criteria and methods on the P&R system that have been emphasized in connection with public transport.

Public transport and the P&R system are closely linked. For this reason, studies at bus terminals have been carried out through surveys. The results of the terminal surveys showed that riders used the P&R system for more than 7 h. This also leads to an increase in public transport capacity [93]. The studies carried out determine that the combination of a private vehicle and public transport allows considering the P&R as a travel mode. In other words, three modes of travel can be determined in a study about P&R: the automobile mode, the bus-only mode, and the P&R mode. It is assumed that the P&R mode should be more attractive with respect to travel time and costs than the other travel modes for the potential user to use it [94]. The factors for using the P&R mode are high parking fees in

the CBD area, travel time by public transport, and transfer time to P&R affect the use of P&R by commuters. It is even possible to determine which has more relevance: so, transfer time to the P&R has the highest sensitivity, while travel time by public transport is the lowest. For this reason, P&R system facilities should be located as close as possible to public transport stations [95]. Also, factors such as parking availability, parking convenience, and safety made a significant difference for travel through the P&R mode [15,96,97]. However, even adding other transportation types into the P&R system can change the use of public transport. In other words, including bike parking, mode of access, and time of day were the most important factors influencing the choice of a particular facility [98]. An empirical study found that factors such as radial distance to parking, availability of P&R locations in the direction of travel, gender, age, income, and group size are important factors in parking preference. The analysis suggests that more public transport and walking or cycling are probable, with improved factors [99,100]. However, the inclusion of the P&R within public transport produces an undesirable effect, the best-known being “public transport abstraction”; in other words, some P&R users had made the entire trip by public transport before introducing the P&R facility. Other effects such as “bicycle abstraction” and “park-and-ride users” of P&R facilities reinforce the ambiguity surrounding the impact of P&R. Also, significant differences have been found between the perceived impact of P&Rs according to their function: remote P&Rs perform better than peripheral P&Rs. Rather, the planning of the P&R system should be carefully studied because it can produce the opposite effects [60]. Table 5, shows the main studies carried out with respect to P&R and public transport.

Table 5. The main studies carried out with respect to P&R and public transport.

Category	Description	Reference
Public transport	The P&R system is closely related to public transport. Therefore, surveys have been conducted in bus terminals. The results of the terminal surveys showed that riders spent more than seven hours using the P&R system. This also increases the capacity of public transport.	[93]
	The studies also show that the combination of private and public transport enables the P&R to be taken into consideration as a mode of travel. In other words, three travel modes can be identified in a P&R study: private car mode, mode only for buses, and mode P&R.	[94]
	Public transport may also be increased if other modes of transport are added to the P&R system. In other words, the main factors influencing a specific facility’s preference were bike parking, mode of access, and time of day.	[98]
	However, P&R integration with public transport has an adverse impact, as “public transport abstraction” is the most famous; in other words, before implementing the P&R system, some P&R users had traveled in its entirety via public transport before introducing the P&R facility.	[60]

Public transport is closely linked to the P&R system, as references to this issue have already been given in the previous sections. However, to recapitulate, it should be mentioned that the location of the facilities belonging to the P&R system must be close to the public transport stations to allow the connection to the users. Regarding the demand for the P&R system, it, in turn, becomes part of the demand for public transport. Thus, these studies mentioned here focus more specifically on public transport. They have a common denominator in that the planning of the P&R system was based on existing public transport routes. However, an interesting point arises that may seem obvious or unrealistic but needs to be addressed. Could the P&R system be planned first to plan later the public transport system that allows the connection with public transport, or in which cases or in which type of city is it much more favorable to plan the P&R systems first? Should the planning of the transport system go together with the planning of new public transport routes? We hope that future research will clarify these doubts.

7. P&R in the Future Transportation (Autonomous, Electric Vehicles)

The P&R system is a mobility planning tool that has evolved over time. Therefore, P&R has been used according to the policies and trends that the city requires at the time. Some researchers and planners have used it to promote the change to a more sustainable transport mode, such as public transport. In other cases, the use of P&R facilities aimed to reduce congestion caused by private vehicles in the CBD; to reduce pollution from private vehicles by reducing the number of trips. New technologies applied to private vehicles such as electric vehicles change the role of the P&R system, including charging stations. Besides, the latest technologies such as autonomous vehicles make the P&R system part of daily activities. This section aims to investigate the most recent applied studies and future studies that researchers recommend concerning combining electric or autonomous vehicles with P&R systems.

The world's major urban agglomerations have already embraced intermodal tools such as P&R, demonstrating great potential to improve and reduce travel time from an origin to the city center. Some cities already have P&R systems in place, and others are in the planning stage. However, these P&R systems must be adapted to the new technologies of private vehicles. This seems easy to do but is more complex because it requires that the P&R system not be seen as an independent element of a city's transport infrastructure [101]. The P&R system can reduce the pollution caused by private vehicles as a result of reducing trips to the city center. Also, it is necessary to combine P&R with other environmental policies, since P&R by itself cannot reduce pollution. This means restricting access or parking of private vehicles to the city center [102]. Even the comfort due to the time the private vehicle is parked has been measured. In other words, the vehicles' temperature increase during the whole day of parking has been measured. In the preliminary investigation, the problem of long-term parking in parking areas exposed to heatwaves was highlighted. This also affects the performance of electric vehicles with electronic components [103].

The impacts of P&R on travel behavior and daily activity plans of workers and commuters, including shopping purpose were investigated by a simulation of autonomous vehicles as part of a multimodal system. The P&R system was integrated into the daily activity plans, to determine the size of the required AV fleet to meet a given demand and to study the impacts of AVs on travel behavior [104]. It is well known that the implementation of electric vehicles helps reduce pollution in a city's urban environment. This leads to the implementation of electric vehicle charging stations throughout the city. The question arises: what happens or what percentage of pollution is reduced by combining electric vehicles and the P&R system? How feasible is it to implement electric vehicle charge stations in P&R system facilities? [105].

Studies have already been conducted that include P&R services associated with public transport and a shared autonomous vehicle system. Results have shown that P&R functionality improves with the introduction of autonomous vehicles [106]. The use of electric vehicles (EVs) and P&R can potentially help improve transit accessibility, improve charging, and facilitate EV adoption. A further consequence is the reduction of pollution. The result shows that the combination of EVs and P&R can reduce up to 52% of carbon emissions. However, a more advanced study for the second part of the P&R trip is needed by public transport. That is a combined study of a public transport system equipped with friendly technology. This set of policies could help to reduce pollution further in the urban environment of the city [107]. Studies develop a deterministic continuous equilibrium model for a mono-centric city to analyze the modal choice behavior of travelers in a transport system with electric vehicles and P&R services [108].

Even more advanced models have been made that allow the scheduling of large-scale electric vehicle charging in P&R systems. The result shows that by installing large-scale recharging systems in the P&R system, significant savings in energy system reduction are achieved [109,110]. Table 6, shows the main studies carried out with respect to P&R in the future transportation

Table 6. The main studies carried out with respect to P&R in the future transportation (autonomous, electric vehicles).

Category	Description	Reference
P&R in the future transportation	Adaption to an innovative industry of private cars (EV, AV) is needed for P&R systems. This seems straightforward but is more complicated since it demands that the P&R system not be viewed as a separate component of a city's transportation infrastructure.	[101]
	The effects of P&R on travel behavior and daily activity plans of workers and commuters, including shopping, were studied using a simulation of autonomous vehicles. The P&R system was incorporated into daily activity plans to evaluate the size of the AV fleet needed.	[104]
	El transporte público y un sistema de vehículos autónomos compartidos están conectados con los servicios de P&R. Los resultados han demostrado que la funcionalidad de P&R aumenta a medida que se introducen los vehículos autónomos.	[106]
	The use of electric cars and P&Rs may potentially contribute to improved accessibility of public transport, charging, and adoption of EVs. This shows that EV and P&R combinations will reduce carbon emissions by up to 52 percent.	[107]
	There have also been advanced models that allow for the scheduling of large-scale P&R charging of electric vehicles. The result indicates that substantial energy savings have been achieved by installing large-scale charging systems in the P&R System.	[109,110]

The future of transportation regarding the P&R system entails studying the means of transportation involved, such as private and public transport. In other words, if the infrastructure is already in place or a P&R system is to be planned, it involves studying electric and autonomous vehicles and their interaction along the route of the P&R system [111]. Besides, smart cities in the future will be connected to transportation systems and P&R systems. In other words, applications regarding travel within a city currently show the routes or combinations of routes that generate the shortest time from an origin to a destination. For example, the application shows the best route by car or bus from home to work and, in the best case, the amount of walking. However, there is no application that a private vehicle user can use to get the information from the P&R route and ascertain whether there is a parking space and the connection to public transport through the travel application. We believe that, in the future, researchers and planners will be able to include the P&R system within the routes of travel as well as the real-time capacity of the P&R. Whether a private electric vehicle user can charge their vehicle in the P&R system should also be included. How the P&R system will function in the future arises with the advent of autonomous vehicles. Future research should consider the P&R system as a facility that is part of mobility, not a separate element.

8. Conclusions

The P&R system is part of the transport infrastructure in a city and has been studied over time and currently has evolved from being considered an external element of mobility to become one of the integrated systems that are part of mobility. In fact, P&R has remained present over the years in various studies and planning. However, some guidelines have already been developed in which they are integrated into the planning of a P&R system [7,36,37,112,113]. Planning the P&R system needs to include new technologies, such as autonomous and electric vehicles, as a new perspective that combines many elements and details. Besides, smart cities should be included a travel option, which is the P&R system.

The results to describe the literature show that in terms of the origin of P&R system trips, research has been conducted showing that private vehicle users make these trips for work and shopping purposes. However, further research is needed on the purpose of

P&R trips, as trip purposes may change by city, land use, and transportation policy. While with respect to location, there are studies on methodologies and methods for determining P&R system location, which includes a wide range of variables. What is more, it is one of the most researched topics on the P&R system. Planners must select the most appropriate study based on the city where the P&R system is to be planned. The demand for the P&R system is much more complex than one might think, as it is linked to parameters such as the decision of users to take the P&R route or, rather, to use the system. This decision is based on more specific criteria, such as the cost of the trip and the use of the P&R system.

The catchment area of the P&R system can be represented in a simple way. As software development has progressed, more complex analyses and representations of the P&R system catchment area have been developed. The evolution of these methods has come to provide a realistic representation of the P&R system catchment area through dynamic methods. Thus, it is possible to include within the representation parameters inherent to the P&R system, such as costs, travel time, and even the interaction of catchment areas of other transportation systems. Therefore, the development of dynamic methods for mapping the catchment area of the P&R system would be a topic for future research.

Public transport is closely related to the P&R system. However, a new problem arises that may seem obvious or unrealistic, but needs to be addressed. Could the P&R system be planned first in order to plan the public transport system then, to enable connection to public transport? In which cases or in which type of city is it much more favorable to plan the P&R systems first? Should the planning of the transport system be accompanied by the planning of new public transport routes? The future of transportation concerning the P&R system involves studying the modes of transportation involved, such as private and public transport, developing an application that allows a private vehicle used to get the P&R route information, and whether there is a parking space and connection to public transport through the travel application. We believe that, in the future, researchers and planners will be able to include the P&R system within the travel routes as well as the real-time capacity of the P&R. Also, the question remains whether a private electric vehicle user can charge their vehicle on the P&R system. How will the P&R system function in the future with the advent of autonomous vehicles?

This article compiles the literature about the P&R system in order to provide transport researchers and planners with an instrument that can be adapted to the city design they are planning. There are some cities where the system is already in operation, others that want to start implementing the system, and some that have already fully implemented the system, and places which are on their way to becoming smart cities. New technologies, such as autonomous and electric vehicles, should be included in P&R system planning. Furthermore, transport policies included in a SUMP of a city should include the idea that the P&R system is an element of mobility that interacts with the different transport systems. P&R should not be considered as a separate element of mobility.

A perspective on the future of transportation offers the question whether a private electric vehicle user can charge their vehicle on the P&R system, or how the P&R system will operate in the future with the advent of autonomous vehicles. The future of transportation concerning the P&R system involves studying the modes of transportation that are involved, such as private and public transport, developing an application that allows a private vehicle to use the P&R route information, and whether there is a parking space and connection to public transport through the travel application. Future research should consider the P&R system as an element that is an integral part of mobility.

Author Contributions: Conceptualization, J.O., J.T. and T.P.; methodology, J.O., J.T. and T.P.; formal analysis, J.O., J.T. and P.T.; investigation, J.O., J.T. and T.P.; re-sources, J.O., J.T. and T.P.; writing—original draft preparation, J.O., J.T. and T.P.; writing—review and editing, J.O., J.T. and T.P.; visualization, J.O., J.T. and T.P.; super-vision, J.O., J.T. and T.P.; project administration, J.O., J.T. and T.P.; funding acquisition, J.O., J.T., and T.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data sharing not applicable.

Acknowledgments: Special thanks to the Department of Transport Technology and Economics of the Faculty of Transportation Engineering and Vehicle Engineering of Budapest University of Technology and Economics for their collaboration and support.

Conflicts of Interest: The authors declare no conflict of interest.

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