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A Functional Thinking Approach to the Design of Future Transportation Systems: Taxis as a Proxy for Personal Rapid Transit in South Korea

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Abstract: For over 50 years, personal rapid transit (PRT) has been viewed as one of the most promising ways to provide sustainable, economical, and convenient transportation while reducing reliance on personal automobiles. However, despite concerted efforts around the world, the promise of PRT has yet to be realized. This work demonstrates that different physical means, such as the Korean taxi system, can be used to perform the same highest-level functional requirement, satisfy the same constraints, and provide many of the benefits that are expected of a city-scale personal rapid transit system. Thus, Korean taxis can be used as an alternative embodiment of personal rapid transit and can serve as a test bed to support PRT-related design, research, and development. The paper then explores the transportation patterns and characteristics of cities in South Korea and the United States in order to determine the conditions necessary to create and maintain a PRT-like taxi system and to demonstrate the differences between 'normal' and PRT-like taxi systems. Finally, the future of personal rapid transit as a functional and physical transportation paradigm is discussed.

Keywords: Personal Rapid Transit, Taxis, Functional Thinking, Korea, United States.

Introduction

For over 50 years, personal rapid transit (PRT) has been viewed as one of the most promising ways to provide sustainable, economical, and convenient transportation while reducing reliance on personal automobiles. However, despite concerted efforts around the world, the promise of PRT has yet to be realized.

This work suggests that the adoption of personal rapid transit has been limited, in part, by a fixation on the physical attributes of PRT systems such as exclusive guideways and autonomous operation, and demonstrates that the basic functions of an ideal PRT system can be performed and many of the same benefits can be achieved using different physical means such as taxis. By taking a functional approach, taxi systems that exhibit PRT-like behavior can be used as PRT alternatives for existing cities and as test beds to support PRT-related research and development. This could provide important insights into PRT user behavior, allowing designers to formulate better requirements and validate design concepts before a substantial investment is made in their technological implementation.

In the first part of this paper, we describe the history and challenges of personal rapid transit. We define the highest-level functional requirement and constraints of personal rapid transit. Then, we present the results from a series of observations of taxis and their users in a medium-sized city in South Korea. This information is used to compare the functions, characteristics, and benefits of Korean taxis and an ideal PRT system. Next, we examine the taxi usage patterns and characteristics of cities in South Korea to determine the conditions necessary to create and maintain such a system. The taxi system in the United States is briefly introduced to demonstrate how taxi usage patterns and characteristics are different in cities without PRT-like taxis. Finally, we discuss the benefits and limitations of taxis as a proxy for personal rapid transit and the implications of this work for the development of future transportation paradigms.

Personal Rapid Transit Systems

Personal rapid transit systems are defined by 5 characteristics (Delle Site and Filippi 2005):

- Small vehicles "for exclusive use by an individual or a party, i.e. a small group – typically 1 to 6 passengers - travelling together by choice"
- Vehicles that are fully automated (no human drivers)
- Vehicles that operate on a reserved guideway (parallel to existing transportation infrastructure)
- On demand service (no fixed schedules)
- Direct station-to-station service (no need to transfer or stop at intermediate stations)

Theoretically, these characteristics result in shorter waiting times, shorter transit times, and shorter walking distances to the station than traditional public transit options; comfort, convenience, privacy and security that is comparable to a personal automobile; lower traffic congestion, energy usage, and air and noise pollution by replacing fossil fuel based personal automobiles with shared electric vehicles; and improved mobility and reduced disenfranchisement of citizens who do not have access to a car because of age, health, income, or other factors (Parent 1997; Dunning and Ford 2003; Anderson 2006; Carnegie and Hoffman 2007; Lohmann and Guala 2009).

A Brief History of Personal Rapid Transit

The concept of personal rapid transit emerged around 1953, when "Donn Fichter and Ed Haltom, working with no knowledge of each other, invented … a system of small, fully automated vehicles that carry people nonstop between off-line stations on a network of exclusive guideways". The idea was re-invented (or re-discovered) at least a "half dozen" times during the 1960s (Anderson 2000).

There were a number of projects to develop PRT systems in late 1960s and early 1970s including Aramis in France, Cabtrack in England, Cabintaxi / Cabinlift in Germany, CVS in Japan, Kruass Maffei in Germany (Carnegie and Hoffman 2007), and the Morgantown PRT in the US. However, only three were ever put into operation: the Morgantown PRT, the CVS PRT, and the Cabinlift.

The Morgantown PRT system was commissioned in 1970 to link the three Morgantown campuses of West Virginia University. The system consists of "8.7 miles of guideway serving five passenger stations and two maintenance facilities." It has a fleet 71 electric vehicles, each capable of carrying 21 passengers (Raney and Young 2005). The system began limited operation in 1972 (Carnegie and Hoffman 2007). It was briefly closed for expansion in 1979 and has been operating at its current capacity since (Raney and Young 2005).

The CVS PRT was a demonstration system that "carried 800,000 passengers during a 7 month exhibition" in a suburb of Tokyo in 1972 (Andréasson 2001). Each vehicle could accommodate up to 4 passengers and ran between 2 stations along a 4.8km long track (Anon. 2014a).

Finally, a spin-off of the Cabintaxi program, the Cabinlift, was build at the Schwalmstadt-Ziegenhain hospital in Germany (Carnegie and Hoffman 2007). This system could move up to 12 passengers (or a smaller number of gurneys) 578 meters between 2 stations. This system was used between 1975 and 2010 (Anon. 2014b).

During the 1980s and 1990s, three projects made it to the prototype stage. A test track for the PRT 2000 system was built in Marlborough, Massachusetts as part of the Raytheon project for Rosemont, Illinois. The system, which had one offline station and 3 vehicles, was operational by 1995 (Anderson 2006). A test track and 22 vehicles for Austrans, an Australian hybrid personal rapid transit (off-peak) / group rapid transit (GRT) (peak travel) concept, was completed outside of Sydney in 2000 (Andréasson 2001). And, a test track for the Vectus PRT system with one station was operational in Uppsula, Sweden in 2007 (Gustafsson 2009). A second Vectus demonstration system was built in Suncheon Bay, South Korea and was operational in 2013 (TDI 2014).

The company 2getthere has been developing technology that can be used for personal rapid transit, group rapid transit, and freight rapid transit since the 1990s. They developed the FROG Park Shuttle, a GRT driverless mini-bus. Four Park Shuttles have been operating in a long term parking area at Schiphol airport near Amsterdam since December 1997. An addition three Park Shuttles have been "operating over a distance of 1.3 kilometers between a metro station" and Rotterdam's Rivium Business Park since Februrary 1999. Both systems use a fenced-off 3-meter wide asphalt surface with embedded transponders (Andréasson 2001). 2getthere also developed Abu Dhabi's Masdar PRT system. The Masdar system has been operating since 2010 with 2 passenger stations, 3 freight stations, and 1 station for maintenance (De Graaf 2011).

Finally, from 2001 to 2004, the European Union sponsored the Evaluation and Demonstration of Innovative City Transport (EDICT) project to evaluate PRT as a potential urban transport solution in Cardiff, Wales; Huddinge, Sweden; Eindhoven, Netherlands; and Ciampino, Italy (Carnegie and Hoffman 2007). A 1 km long test track for the ULTra PRT system was constructed in Cardiff in 2001. This laid the groundwork for London Heathrow Airport's ULTra PRT system, which has been operating since 2011 with "21 vehicles, a total of 3.8 kilometers of one-way guideway, and three stations" (Ultra Global 2014).

In total, "about 40 known PRT concepts existed as of 2007". Of those, "19 were being actively developed (i.e., not dormant, with some testing completed)" (Cottrell and Mikosza 2008). However, only five concepts (the Morgantown PRT, the Cabinlift, the Park Shuttle, the Masdar PRT, and the Heathrow PRT) have ever seen long-term use. Of those, only two (the Masdar PRT and the Healthrow PRT) carry few enough passengers to be classified as personal rapid transit instead of group rapid transit systems. And none of the systems ever built are of sufficient scale (i.e. have enough stations) to fully test the concept or realize the benefits of PRT.

Challenges to Operationalizing PRT Systems

A number of factors have slowed the adoption of PRT. Most cities do not have the space to accommodate new infrastructure for PRT guideways. Even if a system can be built, the guideways and stations can have a substantial and potentially negative impact on the visual landscape (Cottrell 2005).

The need for a separate guideway substantially increases the cost to build a PRT system. For example, the PRT study for San Diego estimated a cost of $18 million USD per kilometer, while the Wellington Public Transport Spine Study estimated the capital expenditure of the PRT system at $7.5 million to $16.8 million dollars per kilometer (Cottrell 2005). Guideway construction cost was cited as one of the reasons why the PRT 2000 project for Rosemont, Illinois was cancelled (Carnegie and Hoffman 2007).

There has been a long-standing concern that “PRT technology has not yet advanced to a state of commercial readiness” (Carnegie and Hoffman 2007). The systems discussed above have “successfully demonstrated several aspects of PRT with a small number of vehicles operating on a closed circuit” but say nothing about the “reliability, availability, dependability, and safety of a large number of PRT vehicles operating over a large network” (Cottrell 2005).

There is also still no validation for the social acceptance, expected operating income, and operating costs for full-scale PRT systems (Carnegie and Hoffman 2007). This is illustrated by the fact that “low fare-box recovery estimates” were another reason for cancelling the Rosemont PRT 2000 project (Carnegie and Hoffman 2007).

Finally, the “theoretical benefits of PRT,” including improvements to the personal transit experience, the environment, and society as a whole, have yet to be demonstrated (Carnegie and Hoffman 2007).

A Functional Approach to Personal Rapid Transit

The challenges above combined with the financial and political risks associated with building a new PRT system mean that investors usually want “to see a [full scale] PRT system running somewhere else before a purchase will be seriously considered” (Anderson 2000). This leaves the public without a convenient replacement for personal automobiles and leaves companies and researchers in a position where they must prove the benefits of PRT without a city-scale system to study. To address both sets of needs, we can simulate a PRT system by finding or building a system that “can be organized to exhibit nearly identical behavior” (Simon 1969). In other words, we need to find or build a system that performs the functions of a PRT system, and thus provides (most of) the same benefits, using physical means that are less costly and more readily available. This is consistent with the principles in Suh’s (1990, 2001) Axiomatic Design Theory and with engineering design thinking in general.

Based on the characteristics and expected benefits of PRT systems described above, PRT systems can be said to have one highest-level functional requirement (FR):

FR1 = Provide non-stop on-demand station-to-station transportation to individuals and small groups choosing to travel together using public vehicles and infrastructure.

In order to perform this function and still provide most of the anticipated benefits of PRT systems, several constraints must be added:

C1 = The system must have many stations (pick up / drop off locations)
C2 = The walking distance to a station must be short
C3 = The waiting time for a vehicle must be limited
C4 = The travel time (and therefore the congestion within the system) must be limited
C5 = The price to use the system must be reasonable
C6 = The cost to build and operate the system must be reasonable

Automated vehicles running on a captive guideway can perform the highest-level FR and may be able to satisfy all of these constraints. We hypothesized that a well-run system of taxis with substantial ridership could too.

Methods

In order to test this hypothesis, 440 taxis and their users were observed at 11 common destinations around the Korean city of Daejeon during the summer and autumn of 2009 (figure 1). The locations included a large apartment complex, two shopping malls, a shopping district (market), two train stations, City Hall, a hospital, a hotel, a park, and a movie theater (table 1). All of the observations were performed in areas where high accessibility to public transportation would be expected or needed. Several were chosen based on PRT station locations discussed in the literature (Andréasson 2001; Carnegie and Hoffman 2007; Tegnér *et al.* 2007). The redundant locations were added to determine whether an available subway connection would affect taxi (PRT) usage.

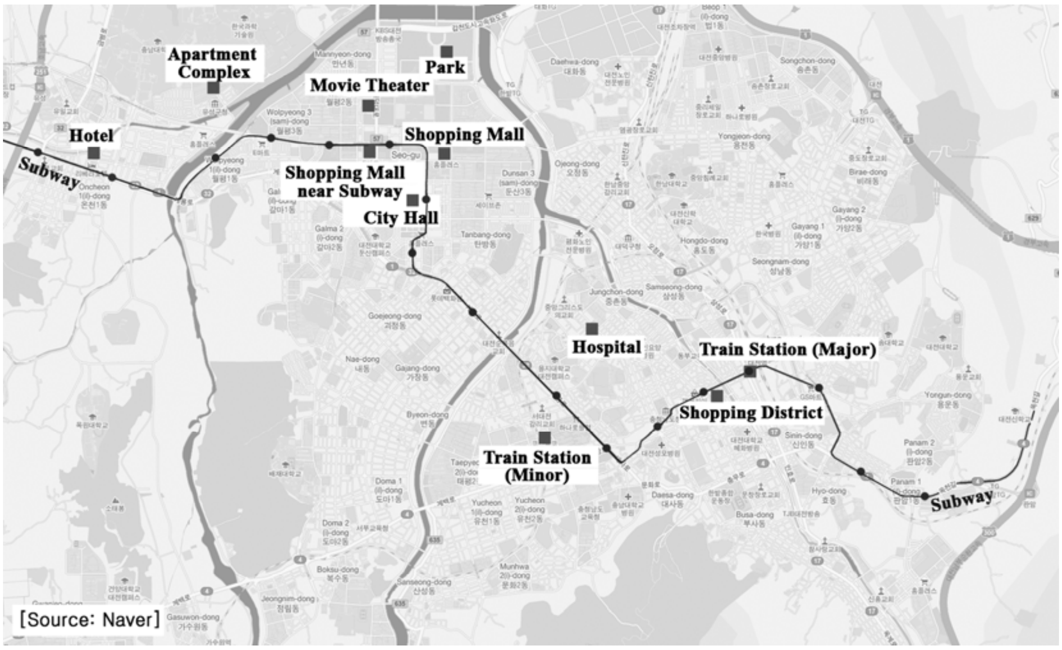

Figure 1. Taxi Observation Locations in Daejeon

Table 1. Details of Taxi Observation Sites and their Accessibilities to the Subway and Parking

Description	Name	Off Peak	Peak	Subway Accessibility	Parking Availability
Shopping Mall	Dunsan Homeplus	Tue - Thu 10am - 1pm	Sat 2pm - 11pm	-	+
Shopping Mall near Subway	Dunsan E-mart	Tue - Thu 10am - 12pm	Sat 2pm - 11pm	+	+
Train Station near Subway	Daejeon Station	Tue - Thu 2pm - 5pm	Fri 6pm - 10pm	+	
Train Station	SeoDaejeon Station	Tue - Thu 2pm - 5pm	Fri 6pm - 10pm	-	
Movie Theater	Dunsan CGV	Tue - Thu 10am - 2pm	Sat 4pm - 10pm	-	
Hotel	Yuseong Hotel	Mon - Thu 10pm - 4am	Sat - Sun 11am - 3pm		+
Hospital	Daejeon Sun Hospital	Tue - Thu 2pm - 5pm	Mon 9am - 12pm	-	+
City Hall	Daejeon City Hall	Tue - Thu 9am - 4pm	Mon 9am - 4pm	+	
Shopping District	Eun-Hang Dong	Tue - Thu 9am - 3pm	Sat 3pm - 9pm	+	-
Apartment Complex	Hanbit Apartments	Sun 7am - 9am	Mon - Thu 7am - 9am	-	+
Park	Daejeon Grand Park	Mon - Thu 10am - 2pm	Sat - Sun 11am - 3pm	-	+

Video recordings of each destination and the roads adjacent to it were taken during two time periods (peak and off-peak) for twenty minutes each during good weather. Multiple cameras were used for locations with multiple entrances. The recordings were examined to determine:

- The number of taxis arriving at, departing from, and passing by each site
- The number of other vehicles arriving at, departing from, and passing by each site
- The number of visitors arriving at and departing from each site by taxi
- The number of visitors arriving at and departing from each site without a personal vehicle
- The initial, final, and total number of taxis at taxi stands near each site
- The waiting time of each taxi for a passenger and of each passenger for a taxi
- The number of passengers in each taxi arriving at or departing from each site.

No distinction was made between roaming taxis and call taxis at any location or between available or occupied taxis passing each site. The data sets for the shopping district and the main train station are incomplete because of the difficulty in determining the origin of pedestrians approaching or leaving the site.

Results

The detailed results of the Daejeon taxi observations and the derived data from those observations are listed in tables A1 through A3 at the end of the paper. Selected results concerning the distribution, supply, demand, and usage patterns of taxis in Daejeon are discussed below.

Distribution of Taxis in Daejeon

During the period of observation, taxis in Daejeon constituted 14.56% of local traffic, with an average of 101 taxis (or 5 taxis per minute) observed passing each site. The percentage of taxis in passing traffic was relatively stable between peak and off-peak periods. The greatest difference in passing taxi percentages was observed at the hotel (9.47 to 20.21%) where demand is primarily determined by event schedules. The smallest difference in passing taxi percentages was observed at the park (8.26 to 8.61%) where there is little or no demand. The average difference was 4.35%.

Demand for Taxi Transportation to and from Popular Locations

Taxis are predominantly used in Daejeon to connect to other forms of transportation and for recreation. The highest numbers of arriving taxis and passengers were observed at main train station and the shopping district, while the highest percentages of arriving taxis and passengers were observed at the minor train station and the movie theatre. Similarly, the highest numbers of departing taxis and taxi passengers were observed at the main train station, while the highest percentages of departing taxis and taxi passengers were observed at the train stations and the movie theatre.

Taxi usage appears to increase in areas where congestion is heavy and parking is expensive and/or scarce. By far, the largest percent of passing taxis were observed in the shopping district (30.27% during peak hours, 28.64% total) where traffic is high and parking availability is poor. The locations with the largest numbers and percentages of arriving and departing taxis and passengers (both train stations, the shopping district, and the movie theatre) all have limited pay parking.

Overall, the number and percentage of arriving taxis (5.85 or 12.10%) and passengers (7.27 or 5.63%) are substantially lower than the number and percentage of departing taxis (19 or 16.09%) and passengers (14.14 or 19.35%). The most notable exception was City Hall, where taxis constitute 18.52% of arriving traffic but only 10.53% of departing traffic.

We believe the discrepancy between arriving and departing passengers occurs because passengers are too tired or have too many packages to carry to walk or take public transit on their return trip. We assume that there are more arriving visitors at City Hall because visitors use taxis to ensure an on-time arrival for business meetings. However, the high arrival rates at City Hall may be coincidental since relatively few passengers (7 arriving and 3 departing) were observed.

Subway access did not appear to play a major role in taxi availability or usage.

Waiting Time

During this study, only 7 out of 418 observed passengers waited for a total of 5 taxis. The average recorded waiting time of a passenger for a taxi was 2 minutes at City Hall and 36 seconds at the apartment complex. Passengers did not wait at any of the other locations.

The longest average waiting times of taxis for passengers were observed at the shopping district (36:41) and the hospital (30:00) both during off peak hours. The shortest average waiting times of taxis for passengers were observed at City Hall (0:00), the apartment complex (1:40), and the hotel (1:39) all during peak hours. The overall average waiting time of a taxi for a passenger was 10:49.

Taxi Stand Inventory in Daejeon

The inventory of taxi stands in Daejeon seems to be based on their maximum instantaneous demand rather than their time averaged demand. The largest queue was located at the main train station (40 taxis with roughly 200% turn over in each 20 minute period), followed by the minor train station (15 taxis with roughly 100% turn over in each 20 minute period), the shopping district (9 - 15 taxis) and the movie theatre near the express bus terminal (9 - 14 taxis). With the exception of the shopping district, each of these locations is subject to impulse loading when trains, buses, and/or movies disgorge large numbers of people over a short period of time. Thus, a larger taxi inventory is required to ensure a zero wait time for customers. During their peak periods, both the movie theatre and the shopping mall near the subway had similar numbers of departing taxi passengers (26 vs. 21) but substantially different taxi queue sizes (9 - 14 vs. 4 - 6 taxis) because the taxi demand of shoppers is more continuous than the bus / movie theatre patrons.

Taxi supply and demand is well matched in Daejeon. Only the hospital (+6) and the movie theatre (-5) showed a surplus or deficit of more than 3 taxis in their taxi stands during the 20-minute observation period. Interviews with Daejeon taxi drivers revealed that they kept personal records of taxi user behavior in Daejeon and had different taxi stand preferences for different times of day and days of the week. Thus, the taxi drivers automatically and efficiently reallocate themselves to meet the demand in a remarkable example of group intelligence.

Number of Passengers Per Taxi

The average number of passengers per taxi was 1.31 with 75% of taxis carrying a single passenger, 19% carrying two passengers, and 6% carrying three passengers. No taxis were observed with four passengers, although a fourth passenger is permitted in the front seat. The movie theatre, the shopping district, and both shopping malls had highest percentages of multi-passenger taxis (7 to 10%) and the highest passenger to taxi ratios (1.32 to 1.83) for the combined peak and off peak periods. This is to be expected since these are often group-based or family-based activities. The smallest ratios of passengers to taxi were found at the hotel (1.0), the minor train station (1.05), the apartment complex (1.05), and City Hall (1.11).

Comparison of PRT and Korean Taxis

In this section we use the results from the taxi observations and additional information from the literature to compare the Korean taxi system to an ideal PRT system.

Short Walking Distance to Stations

Lohmann and Guala (2009) state that an ideal PRT system should ensure that the maximum walking distance from any point in the city “to the nearest PRT stop is no greater than 150 meters.” This requires 14.2 stations per square kilometer. Dunning and Ford (2003) state that the walking distance should be “around 500 meters or less.” This requires 1.27 stations per square kilometer.

In Daejeon, there are 157 government taxi stands. Of those, 147 are located in the central part of the city. The city occupies an area of 539.97 km^2 and the city center is approximately one quarter of the total area (Daejeon Metropolitan City 2012). Therefore, there are approximately 1.08 taxi stands per square kilometer in the city center. This calculation includes the areas covered by parks, forest, and rivers. Thus, a taxi stand should usually be located within 500m.

In addition to the government taxi stands, there are an unknown but large number of taxi stands that are hosted by schools, universities, companies, and other organizations. Taxi drivers also regularly establish defacto taxi stands in areas with reliable patronage and room to park. As a result, many of the taxi stands in Daejeon also meet the 150m criterion.

Short Passenger Waiting Time

In “a well functioning system, PRT vehicles” are expected to wait for passengers (Dunning and Ford 2003). Lowson (2001) says that the ULTra PRT design target is to provide 90% of immediate services within a minute. Anderson (1988) suggests that in off-peak periods, there should be no wait at all and that “about 98% of the rush-period wait times” should be less than three minutes with an average wait of less than one minute. It was shown above that taxis at popular locations in Daejeon are able to meet and exceed these design targets. The taxis observed provided immediate service (no wait) to over 98% of their passengers during both peak and off-peak times at popular destinations. All passengers observed received service within 2 minutes.

Non-Stop Station-to-Station Service

By definition, PRT systems provide non-stop, station-to-station service (Delle Site and Filippi 2005). By law, Korean taxis must also provide non-stop service between their pick up and drop off locations.

Privacy and Choice of Companions

As noted above PRT vehicles are intended to be “for exclusive use by an individual or a … small group - typically 1 to 6 passengers - travelling together by choice” (Delle Site and Filippi 2005). Most Korean taxis are sedans and can accommodate up to 4 passengers. A small number of Korean taxis are minivans and can accommodate 5 or more passengers. Full sized vans are usually only available as livery or call taxis. Choice of traveling companions is guaranteed in Korean taxis by the Passenger Transport Service Act, Chapter I, Article 26 (Korean Ministry of Government Legislation 2012).

Round-the-Clock Service

PRT systems are expected to “run 24 hours a day and seven days a week” (Dunning and Ford 2003) Korean taxis are also available 24 hours a day and seven days a week. However, their relative availability is not the same. Because the vehicle supply is constant in a PRT system, there should be better availability and decreased waiting times for a vehicle during off peak times when demand is low (Lohmann and Guala 2009). In contrast, taxis in

Korea match supply to demand. As a result, they have less availability and increased waiting times during off peak periods. The difference is primarily due to the need for human taxi operators.

Dynamic Distribution of Vehicles in the Network

PRT systems are expected to have "demand-responsive, fully-developed vehicle prepositioning capability" that can place "empty vehicles that are ready for use in locations where demand is expected to materialize" (Dunning and Ford 2003). The observations of taxis in Daejeon demonstrated that Korean taxi drivers also distribute themselves throughout the city automatically, dynamically, and extremely effectively.

Dynamic Rerouting

PRT systems are also supposed to avoid network congestion, thereby decreasing travel time, by dynamically rerouting vehicles (Lohmann and Guala 2009). The same is true for taxis. Korean taxi drivers automatically adjust their routes to compensate for traffic in order to maximize their daily revenue. However, Korean taxis offer one additional service: Korean taxi drivers provide advice to travelers and sometimes refuse passengers who would be better served by an alternate mode of transportation. For example, it is common for taxi drivers in Seoul to suggest that a potential passenger take the subway for a long trip across the city during rush hour. Thus, Korean taxis not only reroute themselves throughout the taxi system, they also reroute travelers throughout the transportation network.

Shared Vehicles and Infrastructure

Finally, Lohmann and Guala (2009) state that in an ideal PRT system, one vehicle should be able to perform the task of 30 to 40 private cars. Korean taxis do as well. Lee and Kim (2001) reported that taxis in Gwangju made an average of 57 trips per day in 2000. Hwang and Yoon (2006) reported that taxis in Daegu made between 33 and 39 trips per day in 2005. In interviews with the authors, Daejeon taxi drivers reported an average of 40 trips per day in 2009.

Implications

This comparison shows that the Korean taxi system performs the same highest-level functional requirement, satisfies the same constraints, and provides many of the benefits that are expected of a city-scale personal rapid transit system. This implies that the Korean taxi system can be used as a test bed to support PRT-related design, research, and development. It also implies that PRT-like taxi systems can be developed in other countries and contexts to address the challenges associated with operationalizing PRT. For example, a PRT-like taxi system could be used to verify local demand and predict user behavior before building a PRT system. It could also serve as a short to medium term alternative while PRT technology and infrastructure are being developed or as a long-term replacement for PRT in areas where separate guideway infrastructure is infeasible.

Usage Patterns of PRT-Like Taxis in Korea

In this section, we examine the transportation patterns in South Korea to better understand how a city-scale system that provides PRT-like services is and could be used.

Choice of Transportation Mode in Korea

In 2008, taxis were used in 5 to 11% of all trips, and 7 - 26% of all motorized trips, made in major Korean cities (table 2). In comparison, personal automobiles were used in 20 to 36% of all trips, local buses were used in 17 to 25% of all trips, the subway was used in up to 29% of all trips (where available), and walking was chosen between 17 and 37% of the time (KMLTM 2009). The usage rates show that taxis are a small but important part of the overall transportation network in Korea. The variations in usage between Korean cities in table 2 shows that transportation mode of choice is strongly dependent on the options available.

Length of Passenger Travel in Korea

The average length of a taxi trip in a medium-sized Korean city is between 3.5km (2.17 miles) and 4km (2.48 miles) (Lee and Kim 2001; Hwang and Yoon 2006). This shows that Korean taxis are generally used for short trips that cannot be made quickly or easily on foot.

Common Destinations in Korea

It was shown above that taxis in Daejeon are predominantly used to connect to other forms of transportation, for transportation to and from recreational activities, to eliminate the need to park, and to ensure an on-time arrival to important meetings. This is consistent with other reports from the literature. The Korea Transport Institute (2004) reported that passengers in Seoul (the capital) and Suwon, (one of the cities in the capital area) used taxis most for recreation, social visits and tourism (36.8%), followed by business trips (21.0%) (KOTI 2004). Similarly, Song and Song (2000) found that the primary use of taxis was for business (50.4%).

Table 2. Transportation Mode of Choice for all Trips in Korea by Region in 2008 (KMLTM 2009)

	Private Car	Public Bus	Subway	Taxi	Bicycling	Walking	Other
Seoul	19.9	23.5	28.5	5.6	1.2	17.4	3.9
Busan	27.7	25.1	8.2	10.8	0.4	24.6	3.2
Daegu	33.4	16.8	5.2	7.7	2.1	33.1	1.7
Incheon	32.1	22.2	8.8	6.4	1	22.6	6.9
Gwangju	32.4	18.1	1	8.4	1.4	37.3	1.4
Daejeon	36.1	17.9	1.5	8.4	1.5	33.4	1.2
Ulsan	36.2	20.6	0.1	9.3	1.3	29.3	3.2

Table 3. Transportation Mode of Choice (%) for Commute to Work / School in Korea by Region in 2005. Private buses are run by schools and corporations for the benefit of their students and employees, while express buses are exclusively for intercity travel (Statistics Korea 2005).

	Private Car	Public Bus	Private Bus	Express Bus	Subway	Train	Taxi	Bicycle	Walking	Other
Total	33.3	17.7	5.2	0.7	7.5	0.1	0.5	1.2	30.3	3.6
Seoul	22.2	18.6	2.3	0.6	24.1	0.1	0.4	0.9	29.3	1.3
Busan	30.0	28.4	4.9	0.4	6.6	0.1	0.6	0.5	26.3	2.2
Daegu	38.6	21.6	4.4	0.3	2.7	0.2	0.5	1.5	27.5	2.7
Incheon	35.7	21.1	4.5	0.9	8.4	0.0	0.5	0.8	25.9	2.1
Gwangju	38.6	24.3	5.3	0.4	0.5	0.0	0.5	1.0	27.4	2.0
Daejeon	43.7	19.9	4.1	0.5	0.0	0.4	0.6	1.0	27.9	1.9
Ulsan	37.7	18.2	8.5	0.4	0.0	0.0	0.8	1.9	27.3	5.1

However, taxi usage in Korea depends on the time of day. During interviews with the authors, taxi drivers in Daejeon said that between midnight and 2am passengers are generally coming from downtown and want to go home. From 4am to 8am passengers generally want to go from home to work. From 8:30am to noon passengers want to go from home to shopping areas. From 4pm to 7pm travelers usually go home. And, from 7pm to 9pm travel is mostly to the downtown areas. This implies that taxis are also used at night to avoid drinking and driving.

Taxis in Korea are rarely used for daily commutes to work or school. Jung and Kim (2000) found that only 1.8% of commuters in Busan (Korea's second largest city) chose to use taxis for their entire daily commute, while the Korean Statistical Information Service (Statistics Korea 2005) indicates that taxis were only used for 0.5% of commutes to work or school in 2005 (table 3).

The Korea Transport Institute reports that Koreans generally choose taxis because they provide the fastest transit time (47.5%) and the most comfort and convenience (31.5%) for a given situation (KOTI 2004). This is consistent with the observations above.

User Profile

Korean taxi usage is relatively consistent among socio-economic groups with the most usage by those with average annual incomes. Song and Song (2000) found that 82.4% of taxi use was by those with annual incomes between 6 and 42 million won per year (table 4). For reference, the average salary in 2000 was 15,766,920 won (KMOEL 2000). While this tells us nothing about the percentage of taxi users within each socioeconomic group, it is likely that individuals with the lowest annual incomes prefer to less the less expensive bus system, while those with the highest annual incomes prefer chauffeured black cars.

Song and Song (2000) found that the highest taxi use in Gyeonggi-Do (the Seoul metropolitan area excluding Seoul) was by 20 to 30 year olds. In interviews with the authors, Daejeon taxi drivers also reported that approximately 80% of their fares are between 20 and 30 years old, with fewer than 5% younger than 20 or older than 40.

In interviews with the authors, taxi drivers in Daejeon reported that most of their passengers are female (80%). However, gender ratios change over the course of the day with more female passengers during the day and more male passengers at night. This is consistent with the day and nighttime destinations reported by taxi drivers.

Table 4. Korean Taxi Usage by Socioeconomic Group in 2000 (Song and Song 2000)

Annual Income (million won)	Taxi Users (%)
6,000,000 or less	5.7
6,000,000 - 18,000,000	31.5
18,000,000 - 30,000,000	30.1
30,000,000 - 42,000,000	20.8
42,000,000 - 54,000,000	7.1
54,000,000 - 66,000,000	2.9
66,000,000 or more	1.9

Conclusions About PRT-Like Taxi Usage

From this discussion, we conclude that passengers in a PRT-like taxi system are average people who weigh the costs and benefits of using mass transit, of using personalized transit, and of operating and parking a private automobile for each situation. They do not use taxis as a daily or default mode of transportation. Given the age and gender of passengers, PRT-like taxis might also be used to supplement families with a single car or to delay the purchase of an automobile until later in life.

Conditions Necessary to Support PRT and Its Proxies

In this section, we explore the operating environment of Korean taxis in order to determine the conditions necessary to create and support a PRT-like taxi system.

Extensive, High Quality Public Transportation

Korea offers an extensive network of high quality public and private local and long distance mass transit options. The high rates of public transportation use shown in tables 2 and 3, the high rates of taxi usage observed at the train stations in Daejeon, and the short average distance of a taxi trip indicate that PRT-like taxis are used to supplement and connect to the public transportation network rather than to bypass it. On this basis, we propose that an extensive and high quality public transportation network is a pre-requisite to support a personal rapid transit system or its taxi equivalent.

High Quality of Service

The quality of service from Korean taxis is also very high. Taxis are well maintained and are generally considered to be a safe mode of travel. Taxi drivers are proud of their profession and are respected by passengers. And, taxi drivers are usually honest, choosing the quickest and shortest routes to maximize their number of trips per day. Thus, there is little in the taxi experience in Korea to discourage use.

High Population and Housing Density

Next, we believe that high population density in general and high housing density in particular are important to developing a personal rapid transit system. In 2010, approximately half of the Korean population (46.1%) lived in Korea's 7 largest cities. An additional quarter of the population lives in the suburbs of Seoul, giving the Seoul metropolitan area 49% of Korea's population (Statistics Korea 2010a).

Only 27.9% of Koreans live in a single family detached dwelling. Most (58.3%) live in apartments (Statistics Korea 2010a). Korean apartments are usually located in collections of high-rise buildings, some of which host 5,000 families or more. In 2005, 69% of all apartment buildings in Korea and 78% of the apartment buildings in Daejeon were at least 15 stories tall (KMLTM 2007). Korean apartment complexes generally have their own primary (and sometimes middle and high) school and a department store / shopping mall which contains a grocery store. In less dense areas, high-rise apartment complexes are usually surrounded by a village of low-rise (3 to 5 story) buildings that contain shops, restaurants, smaller apartments for rent, and the occasional single-family house. As a result, most basic necessities are available within walking distance of home. This eliminates the need for a personal automobile and supports the use of public transit in daily life. This type of urban planning also means that a taxi stand or PRT station is or can be located near home for most of the population.

Large Numbers of Vehicles in Service

The number of vehicles in service is an important factor to ensure that taxis or PRT vehicles wait for passengers. Over the 5 year period from 2003 to 2007, Daejeon had approximately 8,800 taxis and a population just under 1.5 million, for an average ratio of 167 people per taxi (Daejeon Metropolitan City Statistics 2009). From this, we conclude that large numbers of taxis are needed to foster a PRT-like taxi system.

Reasonable Price and Operating Costs

PRTs and taxis must also be affordable to use and to operate. As of 2013, taxi fares in Korea were 2800 or 3000 won for the first 2 km (depending on the city) plus 100 won for every 140 to 150 meters or every 30 to 40 seconds. A 20% surcharge is also applied for late night trips and trips outside of the operating district (Visit Korea 2014). This policy encourages passengers to take short trips. It also encourages taxi drivers to maximize their number of trips per day rather than the length of each trip.

Although there is no information in the literature about average taxi fares in Korea, taxi drivers in Daejeon reported an average fare of 4000 won (~$4 or $0.625/mile) in interviews with the authors. This is much lower than the average cost in the US ($2.25 per mile) (Litman 2010) but is approximately the same if the costs are normalized by the average incomes for each country. Thus, taxis are still relatively expensive to use in Korea. This implies that taxis and PRT systems do not have to be inexpensive to have high utilization.

The revenue that a taxi driver can earn in a day must be enough to cover all expenses (car, fuel, insurance, etc.) as well as his or her cost of living. In Korea, this is achieved, in part, by zero-cost licensing. In interviews with the authors, representatives from the Seoul Private Taxi Association and individual taxi drivers stated that there is no cost for a taxi medallion in Korea. (There is a small processing fee.) Medallions can be held indefinitely but they cannot be sold. Retiring drivers must return their medallions to the city to be reassigned. This vastly changes the economics of taxi ownership and operation and may be one of the keys to running an economical PRT-like taxi system.

Low Automobile Ownership is Not Required

Given a total population of 48.5 million people in 16.4 million households and a total automobile ownership of 12.8 million cars in 2010 (Statistics Korea 2010b; KMLTM 2010), we estimate that up to 26.4% of Koreans or up to 78% of Korean households have at least one car. This is consistent with Song and Song's (2000) report that only 18.2% of households in Gyeonggi-Do, the providence in which Seoul is located, did not have a personal automobile in 2000. Since most Koreans have access to a personal automobile, we conclude that low personal automobile ownership is not a requirement for high PRT or taxi usage.

Comparison of Taxis in the US

Finally, we present a brief overview of taxis in the United States in order to demonstrate how a 'normal' taxi system differs from a PRT-like taxi system.

Taxi Usage in the US

Taxis are a niche market in the US. In 2001, taxis were used in 0.1% of trips for work and work related travel, 0.1% of trips for shopping and services, 0.1% of trips for social and recreational purposes, and 0.1% of trips for travel to school and church. Overall, taxis were used in less than 1% of all trips made by all socio-economic groups. In comparison, automobiles were used in 86.4% of all trips for all purposes (Pucher and Renne 2003).

Unlike Korea where taxis are used by all but the most and least wealthy, taxi usage in the US is "bimodal, with the highest usage among the poor and the affluent." Individuals with household incomes less than $20,000 per year generally rely on public transit when it is available, and thus use taxis more during off-peak hours (when they constitute 18.4% of taxi users) rather than during peak hours (when they make up only 8.8% of taxi users). Wealthy individuals who make more than $100,000 per year are unaffected by public transit schedules and make up 35 to 38% of taxi users during both peak and off-peak periods (Pucher and Renne 2003).

Taxi usage in the US is also affected by automobile ownership. In 2001, households without a car used taxis 1.0% of the time, while those with only one car used taxis 0.2% of the time and households with 2 or more automobiles used taxis 0.1% of the time (Pucher and Renne 2003). This indicates that automobiles are a necessity in the US and that taxis are used as short-haul automobile replacements.

Taxi drivers in Boston, MA reported that most passengers are professionals, students, and tourists and that the majority of their trips are made on Fridays and Saturdays. Like Korea, common destinations include the airport, hotels, shopping districts, places with poor parking (like Fenway Park) and "home". However, unlike Korea, very few passengers in Boston taxis to connect to the subway or other forms of public transportation; more want door-to-door service. In interviews with the authors, taxi drivers in Austin, TX, where there are limited public transit options, reported that almost all taxi trips in the city were made to and from the airport. For longer trips, visitors generally rented cars or were given rides by friends, family or colleagues.

The average length of a US taxi trip in 2001 ranged from 4.1 miles (for households with incomes less than $20,000) to 7.5 miles (for households with incomes between $40,000 and $74,999) with an average of 5.6 miles per trip for all socio-economic groups (Pucher and Renne

2003). This is more than twice the length of an average taxi trip in Korea.

The low overall rates of taxi usage and the higher average length of trip can be attributed partially to the nature of American cities. In 2000, over half of the US population lived in suburban areas (Hanlon et al. 2010) with 60.3% of the population living in single family detached dwellings and only 17.3% in apartment buildings with 5 or more units (US Census Bureau, 2005). This decentralization increases the cost and decreases the efficiency of mass transit and has led to a massive increase in personal automobile ownership. By 2001, over 90% of US households had at least one car (Pucher and Renne 2003).

The need for, access to, and love of personal automobiles in the US means that there is little demand for taxi services. A 2007 study of taxis in the Coachella Valley near Palm Springs, CA showed that the average number of trips per day per taxi ranged from 1.2 to 15, with only 5 out of 21 taxi companies reporting an average number of trips per day above 6 (Mundy 2007).

New York City: A Special Case

The only place in the United States that comes close to having a PRT-like taxi system is New York City. Taxis in New York transport 11% of all "taxi, bus, subway, car service, or black car passengers in New York City, and 25% of those traveling within Manhattan" (Schaller 2006). These are similar to the usage rates reported in Korea. To satisfy this demand, taxis in New York average 12.29 to 28.10 trips per shift (Farber 2008). The average taxi fare in New York City is "$9.61 for a 2.8 mile trip, or $11.44 when surcharges and tips are included" (Schaller 2006). This is a shorter average trip and a higher average cost per mile than in other parts of the US. New York taxi usage rates, trip length, and trips per shift are closer to those observed in Korea.

The conditions in New York City are also closer to those observed in Korea. In New York, only 9.8% of residents live in single-family detached homes and only 7% live in single-family attached homes. The majority of the population lives in apartment buildings with 5 or more units (60%) with approximately half of those residents (or 30.7% of the NYC population) in large 50+ unit complexes (US Census Bureau 2010). However, there are some major differences. New York is a region of low automobile ownership. For example, in 2000 only 44.3% of households in NYC had an automobile available to them (US Census Bureau 2000). Also, New York has a much lower taxi density than Korea. Given an estimated population of 8,214,426 (US Census Bureau 2006) and a total of 12,779 taxicabs (Schaller 2006), New York City had approximately 1 taxi for every 642 residents in 2006. This is only 26% of the per capita taxi rate in Daejeon.

Discussion

Limitations of Taxis as Proxies for PRT

The functional similarities between the Korean taxi system and an ideal PRT system make the Korean taxi system an ideal way to study the impact of variables such as station density, vehicle availability, travel cost, travel time, and system congestion on user preferences and behavior. However, the physical differences between PRTs and taxis, especially in terms of exclusive guideways versus shared roadways and autonomous operation versus human operation, can have a major impact on the infrastructure costs, operating costs, and safety of the two systems. Studying a PRT-like taxi system will provide little or no information about these factors. Also, PRT-like taxis have a different impact on automobile traffic congestion than a true PRT system would. And, studying taxis with internal combustion engines provides little information about the environmental impact of switching to electric PRTs.

Limitations of PRT Compared to Taxis

On the other hand, taxis have some advantages over PRTs. Taxis provide better service by picking up and dropping off passengers closer to their starting and final destinations. Because taxis use the existing roadway, the taxi system is more flexible and thus better able to respond to changes in technology, city infrastructure, and population. And, taxis create more long-term jobs than an automated PRT system would.

Perhaps more importantly, this work has shown that a taxi system that offers the same level of service (station density, waiting time, trips per day, etc.) as a PRT system will still only be used in 5 to 11% of all trips or 7 to 26% of all motorized trips. This leads us to question whether the cost of the exclusive guideway infrastructure and the station density necessary to address the last mile problem will ever be justifiable. If not, perhaps the very definition of personal rapid transit will have to evolve to place more emphasis on the functionality and less emphasis on the physical attributes of these systems. Such a change could make room for app-based ride sharing programs, public bicycle rental systems, driverless automobiles, and other paradigms that provide different physical means to perform the same functions and obtain the expected benefits of personal rapid transit.

Limitations of this Study

Transportation planning and transportation mode of choice depend strongly on context. This paper showed that urban planning is an important factor in creating and maintaining a PRT-like taxi system. However, urban planning is affected by local factors such as culture, climate, and the age and history of the city. Taxi driver and taxi passenger behavior are also heavily influenced by culture, climate, and the nature of the city. Thus, PRT-like taxis may work better in one context while traditional PRTs may work better in another. Similarly, the conditions necessary to make a physical solution work in one context may not be same in another. This underlines the importance of functional thinking in the design of transportation systems. Clearly and accurately defining the functional requirements and constraints at the beginning of a project can greatly increase the probability of identifying and ultimately selecting the best physical means to achieve them for a given situation.

Implications for the Future

Finally, transportation planning and transportation mode of choice are not static. Instead, they evolve with the economy, society, technology, and public policy. For example, widespread mobile internet access has made networking ride share program such as Uber a reality. Driverless vehicles are also being tested and eventually will be commercially available. New technology may address the existing shortcomings of taxis and personal rapid transit, allowing one or both of these options to reach their full potential. However, changes in technology and society may also lead to demands for new functionality and services that cannot be met by existing transportation paradigms. This could cause taxis and personal rapid transit to become relics of the past. Uncertainty, especially over long periods of time, is one of the major challenges of design in civil and environmental engineering. Designing for uncertainty at the urban scale (both in space and time) is one of the topics that we hope the DCEE community will address in the years to come.

Summary and Conclusions

This work has used a functional thinking approach to explore the past, present, and future of personal rapid transit. It has demonstrated that taxis in Korea perform the same highest-level functional requirement and provide many of the benefits that are expected of a city-scale personal rapid transit system. Thus, Korean taxis can be used as an alternative embodiment of personal rapid transit and can serve as a test bed to support PRT-related design, research, and development.

It was shown that taxis in Korea are predominantly used to connect to other forms of transportation, for transportation to and from business and recreational activities, and to eliminate the need to own, operate, and/or park an automobile. Taxi trips are short and expensive relative to other modes of transportation. Passengers are average people who weigh the costs and benefits of using a taxi for each situation, rather than using taxis as a daily or default mode of transportation.

It was proposed that five conditions are necessary to create and support a PRT or PRT-like taxi system:

- Extensive, high quality public transportation
- High quality of (taxi / PRT) service
- High population and housing density
- Large numbers of (taxi / PRT) vehicles in service (1 taxi for every 150 to 200 residents)
- Reasonable price and operating costs

Finally, it was shown that regions like the US that do not share these characteristics also do not have PRT-like taxi systems.

It is hoped that the functional thinking approach used in this paper will help us to better understanding existing transportation paradigms like personal rapid transit, to support the development of new transportation paradigms in all physical forms, to match the best functional and physical solution to each context, and to plan for the unknown but inevitable changes that will affect the demands on our transportation systems in the future.

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Table A1. Detailed Taxi Observation Results by Location (Part 1)

		CGV Dunsan Movie Theater		Yuseong Hotel		Sun Hospital		Daejeon City Hall		Eunhang-Dong Shopping District		Daejeon Train Station near Subway	
		Off-peak	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak	Peak
Passing by the Site	Number of vehicles excluding taxis	1346	1377	154	153	331	323	350	258	348	569	725	688
	Number of taxis	111	141	39	16	65	72	59	58	121	247	181	130
	Total number of vehicles	1457	1518	193	169	396	395	409	316	469	816	906	818
	% of taxis to total vehicles	7.62	9.29	20.21	9.47	16.41	18.23	14.43	18.35	25.80	30.27	19.98	15.89
Arriving at the Site	Number of visitors without personal car	29	65	32	96	91	142	27	28			159	748
	Number of visitors arriving in taxis	3	13	1	0	2	7	5	2	10	36	5	44
	% of taxi passengers to total visitors without a personal car	10.34	20.00	3.13	0.00	2.20	4.93	18.52	7.14			3.14	5.88
	Number of cars	5	21	37	67	35	36	12	17				
	Number of taxis	3	9	1	0	2	5	4	2	7	27	4	40
	Total number of vehicles	8	30	38	67	37	41	16	19				
	% of taxis to total vehicles arriving at site	37.50	30.00	2.63	0.00	5.41	12.20	25.00	10.53				
	Initial number of taxis at taxi stands	14	9	3	2	7	10	0	0	9	15	40	40
	Final number of taxis at taxi stands	9	12	4	0	13	9	0	0	9	15	40	40
	Number of taxis entering taxi stands during 20 min period	2	21	2	1	7	8	2	1	5	30	85	78
Departing from the Site	Number of visitors departing without a personal car	15	62	39	27	95	69	19	34			265	745
	Number of visitors departing in taxis	7	26	1	3	2	11	2	1	7	49	107	106
	% of taxi passengers to total visitors without a personal car	46.67	41.94	2.56	11.11	2.11	15.94	10.53	2.94			40.38	14.23
	Number of cars	3	10	58	45	42	45	16	22				
	Number of taxis	7	18	1	3	1	9	2	1	5	30	85	78
	Total number of vehicles	10	28	59	48	43	54	18	23				
	% of taxis to total departing vehicles	70.00	64.29	1.69	6.25	2.33	16.67	11.11	4.35				
	Average waiting time of passengers for taxis	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00	0:02:00	0:00:00	0:00:00	0:00:00	0:00:00
	Average waiting time of taxis for passengers	0:24:29	0:05:34	0:22:52	0:01:39	0:30:00	0:14:49	0:03:55	0:00:00	0:31:40	0:05:51	0:09:32	0:10:19
	Average number of taxis waiting for passengers	13.09	10.91	3.91	0.64	8.27	8.55	0.40	0.00	9.00	15.00	40.00	40.00
Arriving & Departing	Total number of visitors without car	44	127	71	123	186	211	46	62			424	1493
	Total number of visitors arriving and departing in taxis	10	39	2	3	4	18	7	3	17	85	112	150
	% of taxi passengers to total visitors without a personal car	22.73	30.71	2.82	2.44	2.15	8.53	15.22	4.84			26.42	10.05
	Number of cars	8	31	95	112	77	81	28	39				
	Number of taxis	10	27	2	3	3	14	6	3	12	57	89	118
	Total number of vehicles	18	58	97	115	80	95	34	42				
	% of taxis to total vehicles	55.56	46.55	2.06	2.61	3.75	14.74	17.65	7.14				
	Average number of passengers per taxi	1.00	1.44	1.00	1.00	1.33	1.29	1.17	1.00	1.42	1.49	1.26	1.27

Table A2. Detailed Taxi Observation Results by Location (Part 2)

		SeoDaejeon **Train Station**		Homeplus **Shopping Mall**		E-mart **Shopping Mall near Subway**		Hanbit **Apartment Complex**		Daejeon Grand **Park**				
		Off-peak	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak	Peak	Min	Max	Avg
Passing by the Site	Number of vehicles excluding taxis	413	571	390	786	1188	1275	234	433	844	1199			634
	Number of taxis	126	105	49	68	145	251	21	18	76	113			101
	Total number of vehicles	539	676	439	854	1333	1526	255	451	920	1312			735
	% of taxis to total vehicles	23.38	15.53	11.16	7.96	10.88	16.45	8.24	3.99	8.26	8.61	3.99	30.27	14.56
Arriving at the Site	Number of visitors without personal car	180	193	25	85	68	129	20	17	2	9			107.25
	Number of visitors arriving in taxis	8	7	2	1	6	7	0	1	0	0			7.27
	% of taxi passengers to total visitors without a personal car	4.44	3.63	8.00	1.18	8.82	5.43	0.00	5.88	0.00	0.00	0.00	20.00	5.63
	Number of cars	10	11	43	42	77	135	60	74	3	21			39.22
	Number of taxis	8	6	2	1	3	4	0	1	0	0			5.86
	Total number of vehicles	18	17	45	43	80	139	60	75	3	21			42.06
	% of taxis to total vehicles arriving at site	44.44	35.29	4.44	2.33	3.75	2.88	0.00	1.33	0.00	0.00	0.00	44.44	12.10
	Initial number of taxis at taxi stands	15	15	5	6	5	6	5	2	0	0			9.45
	Final number of taxis at taxi stands	15	15	3	5	4	6	6	0	0	0			9.32
	Number of taxis entering taxi stands during 20 min period	14	10	3	6	4	12	8	9	0	0			14
Departing from the Site	Number of visitors departing without a personal car	116	118	47	75	43	169	27	75	2	11			102.65
	Number of visitors departing in taxis	15	10	8	12	10	21	7	13	0	0			19.00
	% of taxi passengers to total visitors without a personal car	12.93	8.47	17.02	16.00	23.26	12.43	25.93	17.33	0.00	0.00	0.00	46.67	16.09
	Number of cars	8	6	53	82	34	128	147	339	0	21			58.83
	Number of taxis	14	10	5	7	5	12	7	11	0	0			14.14
	Total number of vehicles	22	16	58	89	39	140	154	350	0	21			65.11
	% of taxis to total departing vehicles	63.64	62.50	8.62	7.87	12.82	8.57	4.55	3.14	0.00	0.00	0.00	70.00	19.35
	Average waiting time of passengers for taxis	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00	0:00:32	0:00:00	0:00:00	0:00:00	0:02:00	0:00:01
	Average waiting time of taxis for passengers	0:20:00	0:28:58	0:10:06	0:08:41	0:07:39	0:11:57	0:08:58	0:01:40	0:00:00	0:00:00	0:00:00	0:31:40	0:10:49
	Average number of taxis waiting for passengers	15.00	15.00	3.27	4.00	4.10	6.00	4.91	1.27	0.00	0.00	0.00	40.00	9.24
Arriving & Departing	Total number of visitors without car	296	311	72	160	111	298	47	92	4	20			209.90
	Total number of visitors arriving and departing in taxis	23	17	10	13	16	28	7	14	0	0			26.27
	% of taxi passengers to total visitors without a personal car	7.77	5.47	13.89	8.13	14.41	9.40	14.89	15.22	0.00	0.00	0.00	30.71	10.75
	Number of cars	18	17	96	124	111	263	207	413	3	42			98.06
	Number of taxis	22	16	7	8	8	16	7	12	0	0			20.00
	Total number of vehicles	40	33	103	132	119	279	214	425	3	42			107.17
	% of taxis to total vehicles	55.00	48.48	6.80	6.06	6.72	5.73	3.27	2.82	0.00	0.00	0.00	55.56	15.83
	Average number of passengers per taxi	1.05	1.06	1.43	1.63	2.00	1.75	1.00	1.17			1.00	2.00	1.31

Table A3. Number of Passengers Per Taxi by Location

		CGV Dunsan		Yuseong		Sun		Daejeon		Eunhang-Dong		Daejeon		SeoDaejeon		Homplus		E-mart		Hanbit		Daejeon Grand	
		Movie Theater		**Hotel**		**Hospital**		**City Hall**		**Shopping District**		**Train Station near Subway**		**Train Station**		**Shopping Mall**		**Shopping Mall near Subway**		**Apartment Complex**		**Park**	
		Off-peak	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak	Peak
Arriving	1 passenger car	3	6	1	0	2	4	3	2	4	21	3	36	8	5	2	1	0	1	0	1	0	0
	2 passenger car	0	2	0	0	0	0	1	0	3	3	1	4	0	1	0	0	3	3	0	0	0	0
	3 passenger car	0	1	0	0	0	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
	4 passenger car	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Arriving Passengers		3	13	1	0	2	7	5	2	10	36	5	44	8	7	2	1	6	7	0	1	0	0
Total Arriving Taxis		3	9	1	0	2	5	4	2	7	27	4	40	8	6	2	1	3	4	0	1	0	0
Departing	1 passenger car	7	13	1	3	0	7	2	1	3	17	66	54	13	10	3	3	2	5	7	9	0	0
	2 passenger car	0	2	0	0	1	2	0	0	2	7	16	20	1	0	1	3	1	5	0	2	0	0
	3 passenger car	0	3	0	0	0	0	0	0	0	6	3	4	0	0	1	1	2	2	0	0	0	0
	4 passenger car	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Departing Passengers		7	26	1	3	2	11	2	1	7	49	107	106	15	10	8	12	10	21	7	13	0	0
Total Departing Taxis		7	18	1	3	1	9	2	1	5	30	85	78	14	10	5	7	5	12	7	11	0	0
Arriving & Departing	1 passenger car	10	19	2	3	2	11	5	3	7	38	69	90	21	15	5	4	2	6	7	10	0	0
	2 passenger car	0	4	0	0	1	2	1	0	5	10	17	24	1	1	1	3	4	8	0	2	0	0
	3 passenger car	0	4	0	0	0	1	0	0	0	9	3	4	0	0	1	1	2	2	0	0	0	0
	4 passenger car	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Passengers		10	39	2	3	4	18	7	3	17	85	112	150	23	17	10	13	16	28	7	14	0	0
Total Taxis		10	27	2	3	3	14	6	3	12	57	89	118	22	16	7	8	8	16	7	12	0	0
Average		1.00	1.44	1.00	1.00	1.33	1.29	1.17	1.00	1.42	1.49	1.26	1.27	1.05	1.06	1.43	1.63	2.00	1.75	1.00	1.17	0.00	0.00