RATIONALIZING AUTOMOBILE PARK-AND-RIDE ACCESS TO BUS TRANSIT FOR SUBURBAN CUSTOMERS

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ABSTRACT

To save time and money, some urban commuters drive themselves a few miles (kilometers) to specially designated parking lots built for transit customers and located where trains or buses stop. The focus of this paper is the effect Park-and-Ride (P&R) lots have on the efficiency of bus transit.

This study describes a series of probes with models and data to find objective P&R influence measures that, when combined with other readily-available data, permit a quantitative assessment of the significance of P&R on transit efficiency. The authors developed and describe techniques that examine P&R as an influence on transit boardings along an entire route.

In a King County, Washington case study, quantitative evidence was found that the bus routes with higher productivity (measured by boardings per service hour) are associated with P&R facilities to a greater degree than routes with lower productivity.

As an example of financial impact, 53 suburban Seattle bus routes of King County Metro were examined where the strongest influence on boardings per revenue hour was found within the data set. Calculations show that 50 thousand transit service hours, worth $17 million, are saved annually – ten percent of annual operating costs for this sub region – because passengers are picked up at P&R facilities instead of at bus stops not at P&R lots.

The authors also illustrate that reasonable daily parking charges (compared to the cost of driving to more expensive parking downtown) would provide sufficient capital to build and operate new P&R capacity without subsidy from other revenue sources.

Keywords: public transportation, bus public transit, park-and-ride, multimodal facilities, quantitative analysis, regression analysis, geographic information systems

INTRODUCTION

Across the United States, park-and-ride (P&R) lots with frequent bus service to urban employment centers have proven to be very popular. Such facilities are often filled to capacity on workdays. At the same time, the very idea of P&R has been criticized by transit advocates because government-funded construction and operation of parking at transit centers is perceived as an expensive way to increase transit ridership. P&R is also viewed as problematic because it encourages commuters to use their automobiles instead of more environmentally benign forms of transportation.

As a contribution to a deeper understanding of where P&R fits into an urban regional system of public transit, this study explores the effect on bus system operations of the drive-and-park-and-ride means of transit access and its fiscal implications. Transit's economic efficiency is defined as the number of riders per unit of transit resource, in particular, as passenger boardings per vehicle hour in revenue service.

As part of a larger study funded by Mineta Transportation Institute using data from three transit agencies in Washington State and two transit agencies in California (Project 1401, "Bus Transit Operational Efficiency Resulting from Passenger Boardings at Park-and-Ride Facilities" by the authors of this paper, in press), the investigators examined in detail the bus transit system in King County, Washington, the heart of the Seattle region. The other four systems examined produced findings consistent with those reported here, although the efficiency effect was not as strong as in the case reported here.

King County buses (including buses contracted by Sound Transit) carry around 100 million passengers annually. Per capita annual bus ridership (boardings divided by the two million population of the transit service territory) in King County is 50.

The study did not consider many of the policy choices faced by regional transit leaders, such as where to establish bus routes and P&R facilities, the setting of fare levels, or the authorization of financial and nonfinancial incentives for commuters to use transit. While such policies may significantly impact bus transit ridership, they are outside the scope of this study.

LITERATURE REVIEW

Park-and-ride should be viewed in the overall context of public transit in the U.S., which is subsidized by governments with a view toward providing affordable transportation for people who cannot afford a car or are physically unable to drive, and also because it is a mode of transportation that has smaller adverse environmental effects, a view well-stated by Duncan and Cook *(1)*.

P&R fits most clearly with the environmental rationale. However, there is a widespread perception that P&R is not compatible with zones of transit-oriented development, because P&R promotes use of automobiles, contrary to a major objective of Smart Growth and transit-oriented development. Yet this perceived incompatibility is not strictly true. P&R promotes short driving trips over long driving trips. P&R increases vehicle use in less congested suburbs and reduces vehicle use in more congested downtown areas. P&R also promotes short driving trips over greater expansion of costly transit to support picking up dispersed commuters. P&R facilities serve to aggregate riders so that transit can work with greater efficiency in low-density suburbs. As pointed out by Reid Ewing, "…the service area for a transit station or stop with a park-and-ride facility is on the order of 400 times greater than the service area based on walk access alone *(2)*." Ewing's geometric calculation corresponds precisely to comparing a typical quarter-mile (400 meters) nominal walking range for a bus stop to a five-mile (8 kilometer) vehicle movement radius around a P&R passenger access point.

Suburbanization and areas of relatively low density continue expanding in the United

States generally, as revealed by recent U.S. Census estimates *(3).*The locations of the greatest growth are widely dispersed outside the higher-density central city areas, creating a challenge in providing transit service to and between the zones of high growth. Given the distribution of many urban residents in low-density suburbs and the concentration of jobs to denser parts of the region, P&R may be an economically attractive form of commuting. Invariably, there are many suburban residents who are not within walking or cycling distance of fast, frequent transit service to job centers. However, residents with cars and jobs in central places served by transit are able to drive to transit stations and centers with parking lots and leave their vehicle there during the workday.

While increasing transit ridership is usually an important goal for transit agencies, increasing ridership per dollar of expenditure is paramount. Transit agencies able to increase ridership per operating dollar are, in effect, reducing the public subsidy per rider.

The cost comparison of P&R with bus pickup at local stops in a low-density suburb is relatively straightforward. One can compare the cost of (a) providing parking places for transit customers coming (typically in the usual morning commute period) from a series of first origins to a single P&R point of pick up against (b) the cost of a transit vehicle traveling additional hours to reach a series of dispersed bus stops to which travelers walk or are chauffeured from first origins.

The analysis is more complicated if one considers that some potential customers will not ride the bus if only P&R service is provided, and others will not ride the bus if boardings are supported only at neighborhood bus stops. A much more involved calculation is required if one looks at the economics from an overall societal point of view, where the costs of providing transit overall to this region need to be factored in, including the costs of commuters simply using their private vehicles instead of riding the bus.

The benefits of P&R facilities have motivated implementation worldwide. For example, the American Public Transportation Association reports that there are 210,000 P&R spaces in 360 U.S. cities as of January 2012 *(4).*These facilities are not necessarily owned by transit agencies; for example, the State Departments of Transportation in California and in Washington own some P&R lots. A survey of European cities by Dijk and Montalvo *(5)* found moderate or extensive adoption of P&R in cities of the United Kingdom, Netherlands, Germany, Switzerland, Norway, Finland, Czech Republic, Austria, and Poland.

Several aspects of P&R have been systematically investigated in previous work. Research has been carried out on the optimal location of P&R lots to attract the largest number of users *(6)*. Work has also been done to measure benefits to commuters and to the environment from reductions in VMT and emissions *(1)*. As summarized in a policy guidance document from the U.S. Environmental Protection Agency, "In developing and implementing fringe park-and-ride facilities, an assessment of the air quality impacts should be undertaken which looks at the emission reductions expected due to VMT reduction balanced against cold start emissions which are not eliminated and options for reducing auto trips altogether *(7)*." The environmental damage from the cold-start phase of a trip from home to a P&R lot a few miles (kilometers) away is likely to be mitigated in the future as electric hybrid and battery vehicles become more widely used *(8)*. This mitigation of environmental damage is especially likely in California and other states with zero-emission vehicle goals set by regulation, and will become more widespread under the 54.5 mpg Corporate Average Fuel Economy (CAFE) goal for year 2025 new cars set in regulations issued by the Obama Administration *(9).*

However, remarkably little attention has been given to the measurement of park and ride impact on the operational productivity of the public bus lines that serve these lots *(10,11,12).* A key reference on P&R, *TCRP Report 95*, Chapter 3, alludes to the productivity yielded by P&R facilities as a collector of customers by noting the following objective: "Concentrating transit rider demand to a level enabling transit service that could not otherwise be provided." The report goes on to describe that "…in many low-density areas, without park-and-ride facilities and service, no attractive public transit could be effectively operated *(6)*." This objective clearly hints at the importance of attracting enough riders to make transit service a reasonable expenditure of public resources in suburban jurisdictions.

In this research the authors focus on the narrower issue of which of two modes of passenger collection is better – driving buses on suburban routes to a large number of bus stops near the home locations of dispersed customers versus picking up these same customers from a place that they have brought themselves to in their private vehicles.

DATA USED TO ESTIMATE PARK-AND-RIDE IMPACT ON TRANSIT EFFICIENCY

The study focused on bus ridership during morning commute hours. The types of data used in this study are comprised of data in Geographic Information Systems (GIS) layers, files of ridership and cost data by route, boardings at each stop, characteristics of each route such as length and speed, and demographic and economic data about areas near bus stops. GIS and related data on Census tracts, Census block groups, and Census blocks comes from the U.S. Census Bureau as part of the American Community Survey (ACS) and the 2010 Census. GIS data on bus routes, bus stops, P&R lots, boardings, and route efficiency data come from the transit agencies. Data from the U.S. Census Bureau employ a consistent methodology. Data from transit agencies differ in terms of the detail and completeness with which they are provided.

Variables

Variables are usefully divided into outcome variables (dependent variables in a regression equation) and explanatory variables (independent variables in a regression equation). Each type of variable can also be characterized as a route-level variable, a stop-level variable, or a neighborhood-level variable. Route-level variables are always classified by route number, direction (e.g., "inbound" or "outbound"), and time of day. Stop-level variables may sometimes also be identified by route number, direction, and time of day. Some stop-level variables may be characterized by proximity to another feature (e.g., to a P&R lot, to an employment concentration, or to a residential concentration). Neighborhood-level variables are variables associated with areas such as buffers of a given radius around stops or P&R lots, Census block groups, or Census tracts.

For example, the authors construct quarter-mile (400 meter) buffers around stops. This distance is typically considered the maximum range a typical potential bus rider is willing to walk to ride a bus. Neighborhoods consisting of buffers around stops or P&R lots can be associated with stop-level variables or route-level variables. Neighborhoods consisting of buffers around routes can be associated with route-level variables.

Dependent Variable

- Boardings per revenue hour (route-level])

Independent Variables

- Number of stops along a route (route-level)
- Speed (velocity) of bus along a route (route-level)
- P&R Influence (route-level)
- Residential Density (stop-level)
- Number of routes serving a stop (stop-level)

- Distance to nearest P&R lot (stop-level)
- P&R lot characteristics (e.g., number of spaces, stop-level or route-level)
- Demographic and economic characteristics (such as number of works, population density, and income) of a buffer around a stop (stop-level or route-level)

The P&R Influence variable (route-level) can be formulated to include P&R characteristics, such as number of spaces.

Several of the variables mentioned above were created using a GIS program. For example, residential density within a quarter mile of a bus stop was created by first determining quarter-mile buffers (rings) around each stop and then intersecting the quarter-mile buffers with Census Block data on population. Likewise, measures of median income and employment within a quarter mile of a stop were computed by intersecting the quarter-mile buffers with the relevant American Community Survey data for Census Block Groups.

The main outcome variable for route-level analyses is *boardings per revenue hour*. Determinants of the outcome variable include length of route, speed of the bus along the route, and the number of stops along the route. Data that are inherently neighborhood-level or stop-level are converted into route-level data in a manner discussed below.

Since focus of route-level analysis is a key route performance measure (boardings per revenue hour), the regression model seeks to explain boardings per revenue hour as a function of various independent variables.

$$Boardings\ per\ Revenue\ Hour_r = \beta_0 + \beta_{SPEED} SPEED_r + \beta_{PRI} PRI_r + \beta_{ServType} SERVTYPE_r + \epsilon_r$$

Where:
r is the route number;
β_0 is a constant;
β_{SPEED} is the coefficient on the speed (velocity) of the bus along route r;
$SPEED_r$ is the speed of the bus along route r;
β_{PRI} is the coefficient on the P&R Influence variable along route r;
PRI_r is the P&R Influence variable along route r;
$\beta_{ServType}$ is the coefficient on service type along route r;
$SERVTYPE_r$ is the service type (e.g., “limited”) along route r;
ϵ_r is an error term.

REGRESSION RESULTS

Several variables above have been called “influence” variables, most notably the P&R Influence variable. These influence variables arise from using neighborhood or stop-level data in a route-level analysis. P&R lots are associated with catchment areas about which the authors have some demographic and economic data.

Likewise, specific stops can be associated with a P&R lot (say, those stops within walking distance of it). Stop-level data provides us with boardings by stop and by route. For a specific route, the authors can determine the fraction of total boardings along the route (at a particular time and in a particular direction) that arise from stops associated with a P&R lot. This would allow us to construct a variable associated with the route that represents the total fraction of boardings at a particular time and in a particular direction that arise from stops close to P&R lots.

King County Metro Overall Results

In an initial look at King County Metro bus across its entire urban and suburban service territory, the influence of Park-and-Ride as measured by the total number of spaces at P&R lots that a bus passes turns out to be statistically significant. The authors incorporate a quadratic term in the P&R variable to account for any nonlinearities. Other variables include the speed of the bus and a dummy variable for the type of service. All the coefficient estimates are statistically significant (using robust standard errors) and are of the expected sign. The result is given in Table 1.

TABLE 1 Route-Level Regression for King County Metro

```
. regress BoardingsperRevHr MPH TotalREG_SPACES TotalREG_SPACES_Sqrd SeattleCoreDummy, robust

Linear regression                               Number of obs     =        177
                                                F(4, 172)         =      40.06
                                                Prob > F          =     0.0000
                                                R-squared         =     0.4529
                                                Root MSE          =     17.107
```

BoardingsperRevHr	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
MPH	-1.083738	.3519573	-3.08	0.002	-1.77845	-.3890265
TotalREG_SPACES	-.022046	.0101466	-2.17	0.031	-.0420739	-.0020182
TotalREG_SPACES_Sqrd	.0000143	6.06e-06	2.36	0.019	2.35e-06	.0000263
SeattleCoreDummy	25.00968	2.82017	8.87	0.000	19.44308	30.57628
_cons	53.88109	4.879703	11.04	0.000	44.24928	63.5129

The service to the Seattle core has about 25 more boardings per revenue hour than non-Seattle core service, other factors held constant. A decrease of one mile per hour on the bus route decreases boardings per revenue hour by about one.

The effect of the total number of P&R spaces along the route is harder to interpret, because the variable enters as a quadratic. To determine the marginal effect of one additional space along the route, the quadratic is graphed as a function of total spaces in Figure 1.

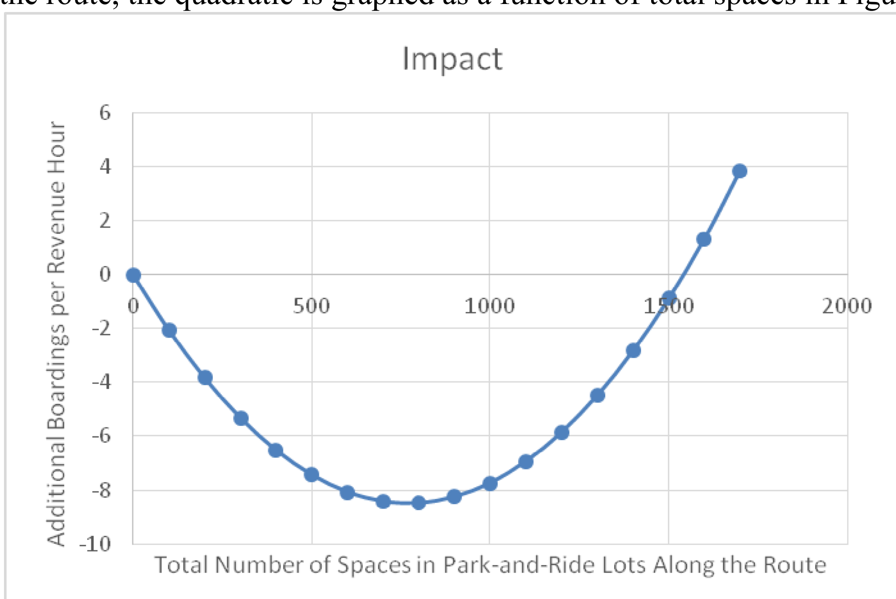

FIGURE 1 The Marginal Effect of Park-and-Ride Capacity for King County Metro

So, roughly, P&R capacity has a positive effect when the bus route passes P&R lots with a capacity of about 1,500 or more. The routes in the Seattle area that have P&R capacity of 1,500 and above are in the bus routes numbered 200, that is, those that serve the Eastside suburbs of

Seattle. These routes are analyzed separately and in more detail next.

Focus on P&R effects in suburbs East of Seattle

P&R is an important form of transit access in the Seattle suburbs. Sixty-two percent of suburban transit customers east of Lake Washington used P&R in the last 30 days before the date of a 2014 survey. Thirty-nine percent of surveyed customers across all parts of the greater Seattle service area used P&R *(13)*. The regional Metropolitan Planning Organization, Puget Sound Regional Council, reports that since 2010, “Park and Rides fill earlier and more frequently *(14)*.”

Figure 2, a Metro route map with the City of Seattle on the left and the Eastside suburbs on the right, shows all the Metro bus stops in this part of the territory that experienced over 250 boardings in the morning peak period in spring 2014. Green numbers are morning boardings divided by 10. Across Lake Washington, east from the City of Seattle, large P&R facilities are prominent among highly used suburban bus stops, with parking capacities shown in red.

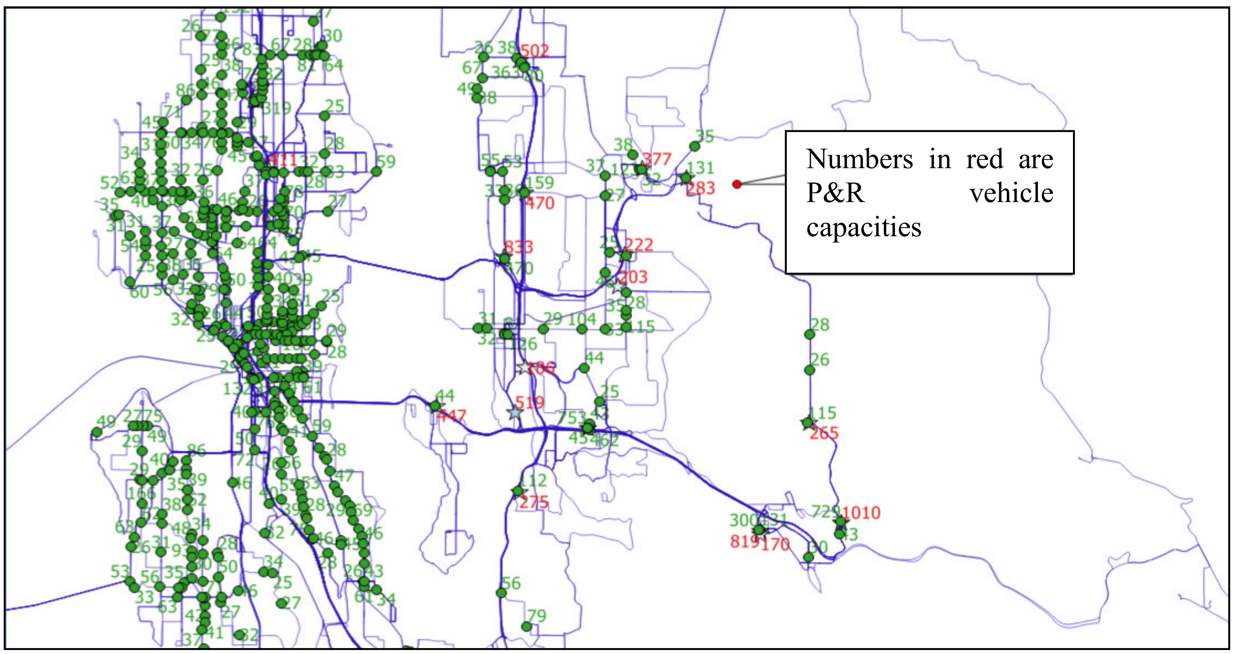

FIGURE 2 Seattle and East King County Bus Stops with More Than 250 A.M Peak Boardings

The authors chose the 53 King County Metro Eastside routes as the target for exploration of P&R influence on productivity because of data availability and the authors’ personal knowledge that P&R is well used in this part of the Puget Sound region. Also, there is evidence from the analysis noted above in this paper that the routes serving the Seattle eastern suburbs are those most influenced by P&R availability. Most of the P&R lots in this sector are filled to capacity before the morning peak period is over. The authors’ data included the 200 series of Metro routes; eight Sound Transit 500 series regional routes operated by Metro under a contract with the Sound Transit multi-county regional transit agency; and one of Metro’s arterial BRT routes, RapidRide B in the City of Bellevue.

As before, boardings per service hour are selected as the productivity performance measure. The focus is on analyzing morning peak inbound runs from residential areas to urban centers as a likely indicator of all-day P&R influence, since the typical and overwhelmingly common pattern of usage is all-day parking beginning in the morning.

The authors sought out how to measure the influence of P&R on ridership of each particular route in a more precise way than that used in the study of all the King County Metro routes, described above. The focus was on the morning peak direction, meaning from lower-density residential areas toward employment centers such as downtown Seattle, downtown Bellevue, and the University of Washington main campus. The authors started by simply creating a dummy variable: routes that went by P&R lots were coded as "1" and those that did not as "0." While using this dummy variable picked up some influence, at the urging of King County Transit staff the authors dug deeper to measure the percentage of ridership on a route that is collected at the bus stops next to P&R facilities, which was then set as the P&R Influence Variable. That number could range in theory from zero if the route did not serve any P&R lots, to 100 percent if all the passengers on a route boarded at the parking lot. In fact, after examining boardings at every P&R lot, this measure ranged from zero to 97 percent. Twelve of the 53 routes in the data set did not pass by significant P&R facilities. Forty-one routes passing by P&R facilities of more than 100 spaces had influence measures between two percent and 97 percent. Table 2 shows examples of the value of the P&R influence variable for some of the 53 Routes.

TABLE 2 Examples of Park-and-Ride Influence Variable Coding for KCM Routes

Route	Coding	Route	Coding	Route	Coding	Route	Coding
200	0.00	218	0.86	243	0.00	271	0.14
201	0.00	219	0.67	244	0.26	277	0.32
202	0.17	221	0.00	245	0.02	522 (ST)	0.49
203	0.00	224	0.18	246	0.00	540 (ST)	0.58
205	0.25	226	0.00	248	0.22	542 (ST)	0.59
208	0.00	232	0.36	249	0.10	545 (ST)	0.60
209	0.02	234	0.17	250	0.00	550 (ST)	0.52
210	0.61	235	0.30	252	0.47	554 (ST)	0.84
211	0.61	236	0.03	255	0.38	555 (ST)	0.75
212	0.97	237	0.40	257	0.42	556 (ST)	0.74

Metro staff mentioned that the influence being measured would also blend in customers who did not drive a vehicle to the P&R lot, but rather walked from nearby housing, or rode a bicycle. In fact, Metro has lately been pursuing a policy of encouraging transit customers to arrive with passengers in their vehicle. This point slightly obscures the influence of car drivers using P&R lots compared to other ways of arriving, but the main point is the aggregation of customers ready to ride at a limited number of places, no matter how they reach the collection points.

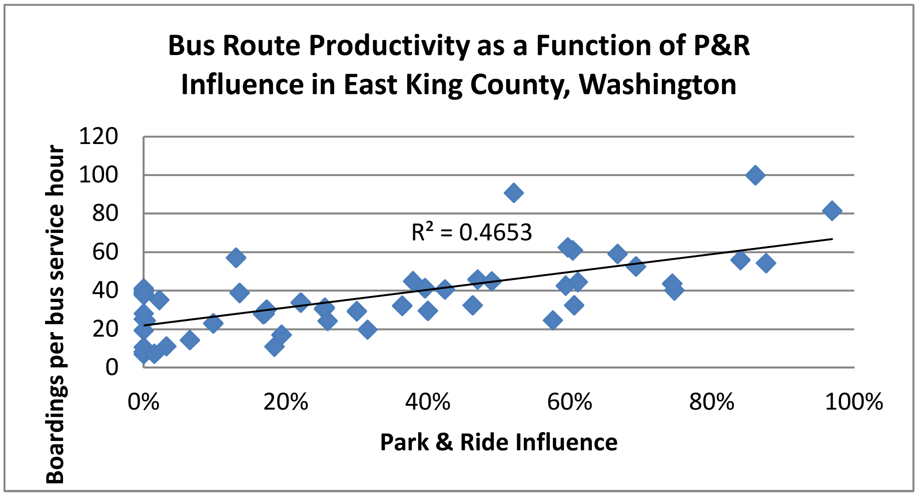

FIGURE 3 Bus Route Productivity in East King County, Washington

The simple correlation of the P&R influence variable with the productivity measure is 0.68, and P&R influence alone explains 47% of the variation in boardings per service hour, as shown in Figure 3.

In order to explain more of the influences on boardings per service hour, the authors experimented with adding other variables into a linear regression model using ordinary least squares. Through trial and error, they found two other variables for a linear equation that estimates annualized peak period boardings per revenue hour. The additional variables are all-day boardings per route mile and bus stops per mile over the entire route of the bus.

The authors expected all-day boardings per route mile to push up boardings per service hour since this is a simple measure of ridership proportional to the length of the route. Bus stops per mile were expected to drive down boardings per service hour, because small numbers of passengers spread over many bus stops would tend to slow the speed of the bus. In the case of both variables, this is how the equation turned out.

When the authors ran all three of the variables in a linear regression calculation, the adjusted R-squared equaled 0.90 with all the coefficients of the equation statistically significant at p<.01 and the constant significant at p<0.1.

The model developed for the 53 King County Metro routes was as follows:

$$\begin{aligned} & Annualized\ peak\ period\ boardings\ per\ hour \\ & \quad = \beta_0 + \beta_1(AM\ Park-and-Ride\ Influence\ Fraction) \\ & \quad + \ \beta_2(All-day\ boardings\ per\ route\ mile) \\ & \quad + \beta_3(Stops\ per\ mile\ over\ entire\ route) + \epsilon \end{aligned}$$

Where
$\beta_0 = 7.9$, $\beta_1 = 16.6$, $\beta_2 = 15.5$, and $\beta_3 = -2.4$.

The constant can be considered to provide an estimate of other undetermined influences on bus service productivity as measured by boardings per service hour.

Economic Benefits of Higher Productivity from Transit Access at P&R Lots

Going further, the authors realized that the model of P&R influence on the productivity measured in boardings per bus service hour permits a calculation of what P&R is worth in dollar terms as a means of aggregating passengers.

The coefficient on P&R influence, when multiplied by the value of the influence variable for each route, represents the marginal P&R contribution to boardings per service hour.

Here is an example of how the model equation can be interpreted for one route: for Metro route 210, with P&R generating 61% of the morning peak customers, the data reveal that this line achieved 44.5 boardings per service hour across 2,288 service hours in a year. The marginal influence of P&R from the coefficient of 16.6 on P&R influence in the regression estimation is 10.2 boardings per service hour, that is, 16.6 times 61%. These 10.2 boardings per service hour over the course of a year is equivalent to saving 678 service hours.

This is proved by calculating that the actually achieved 2,288 hours X 44.5 boardings per hour is equal to (2,288 hours + 678 hours) X (44.5 boardings per hour – 10.2 boardings per hour). In other words, a service hour consumption 678 hours above the actual when multiplied by a boardings per hour number that is 10.2 boarding per hour lower yields the same actual boardings number that is the product of the actual 2,288 hours and the actual boardings per hour of 44.5.

For this one Metro route, when 678 hours of saving is multiplied by the $262-per-service-hour operating cost of route 210, the annual dollar savings for this one route from P&R -influenced operations is $178,000.

The contribution of the 41 routes sums to 49,562 service hours saved in reaching the overall ridership achieved. The multiplication of the service hours array for the 41 routes where there is P&R influence multiplied by the cost per hour array for the same 41 routes yields an array of cost savings that sum to approximately $17 million.

Summing across all the routes, 49,562 service hours are saved annually by the 41 routes out of 53 stopping at P&R facilities. These hours are worth $17 million using available Metro cost data. In other words, if the beneficial impact of the P&R facilities were not present, instead of $95 million actually spent, $112 million in service hours would be spent on the 53 routes. The $17 million difference is 15% of $112 million.

This theoretical saving would be realized to the degree that existing service to customers by operating buses through dispersed neighborhoods were replaced with more service from P&R facilities. On the margin, bus VMT would be reduced, because the buses would have fewer miles traveling in residential areas. Private vehicle VMT would rise as more bus customers drive to P&R facilities rather than wait to be picked up by a bus closer to home. The public policy trade-off of reduced public transit VMT for more private VMT would have to be considered in assessing the public costs and benefits of emphasizing P&R-based service.

CONCLUSIONS AND IMPLICATIONS

The authors have developed through this research some quantitative methods to link the existence and influence of P&R facilities to transit performance measures, in particular, boardings per service hour. As the proportion of riders on a bus coming from P&R facility rises, it appears from this evidence that in some agencies, boardings per revenue hour rise. The authors showed this in four case studies out of five in the Mineta Institute Study. There was evidence of potential for savings in three Seattle area bus systems, and with Los Angeles Metro. The result was not so clear for a fifth agency, Santa Clara Valley Transportation Authority serving San Jose, California, but neither was the opposite found.

P&R service, including the effect of customers who arrive at P&R collection points by other means than a parked car, can thus be more cost-effective in generating bus ridership in a suburban setting than service that does not take advantage of P&R.

Where the P&R differential influence can be shown, the quantified measure of economic benefit for the operations of a transit agency may spur management interest in expanding and improving P&R service to grow transit ridership within the market of frustrated commuters who seek but cannot find space to park in P&R lots, as the authors showed for a set of suburban routes of King County Metro. At the same time, the strong demand for P&R suggests customers may be willing to pay for it, especially if high-quality amenities were to be included, such as guaranteed access to a parking spot in the lot, a short walk to the bus, and a guaranteed seat on the bus *(15)*.

Transit agencies often view P&R as an expensive source of riders. For example, transit officials in Seattle mention a range of thirty to fifty thousand dollars to build each structured parking space. Non-motorized access, for example, walking and bike access from close to where the bus stops, is better for the environment than driving from farther away. However, given the reality of how urban regions disperse, and given the popularity of P&R, agency and societal objections to a supply of parking spaces that keeps up with demand can perhaps be mitigated. That this type of access can be shown to have a quantifiable financial benefit from increasing the productivity of bus service is a useful first step in mitigation.

Additional elements of mitigation for sustainably expanding P&R include the following:

•Give special treatment for smaller, cleaner cars, to motivate purchase of such vehicles by transit customers. The pollution, safety, and congestion negatives of cars are subject to extensive regulation-driven mitigation via improved technology over the coming decades *(9)*.

•Require users to pay to park in exchange for receiving additional amenities, like a parking space closer to the bus stop and a guaranteed seat on the bus. In Seattle, P&R parking has been traditionally free; in California, there is a mix of free and paid parking across P&R facilities.

•Provide incentives for vehicles with multiple passengers.

Although transit agencies may not be in a position to fund P&R expansion out of their current funding stream, the authors note that customer parking fee payments providing a return on private investment capital for expanded P&R construction is a potential mechanism for more capacity on the urban fringe.

The authors have created a parking fee estimator *(16)* that calculates a total daily fee to cover the repayment of a construction loan plus a daily maintenance fee for a structured parking space such as would be found in a new P&R facility. For example, assuming $30,000 borrowed at 5% interest over 30 years to construct a parking space and $500 per year to manage and maintain it, including cleaning, security, and daily parking fee collection, the fee estimator shows that a daily fee of $10.24 would cover costs over 250 annual work days at 95% occupancy. The fare to ride the bus is not included. Because a price to park at this level may be a shock compared to a previous environment of free or nominally priced parking, this level would only work if it provided a significant discount from downtown parking fees, and furthermore supported features such as watchful security preventing car break-ins and guaranteed seating on the bus.

Other assumptions can be tested, and the authors have found that the parking fee under a range of assumptions is likely less than the price of parking in a city downtown such as Seattle. Of course, to attract customers, the P&R fee combined with the transit fare would have to provide an attractive alternative to competition from private vehicle modes that have a price defined by many exogenous component price levels beyond parking, such as for gasoline or for fees to join a car pool. At the same time, even assuming the commuter does not have regular passengers that would allow driving in a high-occupancy vehicle lane (HOV), there are a host of other real-world conditions that bear on commuters' decisions beyond comparing the cost of parking on the fringe of an urban area versus close by an employment-site destination. For example, a traveler may simply prefer the environment sitting in her car, despite driving in congestion, compared to the environment of sitting or standing on a bus. She may also make accustomed intermediate stops traveling to or from work that are easier to make in a private vehicle than in a multi-stop transit trip.

At the same time, the authors acknowledge that other approaches to transit access work well in some markets, for example, walkable transit-oriented development with bicycle access. However, low-density suburbs exist and cannot be picked up and moved. This paper shows a financially sustainable, transit-supportive way to deal with the reality of suburban, car-oriented development beyond the transit-oriented-development market segment.

In conclusion, the authors recommend transit agencies consider engage in analysis aimed at staff understanding and quantifying the economic benefit of P&R to the operations for transit agencies, especially those that can choose whether to provide more or less service via P&R. Available quantitative information collected by transit agencies likely permits this to be accomplished, which (as shown in this paper) can have operational benefit.

SUGGESTIONS FOR FURTHER RESEARCH

The similarities across the findings in King County and in four other West Coast agencies suggest that there may be more to learn by analyzing P&R usage for bus system efficiency in other urban regions of North America. The methodologies in this study could be applied to any other urban region where data is available to enrich the level of understanding of how aggregating transit customers at P&R facilities generates operational efficiencies in transit operations.

In particular, it would be interesting to locate a public transit agency in North America or Europe where P&R is encouraged with the supply of parking spaces managed for all-day availability through ample supply responding to growth in demand, and by pricing. Then researchers should examine boardings per service hour in both peak and off-peak periods throughout the day.

As of 2016, there is a growing number of small-vehicle alternatives available to commuters in new forms of commercially offered, smart-phone-enabled car-sharing, ride-sharing, and internet-dispatched ride services that in principle can be used by travelers to reach transit hubs with frequent bus service. The claim has been made that these services are ideal for building transit ridership without adding all-day parking at hubs. This hope should be subject to measurement to validate the potential for public policy encouragement and support because of beneficial influence on boardings per service hour *(17)* like found here for park-and-ride facilities.

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