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Bus Transit Operational Efficiency Resulting from Passenger Boardings at Park-and-Ride Facilities

MTI Report 12-60

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REPORT 12-60

BUS TRANSIT OPERATIONAL EFFICIENCY RESULTING FROM PASSENGER BOARDINGS AT PARK-AND-RIDE FACILITIES

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16. Abstract

In order to save time and money by not driving to an ultimate destination, some urban commuters drive themselves a few miles 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 as measured in five bus transit systems in the western U.S.

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 at bus stops and on bus boardings along an entire route.

The regression results reported are based on the two in-depth case studies for which sufficient data were obtained to examine (using econometric techniques) the effects of park-and-ride availability on bus transit productivity. Both Ordinary Least Square (OLS) regression and Poisson regression are employed.

The results from the case studies suggest that availability of parking near bus stops is a stronger influence on transit ridership than residential housing near bus stops. Results also suggest that expanding parking facilities near suburban park-and-ride lots increases the productivity of bus operations as measured by ridership per service hour. The authors also illustrate that reasonable daily parking charges (compared to the cost of driving to much more expensive parking downtown) would provide sufficient capital to build and operate new P&R capacity without subsidy from other revenue sources.

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EXECUTIVE SUMMARY

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.[1]

This study uses data from three transit agencies in Washington State and two transit agencies in California. The investigators examine in detail bus transit systems in King County, Washington (Seattle region) and Santa Clara County, California (San Jose region). They inspect three other agencies in less detail: Los Angeles County Metro and two agencies serving the suburbs of Seattle.[2]

For the two agencies (serving Seattle and San Jose) where detailed boarding data were available, evidence from regression analysis indicates that P&R facilities near bus stops generate more ridership per stop than ones that are farther from bus stops. The authors also found evidence in these two systems, which have two distinct service and patronage levels, suggesting that additional car parking near bus stops is more cost-effective in generating ridership than additional residential density near the bus stops.

For four agencies out of the five, quantitative evidence emerged 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. In the transit agency serving San Jose, this relationship could not be found, although neither could a completely opposite relationship.

To provide an example of financial impact of P&R, 53 Seattle region suburban 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 50,000 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 located at P&R lots. This level of savings at the scale of operations found in this one example is sufficient economically to justify investment in expanded P&R facilities if greater operational efficiency in transit operations is an important criterion.

Transit agencies often view P&R as an expensive source of riders. One parking space yields one customer, and parking spaces can cost fifty thousand dollars each. However, given the reality of residential patterns in suburban North America, environmental objections to adding P&R spaces could be mitigated by having a quantifiable financial benefit for the transit agency from increasing the productivity of bus service.

Finally, the authors describe financial calculations illustrating that reasonable fees for customers of P&R would likely be sufficient to pay for constructing and maintaining the facilities where parking is provided. Of course, to attract customers, the P&R fee combined with the transit fare would have to provide an alternative to competition from private vehicle modes that is partially defined by exogenous price levels for motor vehicle fuel and for parking in employment centers that are customer destinations.

ORGANIZATION OF THE PAPER

The first section following this one, “Case Studies,” gives a snapshot of the five cases that we consider in this report. (Details of the five case studies appear in Appendix A.)

The next section of the paper, “Broad Policy Context of Park-and-Ride,” includes a discussion of productivity measures for bus transit services and the costs and benefits of P&R. That section also describes the broad policy implications of the present study.

The next section of the paper discusses Costs and Benefits of Park-and-Ride. This section discusses the trade-offs implicit in supporting transit using park-and-ride.

The next section of the paper, “Data Used to Estimate Park-and-Ride Impact on Transit Efficiency,” discusses the data employed in the analysis of transit systems and P&R and the econometric strategy for estimating parameters associated with P&R. Three types of analyses that correspond to three different sets of variables are employed: route-level analysis, stop-level analysis of boardings, and stop-level analysis of boardings per trip. The different types of analyses examine the same underlying phenomenon from different perspectives. (The connection between stop-level analysis and route-level analysis is developed in a heuristic example detailed in Appendix B.)

Route-level analysis employs *boardings per revenue hour* as the dependent variable; stop-level analysis employs both *boardings at a stop* and *boardings per trip at a stop* as the dependent variables (where the data permit the use of both variables). For stop-level analysis of boardings at a stop, both Ordinary Least Squares (OLS) regression results and Poisson regression are presented.[3] The rationale for and interpretation of the OLS and the Poisson regressions is discussed in greater detail in this section.

The discussion in the next section shows that the results of route-level and stop-level analyses of the two main cases are generally consistent, and the analyses of stop-level results show great consistency between King County Metro and VTA, both for OLS and Poisson regressions across various specifications of the P&R variables.

The next section after this is devoted to the additional case studies. The policy implications of these results are given in the penultimate section. The final section is conclusions and summary.

I. CASE STUDIES

We consider five case studies, each of which represents a different transit agency. A statistical overview of the case studies is given in Table 1. We develop detailed analyses of two of the cases for which we had the most complete data: King County Metro (Seattle) and Valley Transportation Authority (San Jose). The two cases we examine in detail are broadly similar to one another in service area population. Our other cases include small suburban systems near Seattle, and the Los Angeles Metropolitan Transportation Authority – a very large system.

Table 1. Statistical Overview of Case Study Agencies

Agency	Service Area Population (millions)	Annual Boardings (millions)	Passenger Miles (millions)	Vehicle Revenue Miles (millions)	Vehicle Revenue Hours (thousands)	Computed Average Speed (MPH) – vehicle revenue miles divided by vehicle revenue hours	Operating Cost/ Vehicle Hour	Operating Cost/ Boarding
Santa Clara Valley Transportation Authority	1.88	32	166	15	1,210	12.4	$186	$6.93
Los Angeles County Metropolitan Transportation Authority DBA: Metro	8.63	336	1,387	68	6,232	10.9	$143	$2.66
King County Department of Transportation - Metro Transit Division	2.04	98	484	32	2,679	11.9	$161	$4.41
Pierce County Transportation Benefit Area Authority	0.56	10	42	4	374	10.7	$132	$4.75
Community Transit (Snohomish County)	0.69	8	79	6	357	16.8	$239	$10.66
Central Puget Sound Regional Transit Authority	2.81	17	248	12	547	21.9	$194	$6.39

Table 1 summarizes basic operational data on the case studies from the National Transit Data Base for 2013; all motorbus routes considered.[4] King County buses (including buses contracted by Sound Transit) carry around 100 million passengers annually, while VTA buses carry around 32 million. These ridership numbers mean per capita annual bus ridership (boardings divided by population of the transit service territory) in King County is 50, while in the VTA territory, the annual per capita bus ridership is 18. Beyond buses, VTA includes 42 miles of light rail serving 10.7 million boardings annually, while the light rail in King County amounts to a single 17-mile route carrying 9.7 million per year.

Table 2 provides a brief outline comparison of Santa Clara County and King County based on data from the American Community Survey.[5]

COUNTY AND URBANIZED AREA COMPARISONS

Table 2. Comparison of Santa Clara County and King County

	Santa Clara County	King County
Population	1,812,208	1,974,567
Median Household Income	$91,702	$71,811
Total Employment	865,327	1,030,515
Population Density per Square Mile	10,599.37	7,919.26
Housing Unit Density per Square Mile	3,881.68	3,822.69

Santa Clara County and King County are broadly similar in some basic respects. They have approximately equal population, and the housing unit density per square mile is similar. However, in other respects the counties are quite different. Median household income in Santa Clara County is almost 28% greater than median household income in King County.[6] There are 19% more workers in King County than in Santa Clara County (although population is only 9% greater in King County than in Santa Clara County). Population density is almost 34% higher in Santa Clara County compared to King County, although housing unit density is very similar in the two counties. Other factors held constant, higher incomes can be expected to reduce ridership, while greater density can be expected to increase ridership. These suppositions are confirmed for both of the main case studies in the regression results we report below.

Table 3 compares the San Jose urbanized area with the Seattle urbanized area in terms of commuting to work.[7]

Table 3. Commuting Comparisons for San Jose and Seattle Urbanized Areas

Urbanized Area	Total Workers	MEANS OF TRANSPORTATION (Percent of Workers) Car, truck, or van	Car, truck, or van - Drove alone	Car, truck, or van - Carpooled	Car, truck, or van - Workers per car, truck, or van	Public transportation	Walked
San Jose, CA Urbanized Area (2010)	811,698	86.8	76.6	10.2	1.07	3.7	2
Seattle, WA Urbanized Area (2010)	1,572,387	78.9	68.7	10.2	1.08	9.4	3.9

Seattle has 18% more commuters than San Jose, but public transit use in Seattle is more than two-and-a-half times the rate in San Jose. The proportion of workers who walk to work is also about two times as great in Seattle as in San Jose.

TRANSIT SYSTEM COMPARISONS

The bus transit systems that serve King County Washington and Santa Clara County California are very different, as indicated in Table 4.

Table 4. KCM and VTA Transit System[8]

	KCM			VTA		
	Number	Per 100,00 Workers	Per 100 Square Miles	Number	Per 100,00 Workers	Per 100 Square Miles
Routes	221	14.06	21.88	88	10.84	30.80
Stops	8,076	513.61	799.47	3,971	489.22	1,389.98
Park and Ride Lots	130	8.27	12.87	40	4.93	14.00
Total Capacity of Park and Ride Lots	25,528	1,623.52	2,527.10	11,752	1,447.83	4,113.60

King County Metro (KCM) has more than two-and-a-half times as many bus routes, more than twice as many stops, more than three times as many P&R lots, and more than twice as many parking spaces in P&R lots as does the bus network of Santa Clara VTA. Overall, public transit is a more significant component of workers' commutes in the Seattle area than in the San Jose area. Transit resources are greater in Seattle compared to San Jose on a per worker (potential commuter) basis, but because the Seattle urbanized area covers a much greater area than the San Jose urbanized area, the resources per square mile are fewer in Seattle than in San Jose.[9]

The study did not consider many of the policy choices faced by regional transit leaders, such as choices about 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. For example, all of the jurisdictions covered in this study offer a level of employer-managed incentives such as discounted bus fares and guaranteed rides home for emergencies that come up for commuters who do not bring a personal vehicle to their employment site. While such policies may significantly impact bus transit ridership, they are outside the scope of this study.

II. BROAD POLICY CONTEXT OF PARK-AND-RIDE

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. This view is supported by Duncan and Cook.[10] Additionally, public transit is supportive of Smart Growth, meaning compact, relatively dense, walkable communities organized for pedestrian and bicycle access to transit for a high percentage of daily travel. Numerous regional public policy initiatives are meant to motivate Smart Growth and related policies.[11] Examples of public policy promoting Smart Growth and density include Plan Bay Area 2040[12] in the San Francisco Bay Area of California and Vision 2040[13] in the central Puget Sound region of Washington State.

The Smart Growth rationale ties into environmental improvement from emissions reductions brought about by lower use of automobiles in favor of transit. Reducing traffic congestion is sometimes considered by policy makers to be a motivation for supporting transit expenditures, although there is no direct evidence supporting a causal connection between more transit and lower road congestion. A more reasonable justification for transit is that it provides an alternative to driving in congestion.

P&R fits mostly clearly with the environmental rationale mentioned above. As concerns Smart Growth, 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. However, 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."[14] Ewing's geometric calculation corresponds precisely to comparing a typical quarter-mile nominal walking range for a bus stop to a five-mile vehicle movement radius around a P&R passenger access point.

There is a possibility of P&R usage causing Vehicle Miles Traveled (VMT) increases if travelers were motivated to switch from 100 percent transit use to a combination of transit and P&R access. Consider the theoretical example of a neighborhood well served by a bus line to downtown instead suffering the truncation of that bus line at a new P&R facility to which the bus riders would be forced to drive in order to access the bus. Private vehicle mileage rises in this case from zero to the sum of the new driving trips to the P&R facility. However, most studies of real world experience have associated P&R with VMT reduction (Turnbull, Evans, and Levinson 2004). How much reduction depends on how the P&R user would travel if the P&R facility were not available. The general case with P&R involves attracting suburban commuters having no easy bus access to convert from door-to-door private vehicle use to instead making trips in a multimodal combination of driving and bus riding, a commuting mode change that clearly reduces VMT.

Even with all the documented virtues of high-density living and transit-oriented development, many Americans now reside in low-density areas not within walking distance of transit. The sprawling residential neighborhoods on the fringes of most urban areas are likely to remain well spread out for the foreseeable future. In the meantime, (which may be a long time), policies should be pursued to operate transit as efficiently as possible.

Suburbanization and areas of relatively low density continue expanding in the United States generally, as revealed by recent U.S. Census estimates[15] and in the two example regions in particular.[16] As shown in the maps in Figures 1a and 1b, 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.

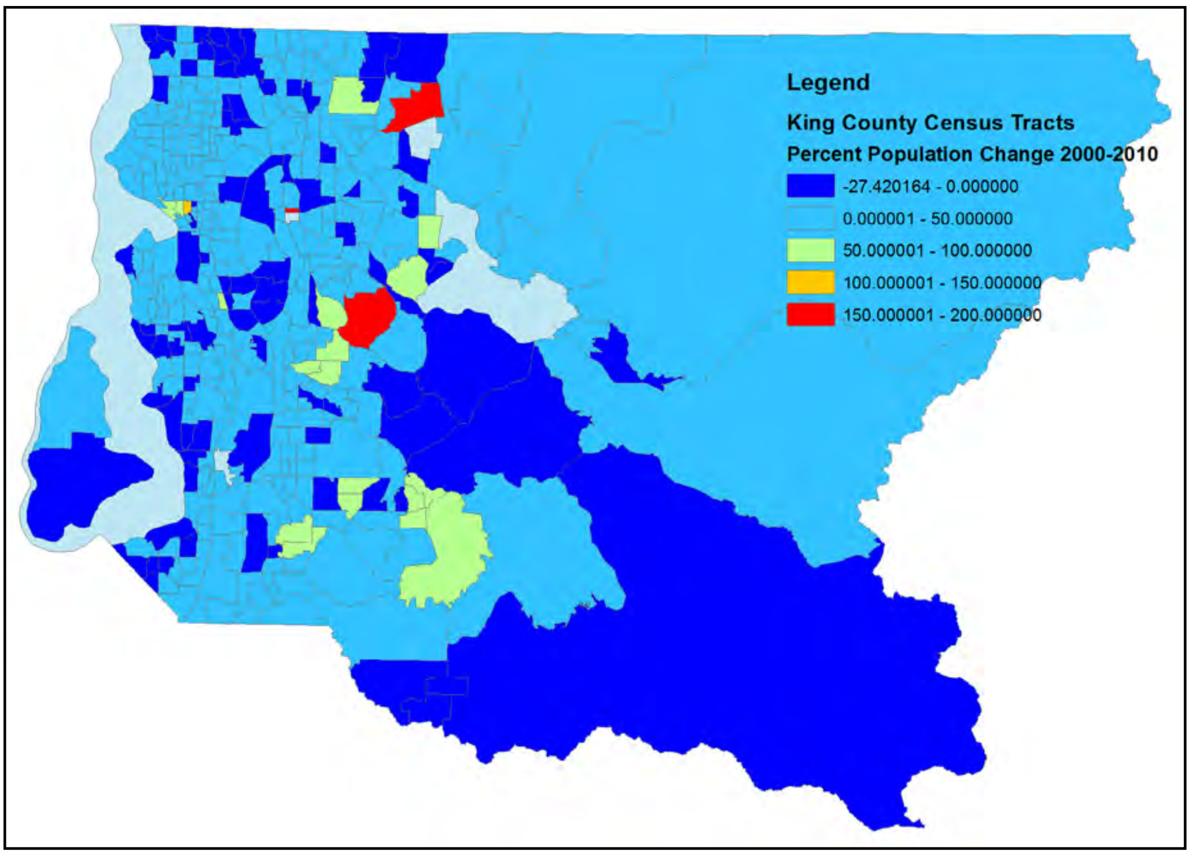

Figure 1. Population Growth 2000-2010 in King County

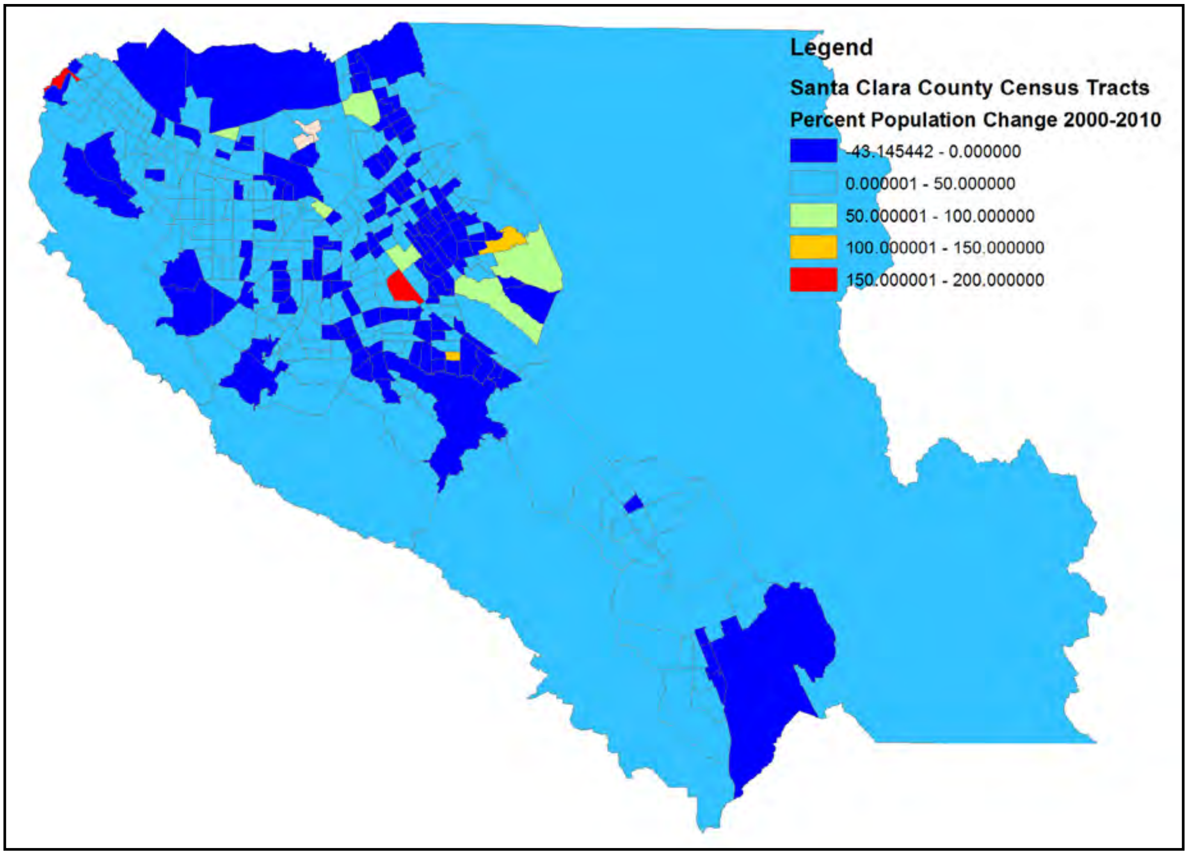

Figure 2. Population Growth 2000-2010 in Santa Clara County

Robert Spillar notes in his comprehensive guide to P&R,

> "Suburban park-and-ride lots, as the name suggests, are typically located at the outer edges of the urban landscape. The chief function of these lots is to collect potential transit patrons as close to their place of origin (their homes) as possible, and provide a transfer point to long-haul (often express) transit service. These facilities rely on the private automobile as the collection and distribution mode. They rely on trunk-line transit routes (bus or rail) to provide the long-haul aspect of the home-to-work trip. Suburban park-and-ride lots are typically funded by public investment, but can in some cases sustain private ownership."[17]

Spillar states further,

> "New park-and-ride facilities should be located adjacent to existing major transit corridors, where peak transit service can be provided with headways on the order of 15 minutes or less (10 minutes or less is optimal). Midday service can also be critical to generating high demand characteristics. Transit service should be oriented to the park-and-ride facility so as to minimize downstream transfers (i.e., the transit mode serving the park-and-ride facility should serve the primary activity center directly, without necessitating a transit-to-transit transfer). To achieve this goal, park-and-ride lots should be placed in proximity to the existing transit route structure within the given corridor." (Spillar 1997, 35, referring to Parsons Brinckerhoff Quade & Douglas, Inc. 1995)

While increasing ridership is important, 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.[18]

Consider this simplified cost analysis based on the "payback period" of an investment: the average operating cost of a bus in 2013 was $127 per hour according to the U.S. National Transit Data Base.[19] According to the same source, all across America in cities large and small, buses averaged 34 boardings per revenue hour of service. The cost of providing a parking space for a car ranges widely depending on cost of land and whether the parking lot is grass and gravel, paved, or in a structure. Structured parking around Seattle costs about $30,000 per space. As an illustration of marginal effect, the authors assume running a single suburban bus an extra hour in the morning and again in the evening would allow service directly to the neighborhoods of 34 suburban customers commuting to a central city district where they worked all day. For the 250 workdays in a year, the marginal bus cost is 250 days times two revenue hours per day times $127 per hour, or $63,500. At the same time, this extra expense would be eliminated if the 34 customers drove themselves to a P&R facility, because we assume the bus would have a shorter route to that place. For simplicity, assume that the bus passes by the P&R facility and continues on for more route distance in the case of traveling through the residential neighborhood. If the cost of providing parking were $30,000 per stall, then the 34 stalls would cost $1,020,000. Payback on that investment, if it came only from reduced bus operating costs in this simplified marginal analysis, would then be $1,020,000 divided by $63,500 or 16 years, well within the expected life span of a parking structure. However, it is also reasonable to assume that an extra fee could be charged for commuters using a P&R facility, which would allow payback on the investment in parking stalls to be realized even more quickly. Parking fees are discussed at the end of this report.

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.[20] 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[21] 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.[22] Work has also been done to measure benefits to commuters and to the environment from reductions in VMT and emissions.[23] 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."[24] The environmental damage from the cold-start phase of a trip from home to a P&R lot a few miles away is likely to be mitigated in the future as electric hybrid and battery vehicles become more widely used.[25] 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.[26]

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.[27]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."[28] 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.

The paper does not distinguish between the various categories of potential owners of P&R facilities, whether owned by a transit agency, by a State Government agency, or a non-government organization. Our analysis also assumes that no part of the bus transit system is at capacity. The provision of bus service is not a smooth, continuous production curve – capacity is added in discrete increments of distinct routes, bus runs and P&R facilities, each with a cost to establish and operate and with a capacity constraint. Considering a single new commuter moving into an existing suburban environment with bus routes and P&R facilities already in place and with spare capacity in both, the transit agency should be indifferent as to how this customer interfaces with the system; there will be space on the bus whether the customer boards at a neighborhood bus stop or drives to a P&R. The marginal cost of the added rider will be zero.

III. COSTS AND BENEFITS OF PARK-AND-RIDE

The efficiency, or productivity, of transit is directly measured by cost per boarding. Boardings of passengers is a key production measure in public transit. The ratio of this production measure to cost is mathematically related to a less direct productivity measure, boardings per vehicle revenue hour. A vehicle revenue hour is an hour when the bus is in operation and available to pick up and discharge passengers. Cost per boarding is the product of cost per revenue hour and revenue hour per boarding. Higher efficiency is marked by lower cost per boarding. Reducing costs per boarding requires reducing service hours per boarding, or considering the reciprocal, raising boardings per service hour. The more boardings per service hour, the greater is the productivity of service.[29]

One way to raise boardings per service hour for a given number of passengers is to collect them at fewer locations. Rather than routing buses through low density suburbs to pick up passengers, the transit agency can let the passengers assemble themselves at a more limited number of locations, ideally located on or near the roads that buses take when going to their final destinations. This strategy is implemented by providing P&R lots for transit customers.

P&R works well if there is a parking space actually available when a customer drives into the facility, and if, after commuters park their cars, buses come to pick up them up according to the schedule or expected frequency of service. These success factors can be present both with all-day transit service and peak-period-only transit service. Because buses are usually more intensively used in peak than in off-peak periods, the transit efficiency would be higher in peak than off peak. However, the performance distinction of P&R that we sought to analyze would be visible in either case, if extant.

At the same time, it must be acknowledged that for midday, off-peak P&R service to be viable, there must be available parking spaces for arriving travelers seeking to access bus service, and there must be bus service itself on a midday schedule. There are examples of P&R facilities in all five of the case study jurisdictions where midday service is either nonexistent by design, or else the parking facility is filled to capacity with morning-arriving cars so that boardings from drive-up customers on midday bus trips on certain routes is necessarily nil.

Different types of bus service may serve a P&R lot, especially if the facility is part of a more general transit hub. Customers may arrive or depart on a local bus serving a residential neighborhood, with a bus-to-bus transfer either to or from an express bus serving an employment center, or even from one local bus route to another. In this study, the authors usually generalized (with exceptions noted) across different types of bus service (local, express, and bus rapid transit) to obtain more general findings about the relationship of parking availability to bus operations.

While P&R lots in theory make public transit more efficient by raising boardings per service hour and thus lowering cost per boarding, the cost of providing the P&R lots needs to be considered. In addition to paying for the construction of parking facilities, or renting such facilities, there may be maintenance costs. These include providing security and monitoring for illegal usage, such as a customer parking in a space for more than a stated length of time of 12 hours or 24 hours. Illegal multiple day parking is sometimes motivated by quick transit access to an airport or train station with intercity service. Additionally, there may be a cost in providing additional bus service if P&R leads to a larger number of transit boardings than before. An agency may choose to collect a fee for parking to offset the cost of the facility, which then requires expenditure for collection of fees via personnel or automated means.

The focus of this report is the impact of P&R on bus transit efficiency. This is only a subset of policy issues that might be addressed. P&R may be established to facilitate, van or carpool assembly, or for use by inter- or intra- city rail passengers. From an analytical perspective, these other uses can be viewed as constraints on the impacts for bus transit productivity, in that fewer slots for bus patrons (because of more space used for non-bus transit) simply limit the impact that car-parking bus passengers can have on operational performance of the buses.

The authors also note that bus passengers who arrive by other means than in a private vehicle parked at the P&R facility are not distinguished in the present analysis from those who simply drive in and park. The other means of arrival can be a walk from a nearby residence, bicycle, kiss-and-ride drop off, a local shuttle operated by other than the transit agency in focus, or an intercity train.

P&R customers save both time and money. Financial savings come from driving fewer miles in a car, and saving on parking at the trip destination. It’s also possible that the experience of parking and riding is simply more comfortable and convenient than driving more and parking at the destination, or than getting to a bus stop closer to the trip origin and waiting for a bus.

Society benefits from reduced vehicle traffic as commuters are take themselves off the road by parking their cars and getting aboard transit vehicles. The local traffic around a P&R may be perceived as a cost by jurisdictions or by citizens who live close to the facilities. If the lots fill up, there can be spillover that consumes parking spots in neighborhoods where P&R lots are located. In fact, P&R lots are often popular to the point of demand exceeding capacity in U.S. and Canadian urban regions.

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

The authors apply consistent methodologies to two case studies where they were able to obtain the most complete data. Broadly speaking, these methodologies are route-level analysis and stop-level analysis. Route-level analysis examines at route-level a performance measure such as boardings per revenue hour; stop-level analysis examines measures such as boardings at a stop or boardings per trip at a stop. The authors extended certain aspects of the methodologies to three other agencies where they had less data. The methodology is intended to elucidate the impact that P&R lots have on the efficiency of transit. The study focused on bus ridership during morning commute hours.

The types of data used in the two most comprehensive cases 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.

The study employed the following types of data:

- GIS layer of bus routes
- GIS layer of bus stops
- GIS layer of park-and-ride lots
- GIS layer of Census tracts with economic and demographic variables
- GIS layer of Census block groups with economic and demographic variables
- GIS layer of Census blocks with population and housing
- Ridership data – typically boardings and trips by stop by route by time
- Route efficiency data – boardings per revenue hour and related measures by route

SOURCES OF DATA AND DATA QUALITY

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

A variety of variables is available for either kind of analysis. These 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 buffers around stops. A quarter mile is often thought of as the distance a potential bus rider is willing to walk to ride the 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 VARIABLES

- Boardings per revenue hour (route-level)
- Boardings (stop-level)
- Boardings per Trip (stop-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.

In some cases, the authors employ several versions of some variables. For example, the variable squared is employed along with the original variable, in order to capture potential nonlinearities. Where appropriate, the natural logarithm of a variable is used, to capture potential nonlinearities and to estimate elasticities. The descriptive statistics of all variables used in the report over various data sets appear in Appendix C.

V. ECONOMETRIC STRATEGY TO ESTIMATE PARK-AND-RIDE IMPACT ON TRANSIT EFFICIENCY

ROUTE-LEVEL AND STOP-LEVEL ANALYSES

Figures 2a – 2e show selected routes and stops for KCM and VTA. These maps are suggestive of the relationships our econometric analysis seeks to uncover.

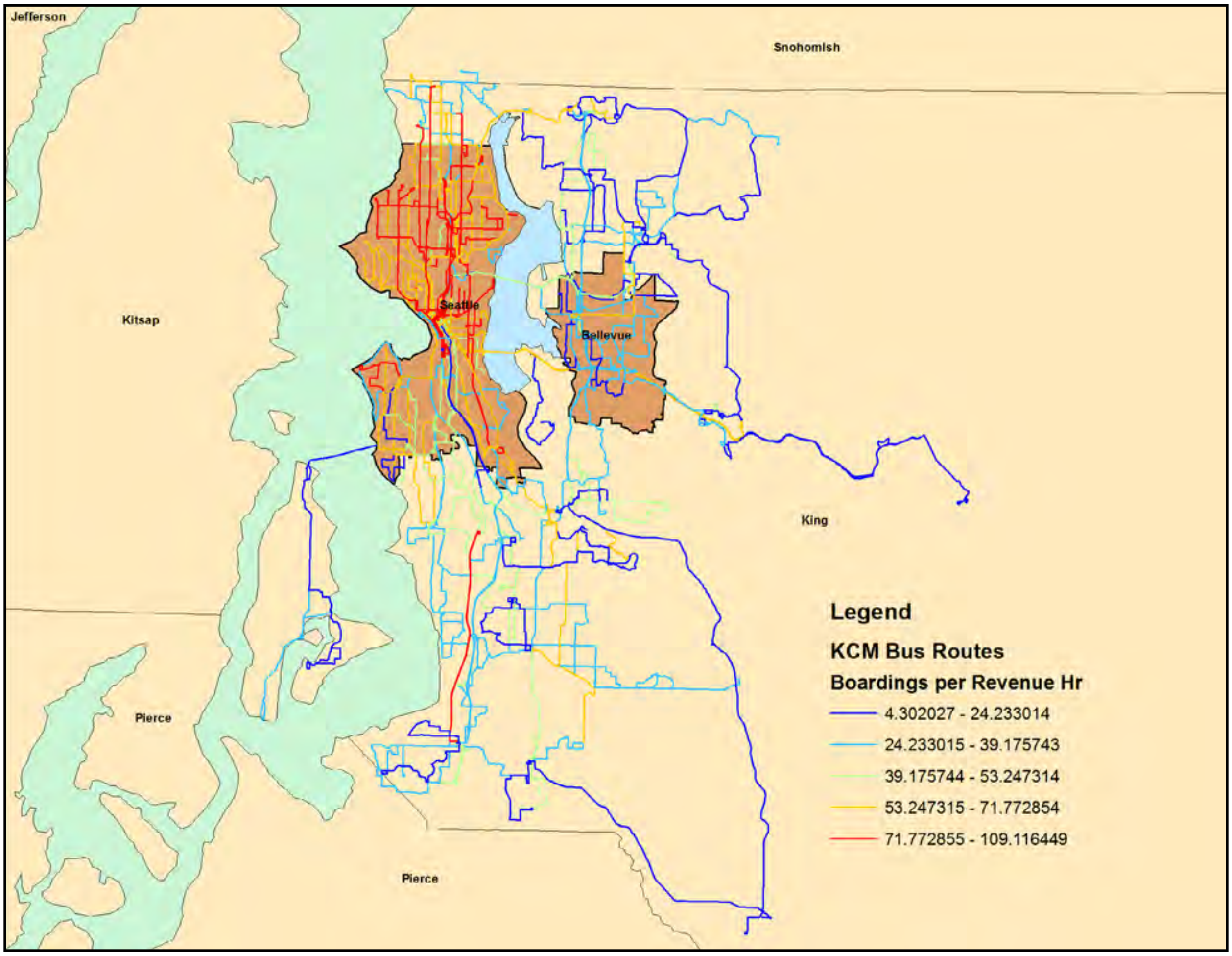

Figure 3. High and Low Boardings-per-Revenue-Hour Routes for King County Metro

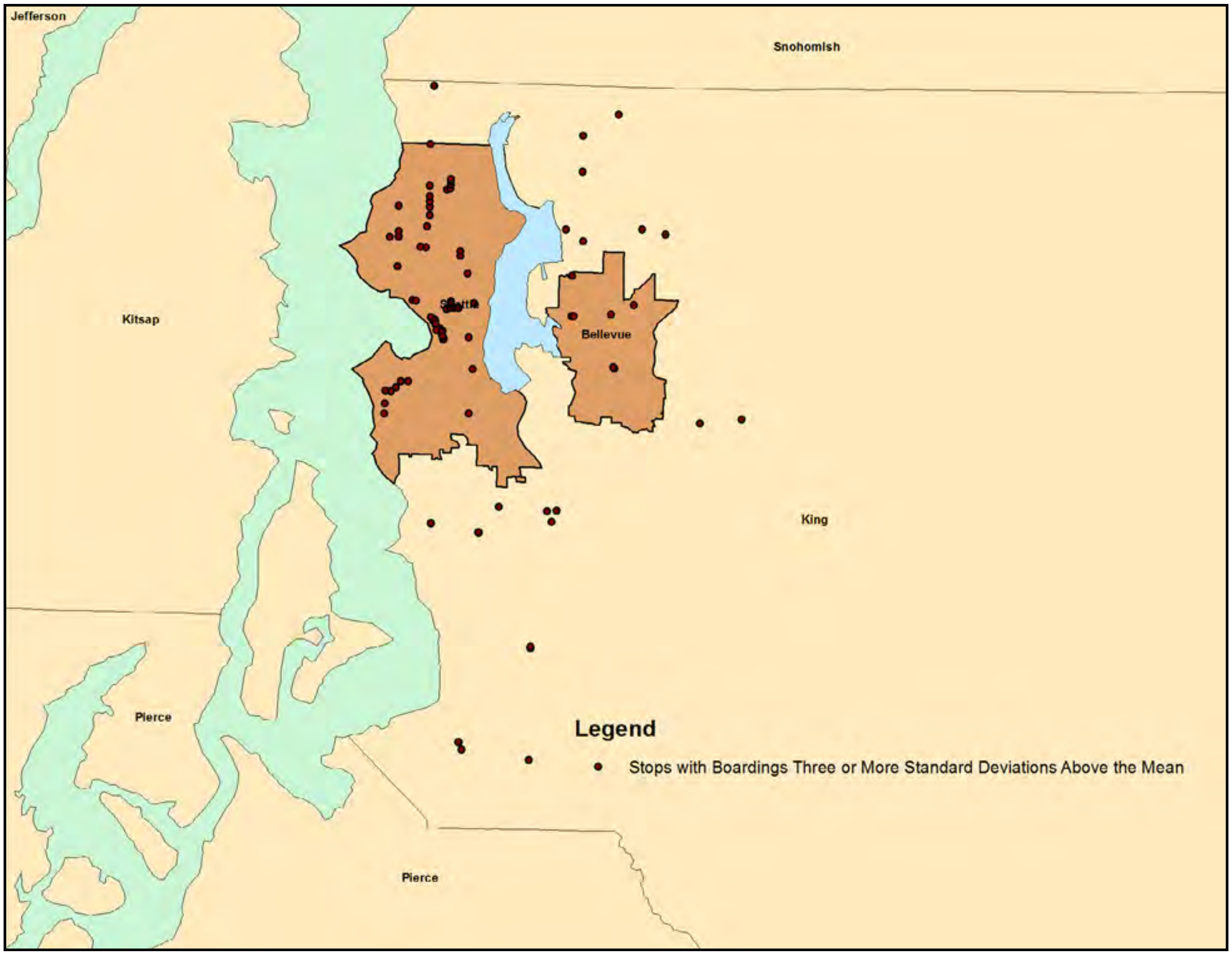

Figure 4. High Morning Boardings Stops for King County Metro

Both Figure 3 and 4 show that higher boardings are seen more within the city limits of Seattle than outside of the city. The city of Bellevue does not exhibit particularly high transit demand compared to the surrounding smaller cities outside Seattle.

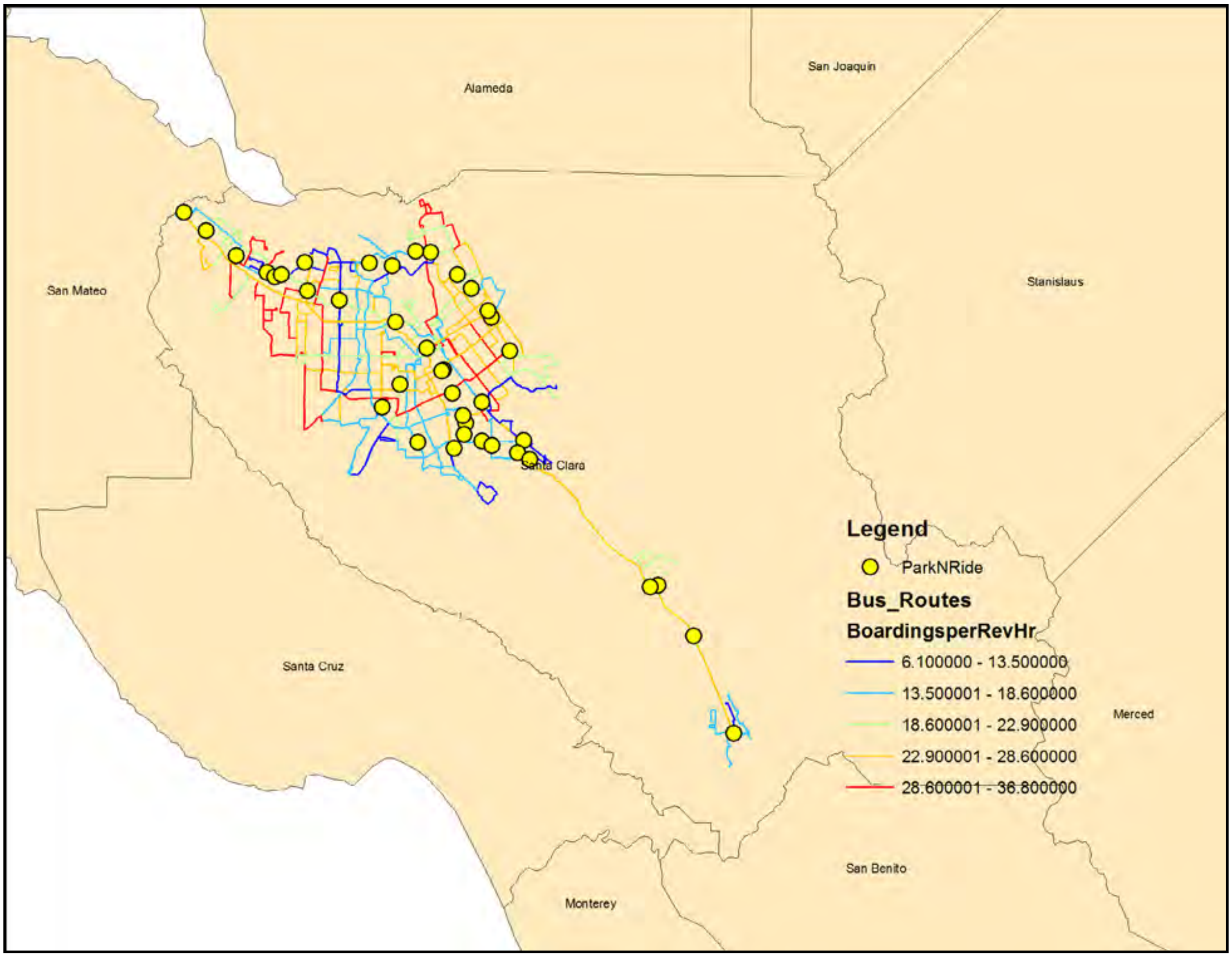

Figure 5. High and Low Boardings-per-Revenue-Hour Routes for Valley Transportation Authority

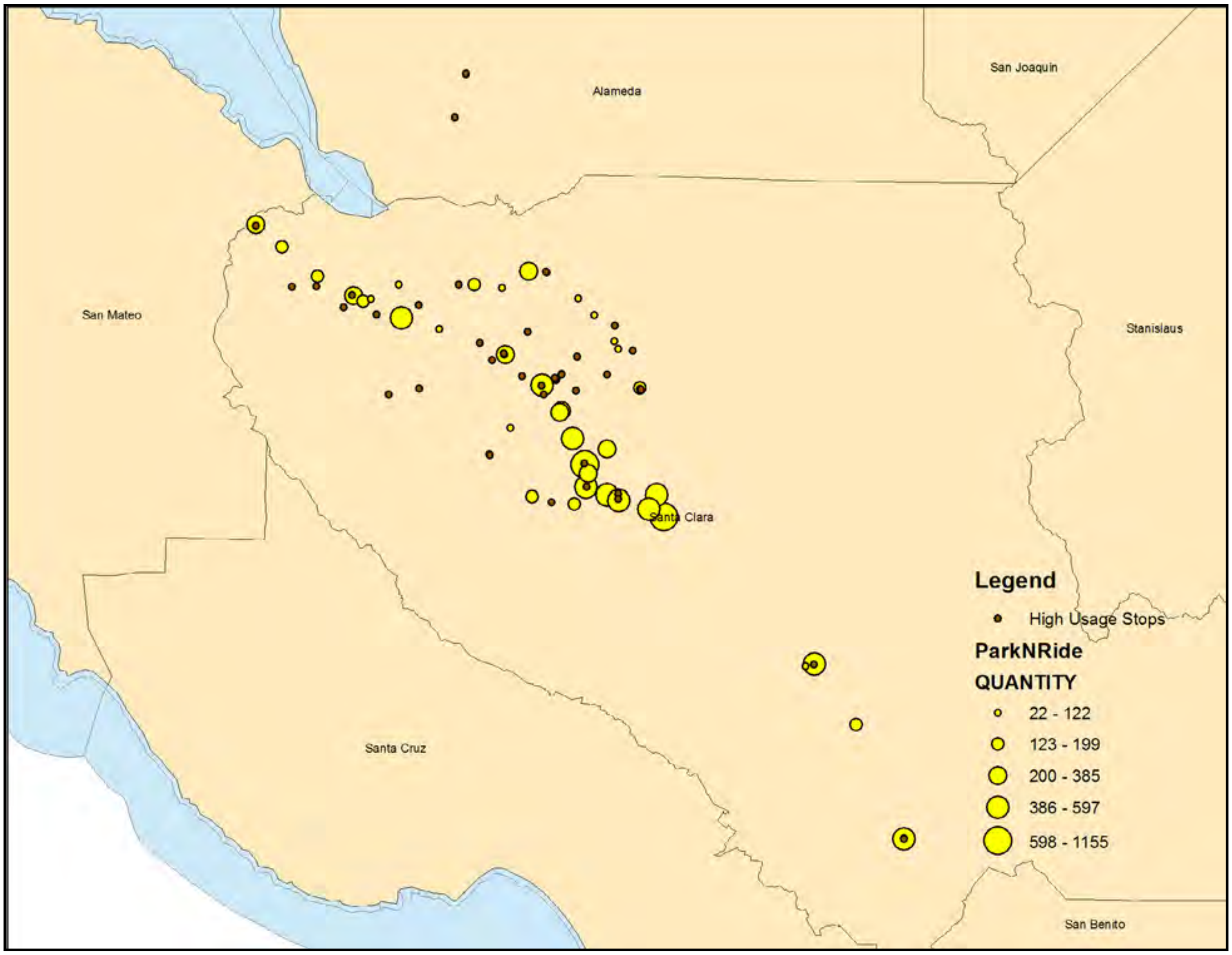

Figure 6. High Morning Boardings Stops for Valley Transportation Authority

Figure 7 shows high boardings-per-trip stops relative to P&R locations and parking capacities for VTA.

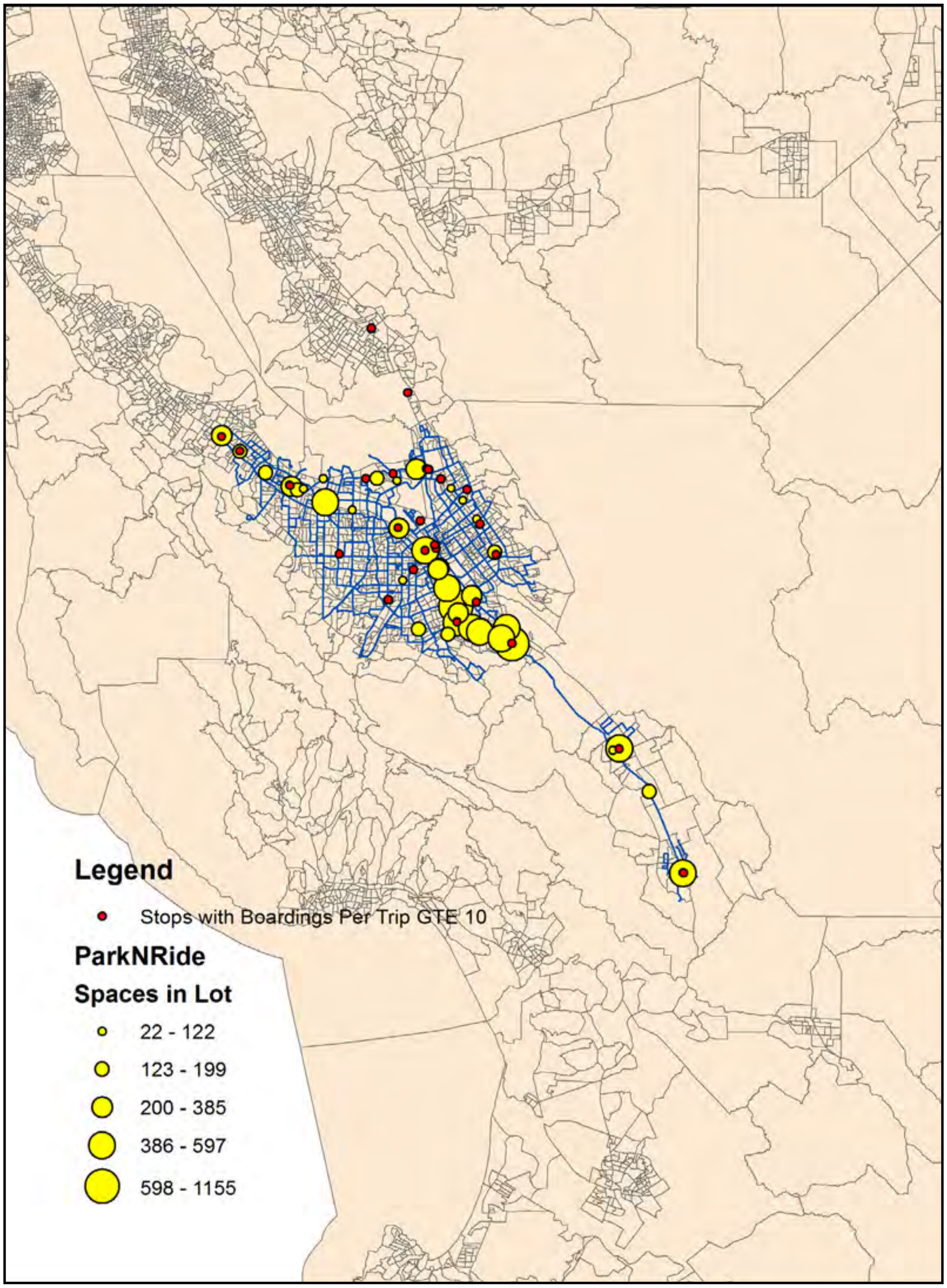

Figure 7. Stops with Boardings per Trip Greater Than or Equal to 10 and Park-and-Ride Lots for VTA

The broad framework for the stop-level results is given in Figure 8.

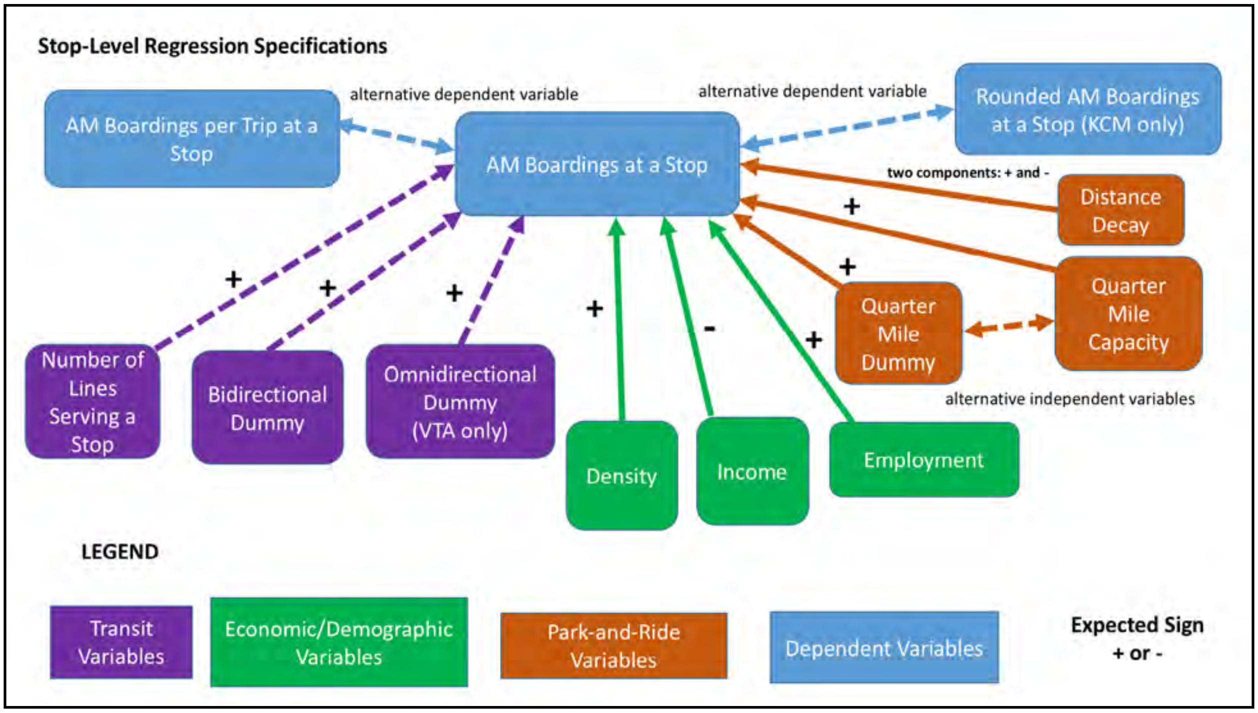

Figure 8. Stop-Level Regression Specifications

Figure 8 shows three alternative dependent variables (blue). Two of the variables represent morning boardings on each system, but the boardings on KCM were averaged, so the original data included decimals. One of the regression methods employed (Poisson regression) requires count data, so the authors rounded the KCM data to the nearest integer when estimating Poisson regressions. The authors determined (by running regressions with both the rounded data and the original data) that rounding did not affect the coefficient estimates.

This Figure also shows three categories of independent variables: transit variables, economic and demographic variables, and P&R variables. For the base cases for KCM and VTA the authors use as a transit variable (purple) the number of lines serving a stop. The authors expect this variable to be positively related to boardings.

The authors also use economic and demographic variables (green) describing the areas within walking distance (a quarter mile) of each stop: population density, number employed, and median household income. The authors expect the first two of these variables to be positively related to morning boardings and the last variable, income, to be negatively related to boardings.

Figure 8 shows three alternative P&R variables (brown): a Quarter Mile Dummy,[30] a Quarter Mile Capacity variable, and Distance Decay variables that have two components (capacity and distance). The Quarter Mile Dummy is equal to 1 if the stop is within a quarter mile of a P&R lot; otherwise it is zero. The Quarter Mile Capacity variable is equal to the capacity (size) of the P&R lot if it is within a quarter mile of the stop; otherwise it is zero. Basically, the authors are weighting the Quarter Mile Dummy by the capacity of the P&R lot. This can be viewed as a sort of Distance Decay function. Finally, for one of the regression methods below (Poisson regression) the authors use a traditional Distance Decay function that results in two independent variables (representing, respectively, capacity of the P&R lot and distance to the bus stop). The reason for introducing this Distance Decay function is explained below.

REGRESSION METHODS: OLS AND POISSON

The authors employ two estimation procedures: Ordinary Least Squares (OLS) regression and Poisson regression. The authors use OLS because it provides a good base line for understanding all regression results; it provides coefficient estimates that are straightforward to interpret; and it will allow them to examine the results of stop-level and route-level analysis in the same framework. OLS is the only method the authors can use for the route-level data (although several specifications of the OLS regressions are examined). The authors employ Poisson regressions to address two issues with the OLS estimates of stop-level data. The dependent variable (boardings) is a count variable. That is, it is 0, or 1, or 2, or …[31] The Poisson model is more appropriate and more accurate than OLS for count-dependent variables. Second, as noted below, the interpretation of the OLS coefficients as marginal impacts is somewhat stilted. Given that absolute changes, say, in income, represent very different things in King County compared to Santa Clara County, it would be better to have coefficient estimates that represent elasticity: the impact in percentage terms on the dependent variable of a given percentage change in the independent variable, holding constant all other variables. In the OLS framework, this would require that the dependent variable be logarithmically transformed. However, as is typical with count data, many of the observations on the dependent variable are zero, for which the logarithm is undefined. The authors can overcome this difficulty and obtain elasticity estimates for some dependent variables in the base case regressions using the Poisson estimation method. Furthermore, Poisson regression is robust to a wide range of specification errors.[32] The functional form of our specifications for stop-level and route-level analysis is detailed below.

STOP-LEVEL ANALYSIS

Stop-level analysis employs stop-level data to determine whether P&R lots contribute significantly to boardings at a stop, and, if so, how much they contribute. Typically, there are many more stops (thousands) than routes (scores), so estimates of stop-level models generally employ many more observations. But just as route-level analysis employs some stop-level data (represented by the various influence variables discussed above), stop-level analysis can employ some route-level and neighborhood-level variables if these variables are made compatible with the stop-level approach. One disadvantage of stop-level analysis is that there appears to be no straightforward way to recover the key performance variable: boardings per revenue hour. However, a host of other policy-relevant variables emerge from stop-level analysis.

We present three formulations of stop-level analysis: OLS analysis with boardings as a dependent variable, Poisson analysis with boardings as a dependent variable, and OLS analysis with boardings per trip as a dependent variable.

OLS Analysis with Boardings as a Dependent Variable

Our formulation is:

$$(1)\ Boardings_s = \beta_0 + \beta_{NUMROUTES} NUMROUTES_s + \beta_{PRDUMMY} PRDummy_s \{or\ \ + \beta_{PRCAP} PRCAP_s\} + \beta_{PopDens} POPDENS_s + \beta_{MedHHInc} MEDHHINC_s + \beta_{Emp} EMP_s + \epsilon_s$$

where

s is the stop;

$\beta_{NUMROUTES}$ is the coefficient on the number of routes serving a particular stop s;

$NUMROUTES_s$ is the number of routes serving a particular stop s;

$\beta_{PRDUMMY}$ is the coefficient on the P&R dummy variable that indicates whether a particular stop s is within a critical distance of a P&R lot;

$PRDummy_s$ is a dummy variable indicating whether a stop is within a critical distance of a P&R lot;

β_{PRCAP} is the coefficient on the P&R capacity variable;

$PRCapacity_s$ is the capacity of the nearest P&R lot to stop s;

$PRCAP_s$ = $[PRCapacity_s * PRDummy_s]$;

$\beta_{PopDens}$ is the coefficient on population density within a quarter mile of a stop;

$POPDENS_s$ is the population density within a quarter mile of a stop;

$\beta_{MedHHInc}$ is the coefficient on median household income within a quarter mile of a stop;

$MEDHHINC_s$ is median household income within a quarter mile of stop s;

β_{Emp} is the coefficient on employment within a quarter-mile of a stop;

EMP_s is employment within a quarter mile of a stop;

e_s is an error term.

Poisson Analysis with Boardings as a Dependent Variable

$$(2)\ Boardings_s = \beta_0 + \beta_{lnPRCAP} ln\,(PRCAP_s) + \beta_{lnPopDens} ln\,(POPDENS_s) + \beta_{lnMedHHInc} ln\,(MEDHHINC_s) + \beta_{lnEmp} ln\,(EMP_s) + \epsilon_s$$

where

s is the stop;

$\beta_{lnPRCAP}$ is the coefficient on the logarithm of the P&R capacity variable;

$ln\,(PRCapacity_s)$ is the logarithm of the capacity of the nearest P&R lot to stop s;

$PRCAP_s = [PRCapacity_s * PRDummy_s]$;

$\beta_{lnMedHHInc}$ is the coefficient on the logarithm of median household income within a quarter mile of a stop;

$ln\,(MEDHHINC_s)$ is logarithm of median household income within a quarter mile of stop s;

β_{lnEmp} is the coefficient on the logarithm of employment within a quarter mile of a stop;

$\ln\,(EMP_s)$ is employment within a quarter mile of a stop;

e_s is an error term.

OLS Analysis with Boardings Per Trip as a Dependent Variable

$$(3)\ Boardings\ per\ Trip_s = \beta_0 + \beta_{PRCAP} PRCAP_s + \beta_{PopDens} POPDENS_s + \beta_{PopDensSqrd} POPDENSQRD_s + \beta_{MedHHInc} MEDHHINC_s + \beta_{MedHHIncSqrd} MEDHHINCSQRD_s + \beta_{Emp} EMP_s + \epsilon_s$$

where

s is the stop;

β_{PRCAP} is the coefficient on the P&R capacity variable;

$PRCapacity_s$ is the capacity of the nearest P&R lot to stop s;

$PRCAP_s = [PRCapacity_s * PRDummy_s]$;

$\beta_{PopDens}$ is the coefficient on population density within a quarter mile of a stop;

$POPDENS_s$ is the population density within a quarter mile of a stop;

$\beta_{PopDensSqrd}$ is the coefficient on population density squared within a quarter mile of a stop;

$POPDENSQRD_s$ is the population density within a quarter mile of a stop squared;

$\beta_{MedHHInc}$ is the coefficient on median household income within a quarter mile of a stop;

$MEDHHINC_s$ is median household income within a quarter mile of stop s;

$\beta_{MedHHIncSqrd}$ is the coefficient on median household income within a quarter mile of a stop squared;

$MEDHHINCSQRD_s$ is median household income within a quarter mile of stop s squared;

β_{Emp} is the coefficient on employment within a quarter mile of a stop;

EMP_s is employment within a quarter mile of a stop;

e_s is an error term

VI. ROUTE-LEVEL ANALYSIS

Route-level analyses focus on route characteristics and performance measures. Route-level analysis casts everything in terms of routes. 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.

$$(4)\ \textit{Boardings per Revenue Hour}_r = \beta_0 + \beta_{SPEED} SPEED_r + \beta_{PRI} PRI_r + \beta_{ServType} SERVTYPE_r + \epsilon_r$$

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 a;

$\beta_{ServType}$ is the coefficient on service type along route r;

$SERVTYPE_r$ is the service type (e.g., “limited”) along route r;

e_r is an error term.

VII. REGRESSION RESULTS

The authors present regression results for stop-level data and then for route-level data. The results are generated by separate but related data sets.

The descriptive statistics show that relative to respective areas of operation, King County Metro (KCM) is the larger and more comprehensive system. KCM has more than twice as many stops, routes, and P&R spaces as VTA in Santa Clara. More than three times as many workers (almost 12%) commute by public transit in King County compared to Santa Clara County (3.6%). Average morning boardings are more than four and one-half times greater for KCM compared to VTA.

VIII. STOP-LEVEL RESULTS

For both KCM and VTA across all specifications of stop-level regression equations, all coefficients estimates are statistically significant (using robust standard errors) and of the expected sign. Generally, the story that emerges from OLS regression is consistent with the story that emerges from Poisson regression. Generally, all the coefficient estimates are larger in absolute value for KCM compared to VTA.

Table 5 gives the results for OLS regressions for KCM and VTA. Four regression results are reported in this table. These are the base line OLS regressions comparing KCM and VTA because the variables are identical for the pairs of regressions. In the upper panels of Table 5, regressions using the Quarter Mile Dummy to capture the effect of P&R are reported. In the lower panels of Table 5 regressions using the Quarter Mile Capacity variable to capture the effect of P&R are reported.

Table 5. Ordinary Least Squares Stop-Level Regression Results for KCM and VTA

Dependent Variable: AM Boardings	KCM						VTA					
Independent Variables	**Coef.**	**Robust Std. Err.**	**t**	**P>t**	**[95% Conf.**	**Interval]**	**Coef.**	**Robust Std. Err.**	**t**	**P>t**	**[95% Conf.**	**Interval]**
Number of Bus Lines	5.955272	0.8695442	6.85	0	4.25067	7.659874	1.553749	0.1944596	7.99	0	1.17242	1.935078
Quarter Mile Dummy	11.29876	2.191439	5.16	0	7.002795	15.59472	2.603722	0.4688241	5.55	0	1.684374	3.523071
Population Density per Square Mile within a quarter mile of a stop	0.0009723	0.000094	10.34	0	0.0007881	0.0011566	0.000097	0.0000143	6.79	0	0.000069	0.000125
Median Household Income within a quarter mile of a stop	-0.0000291	0.0000135	-2.16	0.031	-0.0000555	-2.70E-06	-0.00000594	0.00000163	-3.65	0	-0.00000913	-0.00000275
Total Number of Employed Persons within a quarter mile of a stop	0.0036785	0.0015098	2.44	0.015	0.0007187	6.64E-03	0.0005444	0.0002764	1.97	0.049	0.00000232	0.0010864
Constant	-8.226792	2.245989	-3.66	0	-12.62969	-3.82389	-0.523463	0.3992922	-1.31	0.19	-1.306462	0.2595357
	Number of obs	=	6,321				Number of obs	=	2,373			
	F(5, 6315)	=	44.82				F(5, 2367)	=	47.17			
	Prob > F	=	0				Prob > F	=	0			
	R-squared	=	0.1438				R-squared	=	0.152			
	Root MSE	=	25.909				Root MSE	=	2.9132			

Table 5. Continued

Dependent Variable: AM Boardings	KCM						VTA					
Independent Variables	**Coef.**	**Robust Std. Err.**	**t**	**P>t**	**[95% Conf.**	**Interval]**	**Coef.**	**Robust Std. Err.**	**t**	**P>t**	**[95% Conf.**	**Interval]**
Number of Bus Lines	5.64982	0.7929109	7.13	0	4.095446	7.204195	1.611726	0.1997048	8.07	0	1.220112	2.003341
Quarter Mile Capacity Dummy	0.0438956	0.0116719	3.76	0	0.0210147	0.0667765	0.0054681	0.0011113	4.92	0	0.0032889	0.0076472
Population Density per Square Mile within a quarter mile of a stop	0.0010106	0.0000927	10.9	0	0.0008288	0.0011924	0.0000987	0.0000146	6.78	0	0.0000701	0.0001273
Median Household Income within a quarter mile of a stop	-0.0000321	0.000014	-2.3	0.022	-0.0000595	-0.00000471	-0.00000611	0.00000162	-3.78	0	-0.00000929	-0.00000294
Total Number of Employed Persons within a quarter mile of a stop	0.0034447	0.0014507	2.37	0.018	0.0006008	0.0062886	0.0007274	0.0002762	2.63	0.009	0.0001858	0.0012689
Constant	-7.576285	2.225762	-3.4	0.001	-11.93953	-3.213036	-0.7009497	0.396153	-1.77	0.077	-1.477792	0.0758931
	Number of obs	=	6321				Number of obs	=	2373			
	F(5, 6315)	=	46.9				F(5, 2367)	=	49.68			
	Prob > F	=	0				Prob > F	=	0			
	R-squared	=	0.1657				R-squared	=	0.1468			
	Root MSE	=	25.576				Root MSE	=	2.9223			

Coefficient estimates in OLS regressions are interpreted as marginal effects. That is, the coefficient on the variable "number of bus lines serving a stop" represents the effect on morning boardings of increasing the number of bus lines serving a stop by one, holding all other variables constant. The coefficient estimates in the upper panels of Table 5 say that increasing the number of bus lines serving a stop by one bus line will increase morning boardings at that stop by about six riders in King County and by about one and a half riders in Santa Clara County. Both coefficient estimates are statistically significant.

For the Quarter Mile Dummy, the coefficient estimates are 11.29876 for KCM and 2.603722 for VTA. Both coefficient estimates are statistically significant. The coefficient on this dummy variable has the standard interpretation as a marginal effect. The presence of a P&R lot within a quarter mile of a stop increases morning boardings at that stop by an average of 11.3 for KCM and by an average of 2.6 for VTA. (The average size of P&R lots differs in the two cases. For King County, the average sized P&R lot has 196 spaces; for Santa Clara County, the average sized P&R lot has 294 spaces. The average number of stops within a quarter mile of a P&R lot also differs between the two systems. For KCM there is an average of about six stops within a quarter mile of a P&R lot, while for VTA there is an average of almost eight stops within a quarter mile of a P&R lot. However, KCM has many more lots and many more stops within a quarter mile. About 9.5% of KCM stops are within a quarter mile of a P&R lot, while for VTA the corresponding figure is 7.9 %.)

As expected, increasing median household income has a negative effect on boardings. Apparently, higher income people prefer to drive a car rather than take the bus. Increasing median household income by $10,000 for households within a quarter mile of a bus stop decreases ridership by about one-third of a rider. An increase in median household income by the same amount in Santa Clara County would reduce ridership by six-hundredths of a rider. An increase of $10,000 in median household income is a larger percentage of average income in King County than in Santa Clara County. This observation suggests that it would be better to estimate these comparative effects in terms of elasticities (percentage changes in boardings for a given percentage change in income). This topic will be addressed when Poisson regressions are discussed. Population density and number of employees residing within a quarter mile of a bus stop both have positive and statistically significant effects on ridership.

The lower panels of Table 5 give the OLS regression results for the same dependent variable, but now the authors use a variable called the Quarter Mile Capacity variable to measure the effect of P&R. The coefficient estimates are essentially the same as for the upper panel, except for the coefficient on the Quarter Mile Capacity variable. For KCM, an increase of one space within a quarter mile of a stop increases boardings at that stop by 0.044 riders. For VTA, the corresponding increase is 0.0055 riders. Both coefficients are statistically significant.

In Table 6, the authors present the results of Poisson estimation of the model. This table presents four regression results. The upper panels compare Poisson regressions for KCM and VTA using the Quarter Mile Dummy. The bottom panels compare Poisson regressions for KCM and VTA using a standard distance-decay function with components representing capacity of the nearest P&R lot and distance to the nearest P&R lot.

Table 6. Poisson Regressions for KCM and VTA with Various Park-and-Ride Variables

KCM							VTA						
Boardings	**Coef.**	**Robust Std. Err.**	**z**	**P>z**	**[95% Conf.**	**Interval]**	**Boardings**	**Coef.**	**Robust Std. Err.**	**z**	**P>z**	**[95% Conf.**	**Interval]**
Number of Lines	0.157815	0.0200694	7.86	0	0.1184798	0.1971503	Number of Lines	0.4663701	0.0454978	10.25	0	0.377196	0.5555443
QuarterMileDummy	**1.05605**	0.1076717	9.81	0	0.8450175	1.267083	QuarterMileDummy	**0.7546589**	0.1062149	7.11	0	0.5464816	0.9628362
lnPopDens	**0.4770794**	0.0543236	8.78	0	0.3706072	0.5835517	lnPopDens	**0.1952375**	0.0476164	4.1	0	0.1019111	0.288564
lnMedHHInc	-0.1290285	0.0706135	-1.83	0.068	-0.2674284	0.0093715	lnMedHHInc	-0.3351254	0.074623	-4.49	0	-0.4813837	-0.188867
lnNumberEmployees	0.5071294	0.1614605	3.14	0.002	0.1906726	0.8235861	lnNumberEmployees	0.3458637	0.1059983	3.26	0.001	0.1381109	0.5536166
_cons	-4.365956	1.25215	-3.49	0	-6.820125	-1.911787	_cons	-0.1468349	1.280329	-0.11	0.909	-2.656233	2.362563

KCM							VTA						
Boardings	**Coef.**	**Robust Std. Err.**	**z**	**P>z**	**[95% Conf.**	**Interval]**	**Boardings**	**Coef.**	**Robust Std. Err.**	**z**	**P>z**	**[95% Conf.**	**Interval]**
Number of Lines	0.1702552	0.0207485	8.21	0	0.1295889	0.2109216	Number of Lines	0.4668109	0.0455926	10.24	0	0.3774509	0.5561708
lnParkingSpaces	**0.0725646**	0.024395	2.97	0.003	0.0247512	0.120378	lnParkingSpaces	**0.0457416**	0.0292318	1.56	0.118	-0.0115516	0.1030347
lnDIST_Nearest_PnR	**-0.2987086**	0.0409151	-7.3	0	-0.3789008	-0.2185165	lnDIST_Nearest_PnR	**-0.1742338**	0.0450712	-3.87	0	-0.2625717	-0.0858959
lnPopDens	**0.5289155**	0.0549829	9.62	0	0.4211511	0.63668	lnPopDens	**0.1808069**	0.0449739	4.02	0	0.0926596	0.2689542
lnMedHHInc	-0.1674258	0.0671871	-2.49	0.013	-0.2991102	-0.0357414	lnMedHHInc	-0.2537793	0.0731053	-3.47	0.001	-0.397063	-0.1104956
lnNumberEmployees	0.5615903	0.1649103	3.41	0.001	0.238372	0.8848086	lnNumberEmployees	0.3664808	0.1197535	3.06	0.002	0.1317683	0.6011934
_cons	-2.485067	1.251699	-1.99	0.047	-4.938352	-0.0317833	_cons	0.220165	1.502881	0.15	0.884	-2.725427	3.165757

In order to generate the most meaningful results, the authors used logarithmic transformations of population density, median household income, and number of workers within a quarter mile of a bus stop in all the Poisson regressions. The authors could not apply the logarithmic transformation to either the Quarter Mile Dummy or the Quarter Mile Capacity variable, because they take on zero values for some observations. In the bottom panels of Table 6, the authors replace the Quarter Mile Dummy with a more standard distance-decay function that allows us to use the logarithmic transformation for both the capacity and the distance components.

Starting with the upper panel of Table 6, the authors see that the presence of a P&R lot within a quarter mile of a stop leads to a 1.05% increase in boardings at that stop. Recall that for KCM there is an average of 4.7 stops within a quarter mile of a P&R lot, while for VTA there is an average of 6.5 stops within a quarter mile of a P&R lot. A 1% increase in density results in a 0.48% increase in boardings. Both results are highly statistically significant (z-values/t-stats of 9.81 and 8.78, respectively). By comparison, for VTA the presence of a P&R lot within a quarter mile of a stop leads to a 0.75% increase in boardings at that stop. A 1% increase in density results in a 0.2% increase in boardings. Both results are highly statistically significant (z-values/t-stats of 7.11 and 4.1, respectively) but less statistically significant than for KCM.

The problem with the Quarter Mile Dummy (or the Quarter Mile Capacity variable) is that it is truncated at a quarter of a mile. An alternative is to define a distance decay-variable of the form: Capacity divided by Distance. A logarithmic transformation of the right-hand side of the Poisson equation gives two new variables, *ln*(Capacity) and *ln*(Distance), the logarithms of Capacity and Distance, respectively. These are defined for all observations, and have standard elasticity interpretations. For KCM, the results of incorporating the distance-decay formulation are:

For each 1% increase in spaces, the number of boardings at a stop at the average distance from a P&R lot increases by 0.07%. The effect of increasing the number of spaces at a P&R lot by 1% is strongly influenced by the distance of the stop from the P&R lot. For each 1% increase in distance, the percent change in ridership at such a stop decreases by 0.3%. The effect of a 1% increase in population density is about a 0.53% increase in boardings at a stop within a quarter mile of a P&R lot. All the results are statistically significant with the results for distance and density especially so, suggesting that these variables are the most significant in determining the result.

For VTA the results are:

For each 1% increase in spaces, the number of boardings at a stop at the average distance from a P&R lot increases by 0.04%. The effect of increasing the number of spaces at a P&R lot by 1% is strongly influenced by the distance of the stop from the P&R lot. For each 1% increase in distance, the percent change in ridership at such a stop decreases by 0.17%. The effect of a 1% increase in population density is about a 0.18% increase in boardings at a stop within a quarter mile of a P&R lot. The results for distance and density are statistically significant, suggesting that these variables are the most significant in determining the result. The result for the number of spaces in a P&R is of the expected sign but not statistically significant.

IX. INTERPRETATION OF STOP-LEVEL RESULTS

The coefficients from the stop-level analysis of KCM and VTA illustrate that parking availability is a stronger influence than residential density on the performance measure of boardings per stop. To see this, consider Table 7, which uses the regression results in the bottom panel of Table 5 to illustrate how nearby housing and parking influence boardings at bus stops. The third column in the table uses the reciprocal of the coefficient in the second column as the increment of the independent variable that increases boardings by one person.

For example, across the KCM system, using the increments in the third column, 23 more parking spaces within one quarter mile of an average bus stop have the same influence on boardings per stop as an increase in density of 990 more people per square mile for the housing within a quarter mile of the stop. This latter density number translates by geometry to 194 more people residing within the quarter mile radius. So in and around Seattle, 194 more people (or 97 couples) living near a stop have the equivalent effect of 23 commuter parking cars near the bus stop to access a ride. It is manifestly less costly to achieve parking space for 23 more cars near the stop than it is to build housing for 97 more couples, so the authors rate parking as more influential.

The comparative numbers for VTA adding one more rider at a stop are 18 more car parking spaces versus 199 more people (100 couples), so the influence gap is even larger than in Seattle, where 23 parking spaces had the same influence as housing for 97 couples. Therefore, in the San Jose region, compared to the Seattle region, parking appears to be even more influential than nearby housing for attracting bus riders.

Table 7. Calculating Incremental Impacts of Various Variables

	Mean Value (Appendix C)	Coefficient (Table 5)	Increment of independent variable to Increase boardings by One Person (Reciprocal of the Coefficient)
King County Metro			
Number of Bus Lines	1.5825	5.65	0.2
Number of Parking Spaces within 1/4 Mile	24.1	0.0439	22.8
Population Density within 1/4 Mile	5,839.187	0.00101	990.1
Constant		-7.58	
AM Boardings per Stop	10.11		
VTA			
Number of Bus Lines	1.22	1.612	0.1
Number of Parking Spaces Within 1/4 Mile	22.7	0.00547	18.3
Population Density within 1/4 Mile	7,599	0.0000987	1,013.2
Constant		-0.7	
AM Boardings per Stop	2.21		

Details and further explorations of the relative importance of P&R compared to other variables, especially density, are provided in Appendix D.

X. ROUTE-LEVEL RESULTS

In this section the authors present results of route-level regressions. The authors will discuss the results of the route-level analysis one transit system at a time. The dependent variable in all these regressions is boardings per revenue hour associated with the route.

ROUTE-LEVEL ANALYSIS AND INFLUENCE VARIABLES

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. For example, the clientele of a particular P&R lot may come from several identifiable suburban areas. American Community Survey (ACS) data can be used to estimate the total number of residents in such an area who are employed. Total employees in the catchment area of a P&R lot can be used as a characteristic of the P&R lot, and also as a characteristic of routes that serve that P&R lot.

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.

The authors can construct more refined “influence” variables – variables that account for some characteristics of the P&R lots, such as the total number of spaces in the lot.

The advantage of route-level analysis is that it can be cast directly in terms of what transit agency policy makers view as a key performance measure: *boardings per revenue hour*. There are, however, several disadvantages. There are fewer routes than stops, so compared to stop-level analysis, route-level analysis will always involve fewer observations (scores of observations as opposed to thousands of observations). Also, while it is possible to construct a variety of “influence” variables, these variables do not always have straightforward interpretations in the analysis. With any such influence variable, basically non-route data is being forced into a route mold.

The results for King County Metro, Valley Transportation Authority, Los Angeles Metro, Community Transit of Snohomish County, and Pierce Transit are presented in this section.

KING COUNTY METRO

The influence Park-and-Ride for King County Metro 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 8:

Table 8. Route-Level Regression for KCM

Linear regression	Number of obs	=	177
	F(4, 172)	=	40.06
	Prob > F	=	0
	R-squared	=	0.4529
	Root MSE	=	17.107

BoardingsperRevHr	Coef.	Robust Std. Err.	t	P>t	[95% Conf.	Interval]
MPH	-1.083738	0.3519573	-3.08	0.002	-1.77845	-0.3890265
TotalREG_SPACES	-0.022046	0.0101466	-2.17	0.031	-0.0420739	-0.0020182
TotalREG_SPACES_Sqrd	0.0000143	6.06E-06	2.36	0.019	2.35E-06	0.0000263
SeattleCoreDummy	25.00968	2.82017	8.87	0	19.44308	30.57628
_cons	53.88109	4.879703	11.04	0	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 (the effect of one additional space along the route), the quadratic is graphed as a function of total spaces in Figure 9.

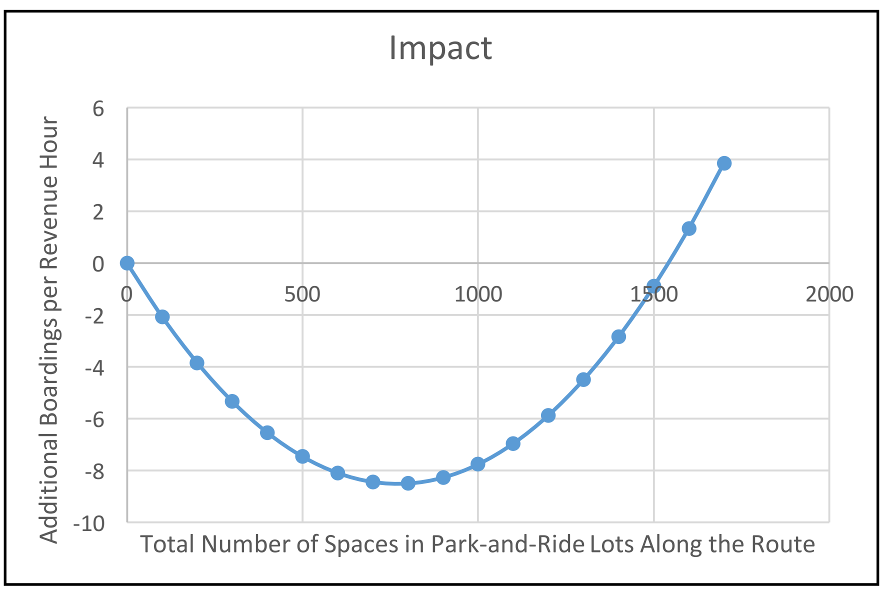

Figure 9. The Marginal Effect of Park-and-Ride Capacity for KCM

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. Which routes are those?

It turns out that 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.[33] These routes are analyzed separately in the next section.

FOCUSED CASE STUDY: KING COUNTY METRO TRANSIT

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.[34]

The regional Metropolitan Planning Organization, Puget Sound Regional Council, reports that since 2010, "Park and Rides fill earlier and more frequently."[35]

Figure 10, 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 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.

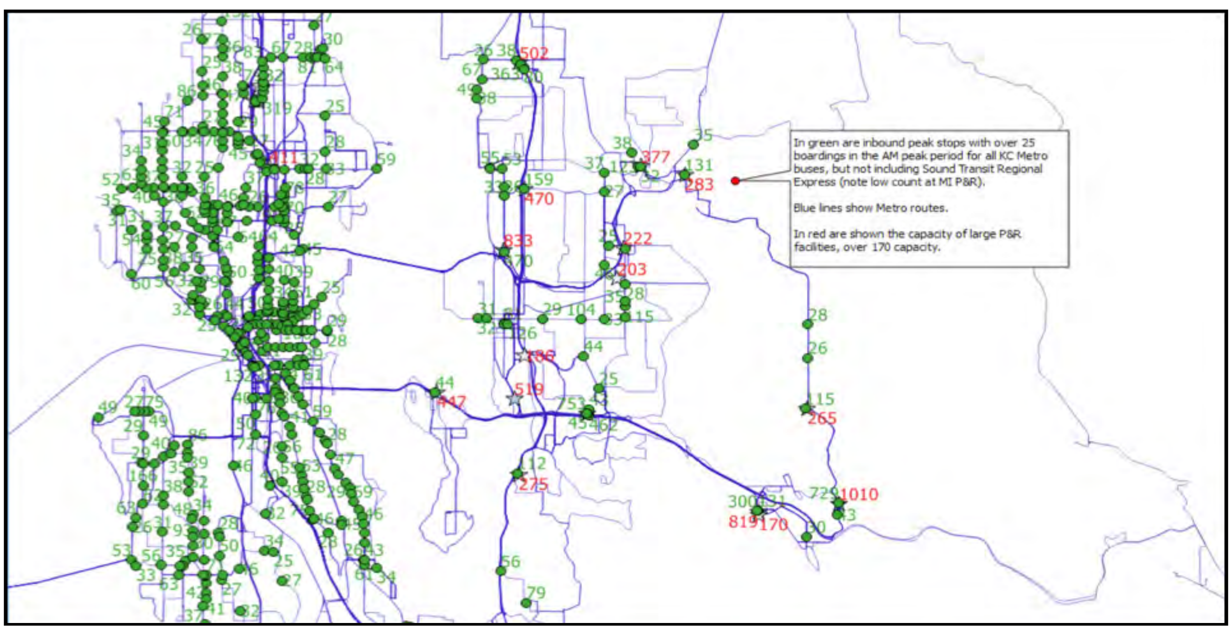

Figure 10. Seattle and East King County Bus Stops with More Than 250 A.M Peak Boardings

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 earlier in this report that the routes serving the Seattle eastern suburbs are those most influenced by P&R availability. Most of the 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, a well recognized ratio of production to resources. 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 9 shows the value of the P&R influence variable for the entire sample of 53 Routes.

Table 9. Park-and-Ride Influence Variable for 53 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
214	0.88	238	0.07	260	0.00	672 (RR-B)	0.13
215	0.40	240	0.00	265	0.46		
216	0.60	241	0.17	268	0.69		
217	0.00	242	0.26	269	0.19		

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.

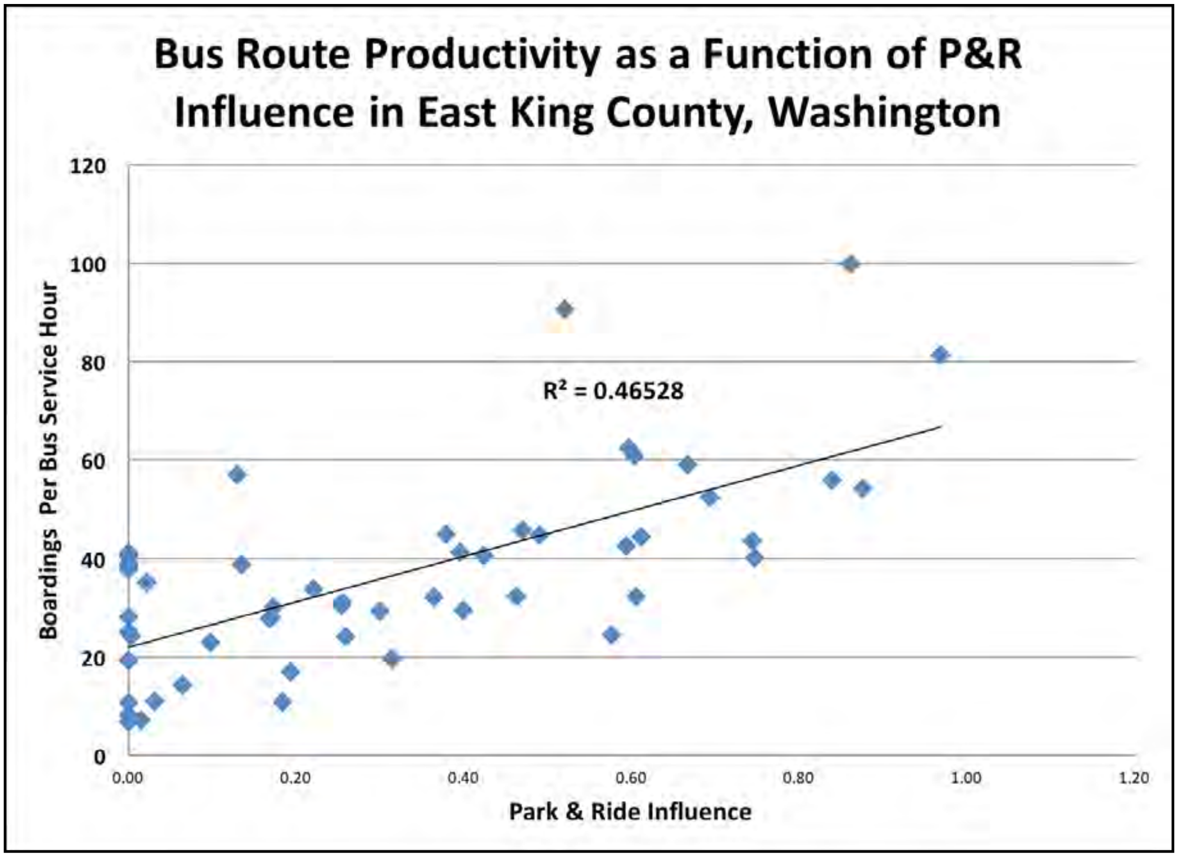

Figure 11. Bus Route Productivity in East King County, Washington

The 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 11.

In order to explain more of the influences on boardings per service hour, the authors experimented with adding other variables to the regression analysis. 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. This is the strongest model found across all five of the case-study agencies.

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

$$(5)\ Annualized\ peak\ period\ boardings\ per\ hour$$
$$= \beta_0 + \beta_1(AM\ Park - and - Ride\ Influence\ Fraction)$$
$$+\ \beta_2(All - day\ boardings\ per\ route\ mile)$$
$$+ \beta_3(Stops\ per\ mile\ over\ entire\ route) + \epsilon$$

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 CONSEQUENCE 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.[36]

Let X be the number of hours of saving, which is already stated as 678 service hours. To derive this number, the problem at hand is to solve for X where

$$(6)\ (H + X) * (P1 - P2) = H * P1$$

P1 = 44.48 boardings per hour

P2 = 10.17boardings per hour

H = 2,288 hours

By algebraic manipulation,

$$(7)\ X = \frac{HP2}{(P1 - P2)}.$$

After substituting data for variables, X = 678.2

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.

SANTA CLARA VALLEY TRANSPORTATION AUTHORITY, SAN JOSE, CALIFORNIA

The authors estimated a regression using route-level productivity data for bus service for VTA. Speed by route data was not available. The route-level regression for VTA is given in Table 10.

Table 10. VTA Route-Level Regression

Linear regression	Number of obs	=	57
	F(4, 52)	=	18.79
	Prob > F	=	0
	R-squared	=	0.3745
	Root MSE	=	5.8278

BoardingsperRevHr	Coef.	Robust Std. Err.	t	P>t	[95% Conf.	Interval]
TotalQUANTITY	0.0025932	0.0073608	0.35	0.726	-0.0121773	0.0173636
TotalQUANTITYSqurd	-4.62E-06	6.08E-06	-0.76	0.451	-0.0000168	7.59E-06
Service Type: Core	8.324875	1.516724	5.49	0	5.281347	11.3684
Service Type: Limited	-4.515359	1.59985	-2.82	0.007	-7.725694	-1.305024
_cons	19.48711	1.773885	10.99	0	15.92755	23.04667

Type of service is very statistically significant. The holdout category for bus service is community buses. Neither of the terms associated with total P&R spaces along the route is statistically significant. In a regression with just the linear term for total P&R spaces, the coefficient estimate is also not statistically significant.

In explaining the lack of structural similarity in the empirical analysis of the two case studies, the authors note that the overall reported bus boardings per service hour in the most recent National Transit Database summary (2013) shows VTA at 27, while King County Metro (KCM) is 33 percent higher at 36 boardings per service hour. In other words, VTA buses operate at a lower level of productivity which may be based on less use of buses by car drivers compared to KCM, a difference that in turn comes from lower availability of parking spaces at VTA (1,448 per 100,000 workers) than at KCM (1,624 per 100,000 workers), as reported above. Also, parking in the VTA network is more supportive of light rail access at multiple stations than is the case with KCM, where only one P&R serves light rail access.

Most of the larger P&R facilities are aligned along the Gilroy-Morgan Hill-San Jose corridor, which is also served by the CalTrain commuter rail. Other P&R lots serve VTA's light rail lines as well as the bus routes, which apparently confounds the interpretation of P&R influence on bus boardings per service hour. Another issue for data analysis is that a number of bus lines in the morning peak period pass through and go beyond the most important work center destinations like downtown San Jose, so that the ridership of a line in the morning represents the daily peak for part of the route, and off peak for the tail of the route. So while the stop-level analysis revealed an influence of parking on ridership, we did not find an influence on route productivity.

LOS ANGELES COUNTY METRO

In this section the authors present route-level results for LA Metro. The focus is on local bus service for which boardings per service hour and ridership data are available. The average daily ridership data are from December 2014. The authors employ both OLS and Poisson regressions using alternative dependent variables of boardings per service hour and average daily boardings. Also employed are alternative measures of P&R influence: the total number of P&R spaces at stops within a quarter mile of stops along the bus route and the total number of P&R lots along the bus route.

First OLS results using boardings per revenue hour are considered as the dependent variable. The results with total spaces along the route (entered as a quadratic term) are:

Table 11. OLS Regression with Boardings per Revenue Hour as Dependent Variable and Total Park-and-Ride Spaces along Route as Park-and-Ride Influence Variable

Linear regression		Number of obs	=	30	
		F(3, 26)	=	11.53	
		Prob > F	=	0.0001	
		R-squared	=	0.2862	
		Root MSE	=	10.452	

BperRH	Coef.	Robust Std. Err.	t	P>t	[95% Conf.	Interval]
TotalSPACENum	2.00E-02	4.07E-03	4.91	0	1.16E-02	2.83E-02
TotalSPACENumSqrd	-4.82E-06	8.90E-07	-5.41	0	-6.65E-06	-2.99E-06
RouteLengthMi	-0.4367271	0.2468826	-1.77	0.089	-0.9442015	0.0707473
_cons	58.08789	9.41299	6.17	0	38.73921	77.43656

The coefficient estimates on the P&R variables are very statistically significant, and the coefficient on the route length in miles is nearly statistically significant. The route length coefficient is negative and indicates that an increase in route length of one mile decreases boardings per revenue hour by 0.44.

The impact of increasing the total P&R spaces available along a route is given by the following graph.

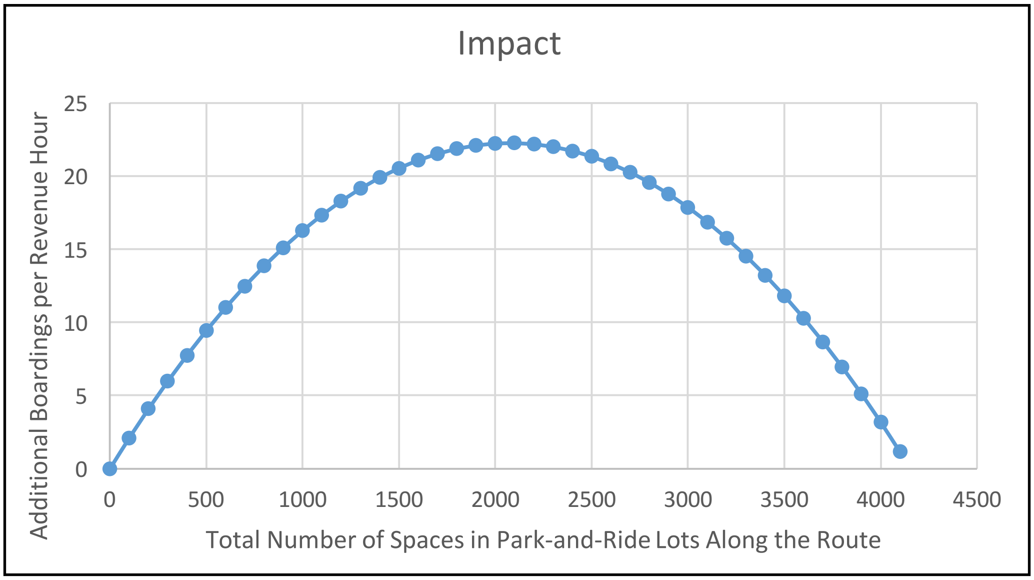

Figure 12. Impact of Total Park-and-Ride Spaces along a Route

The effect of additional spaces is always positive and peaks at more than 20 additional boardings per revenue hour when there are about 2000 total P&R spaces along the route. (The figure is drawn over the relevant range of total P&R spaces in the data.)

Using the alternative P&R variable (the number of P&R lots within a quarter of a mile of stops along the bus route) gives the following result:

Table 12. OLS Regression with Boardings per Revenue Hour as Dependent Variable and the Number of Park-and-Ride Lots along Route as Park-and-Ride Influence Variable

Linear regression	Number of obs	=	30
	F(2, 27)	=	8.1
	Prob > F	=	0.0018
	R-squared	=	0.2371
	Root MSE	=	10.604

BperRH	Coef.	Robust Std. Err.	t	P>t	[95% Conf.	Interval]
CountPnR	5.151005	1.642526	3.14	0.004	1.78082	8.521189
RouteLengthMi	-0.4256165	0.232335	-1.83	0.078	-0.9023285	0.0510956
_cons	57.60502	8.785419	6.56	0	39.57883	75.63121

Again, the route length is nearly statistically significant. The coefficient is negative and indicates that an increase in route length of one mile decreases boardings per revenue hour by 0.43, about the same influence as the previous model. The P&R influence variable is statistically significant and indicates that the addition of a P&R lot of average size along a route increases boardings per revenue hour by just over 5.

Regression analysis of influence on the numerator of the ratio boardings per revenue hour, namely, Average Daily Boardings, reveals that it is the driver of productivity. The data on Average Daily Boardings are counts as opposed to ratios, so Poisson regression can be used in addition to OLS.

Using Average Daily Ridership as the dependent variable and total spaces along the route as the P&R influence variable (analogous to the treatment for boardings per revenue hour above), this result is obtained:

Table 13. OLS Regression with Average Daily Riders as Dependent Variable and Total Park-and-Ride Spaces along Route as Park-and-Ride Influence Variable

Linear regression	Number of obs	=	30
	F(3, 26)	=	5.44
	Prob > F	=	0.0049
	R-squared	=	0.2287
	Root MSE	=	5830.1

AvgDailyRiders	Coef.	Robust Std. Err.	t	P>t	[95% Conf.	Interval]
TotalSPACENum	10.7197	3.199432	3.35	0.002	4.143173	17.29623
TotalSPACENumSqrd	-0.0026654	0.0007442	-3.58	0.001	-0.0041952	-0.0011356
RouteLengthMi	-47.34366	135.6041	-0.35	0.73	-326.0819	231.3946
_cons	11446.64	4943.421	2.32	0.029	1285.295	21607.99

In this case the P&R influence variables are statistically significant, and the route length variable is insignificant. The coefficient values are much larger than was the case for boarding per revenue hour, but that is because the ridership variable is orders of magnitude larger (as indicated by the descriptive statistics). The P&R impact is indicated in the following graph.

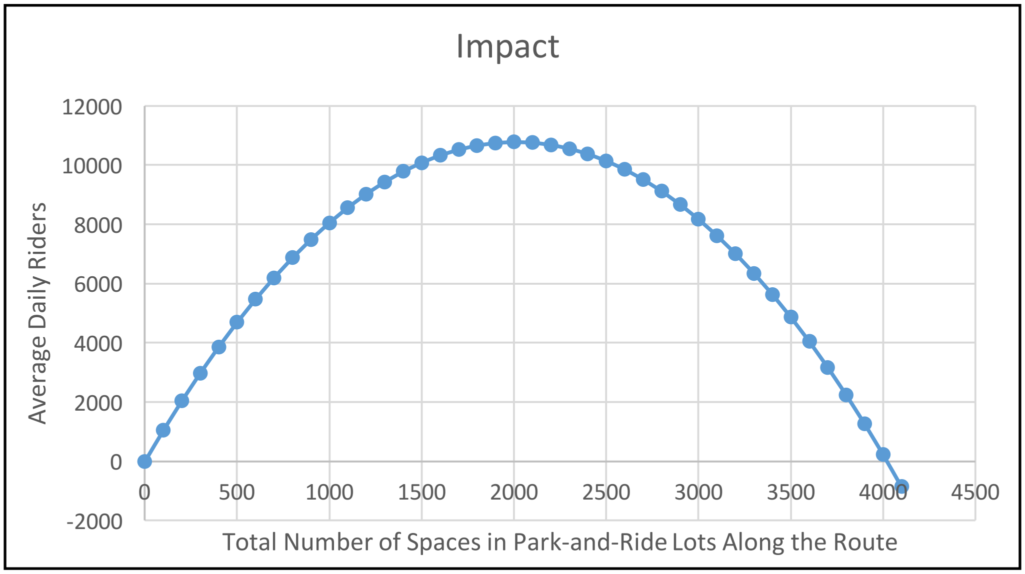

Figure 13. Impact of Total Park-and-Ride Spaces along a Route

The figure looks very similar to Figure 12. However, note that the vertical axis has different units: total boardings instead of boardings per revenue hour. Again, adding P&R spaces along a route yields positive additions to ridership over the relevant range, with a peak at about 2000 spaces, the same maximum point as with boardings per revenue hour as the dependent variable.

The regression using the number of P&R lots along a route gives:

Table 14. OLS Regression with Average Daily Riders as Dependent Variable and Number of Park-and-Ride Lots along Route as Park-and-Ride Influence Variable

Linear regression	Number of obs	=	30
	F(2, 27)	=	2.73
	Prob > F	=	0.0832
	R-squared	=	0.1257
	Root MSE	=	6091.1

AvgDailyRid~s	Coef.	Robust Std. Err.	t	P>t	[95% Conf.	Interval]
CountPnR	2308.35	1006.893	2.29	0.03	242.377	4374.323
RouteLengthMi	-27.08647	133.6691	-0.2	0.841	-301.3529	247.1799
_cons	10976.15	4748.821	2.31	0.029	1232.375	20719.93

The coefficient estimate on the number of P&R lots along a route is positive and statistically significant, and indicates that an additional average-sized P&R lot along the route contributes over 2300 additional daily riders.

The Poisson regression results are given in the table below.

Table 15. Poisson Regression with Average Daily Riders as Dependent Variable and Total Park-and-Ride Spaces along Route as Park-and-Ride Influence Variable

Poisson regression			Number of obs	=	30
			Wald chi2(3)	=	25.23
			Prob > chi2	=	0
Log pseudolikelihood	=	-43802.292	Pseudo R2	=	0.1844

AvgDailyRiders	Coef.	Robust Std. Err.	z	P>z	[95% Conf.	Interval]
TotalSPACENum	0.0007728	0.0002067	3.74	0	0.0003676	0.0011779
TotalSPACENumSqrd	-1.93E-07	4.64E-08	-4.17	0	-2.84E-07	-1.02E-07
RouteLengthMi	-0.0040831	0.0121965	-0.33	0.738	-0.0279878	0.0198217
_cons	9.347731	0.4394227	21.27	0	8.486478	10.20898

Again, the results indicate a statistically significant effect of total P&R spaces along the route. The probability of adding a boarding along the route by adding a P&R space is given in Figure 14.

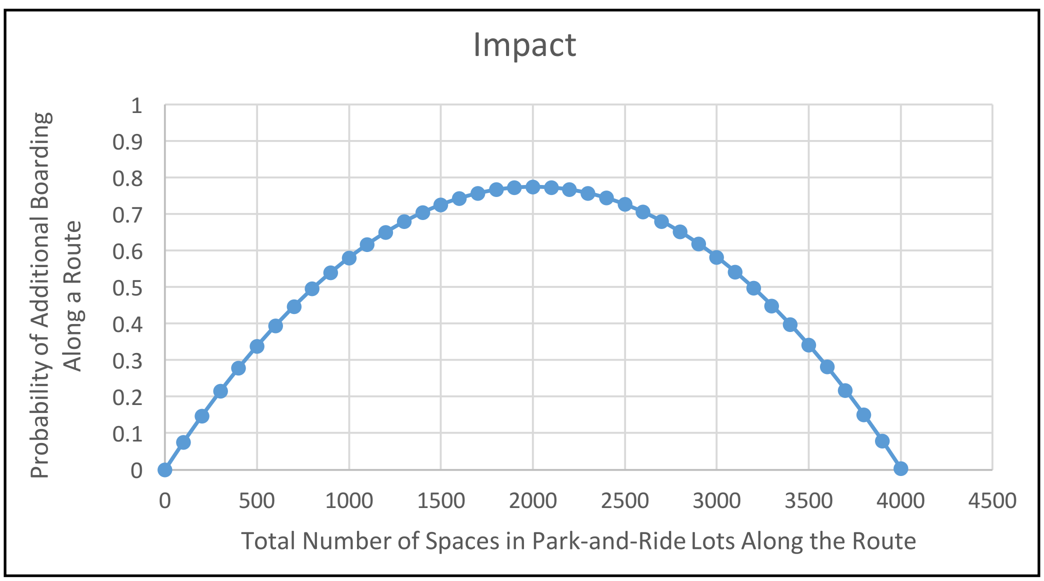

Figure 14. Impact of Total Park-and-Ride Spaces along a Route Based on Poisson Regression

COMMUNITY TRANSIT, SNOHOMISH COUNTY RESULTS

For Community Transit, OLS regression was used on all of the agency's 49 AM peak routes, including six operated for Sound Transit, the regional mass transit agency. After experimentation with several models, the best fit found for explaining boardings per service hour is the equation

$$(8)\ Boardings\ per\ service\ hour = 18.1 + 11.5 * P\&R Influence$$

where P&R influence is measured simply by a dummy variable, zero or one, signifying whether a route explicitly serves one of the listed P&R facilities named by the Community Transit agency, coded as a one. This variable was coded one for 36 of the 49 routes. The regression equation indicates that a route serving P&R exhibits a boarding per service hour that is 11.5 higher than routes that don't serve P&R. The R squared for this equation is 0.16, and both the P&R coefficient and the constant were highly significant, as well as the entire equation as signified by F=8.7, p=.005.

Table 16. Regression Summary, Community Transit, AM Peak Route Sample

SUMMARY OUTPUT

AM peak group

Regression Statistics	
Multiple R	0.395677512
R Square	0.156560693
Adjusted R Square	0.138615176
Standard Error	11.99289398
Observations	49

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1254.800681	1254.800681	8.724222979	0.004891571
Residual	47	6759.986782	143.829506		
Total	48	8014.787464			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	18.14008306	3.326230322	5.45364611	1.78788E-06	11.44857087	24.83159524	11.44857087	24.83159524
X Variable 1	11.46205496	3.880602042	2.953679566	0.004891571	3.655290741	19.26881917	3.655290741	19.26881917

PIERCE TRANSIT RESULTS

With Pierce Transit, the authors again were limited in data available, but did code all 50 AM routes for P&E influence, including the 14 series 500 routes operated under a contract from Sound Transit. We examined bus routes and rated those that served P&R lots as “1” and those that did not as “0.” The authors examined all the routes and found that 29 of them served P&R facilities. The authors again used an OLS model equation for boardings per service hour, leading to the following result.

$$(9)\ Boardings\ per\ service\ hour = 18.4 + 4.2 * P\&RInfluence$$

In this case, the R-squared was 0.06, and the coefficient for P&R influence was positive but statistically significant only at the level of p=.08, t=1.8. The constant was highly significant at t=10.2. The complete equation showed F=3.2 with a significance of p=.08

Table 17. Regression Summary, Pierce Transit, AM Peak Route Sample

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.251109
R Square	0.06305573
Adjusted R Square	0.043536057
Standard Error	8.221750868
Observations	50

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	218.3638082	218.3638082	3.230368257	0.078576913
Residual	48	3244.664992	67.59718733		
Total	49	3463.0288			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	18.37619048	1.794133128	10.24237844	1.14963E-13	14.76884411	21.98353684	14.76884411	21.98353684
P&R scoring	4.234154351	2.355812212	1.797322524	0.078576913	-0.50252348	8.970832182	-0.50252348	8.970832182

XI. SUMMARY WITH 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.

P&R service, including the effect of customers who arrive at P&R collection points by other means than a parked car, can be more cost-effective in generating bus ridership in a suburban setting than service that does not take advantage of P&R. The authors showed this for four case studies out of five. There was evidence of potential for savings in the three Seattle area bus systems, and with Los Angeles Metro. The result was not so clear for Santa Clara Valley Transportation Authority.

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.

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.[37]

- 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[38] 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 or San Jose. 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 the agencies consider engaging 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 report) can have operational benefit.

XII. SUGGESTIONS FOR FURTHER RESEARCH

Both the differences and the similarities between the findings in San Jose and in the Seattle area 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.[39]

APPENDIX A. THE CASE STUDIES

KING COUNTY METRO TRANSIT (KCM)

King County Metro Transit is the largest public transit agency in the Seattle region of Washington State, serving all of King County, which includes the cities of Seattle and Bellevue. Metro in 2013 operated 984 diesel and 131 electric trolley buses, the latter all within City of Seattle. Across the entire region, the agency maintains 130 P&R lots serving about 20,000 customers per day.[40] As a special focus of this study, a selected part of the diesel-electric-hybrid bus network where 20 large P&R lots are well used (east King County, across Lake Washington from Seattle) is also studied. This part of the Metro service territory is covered by the 200 series of bus routes. We also included the Sound Transit Regional Express 500 series, which are limited-stop express buses that travel in this East County part of the network. These buses are operated under contract by Metro.

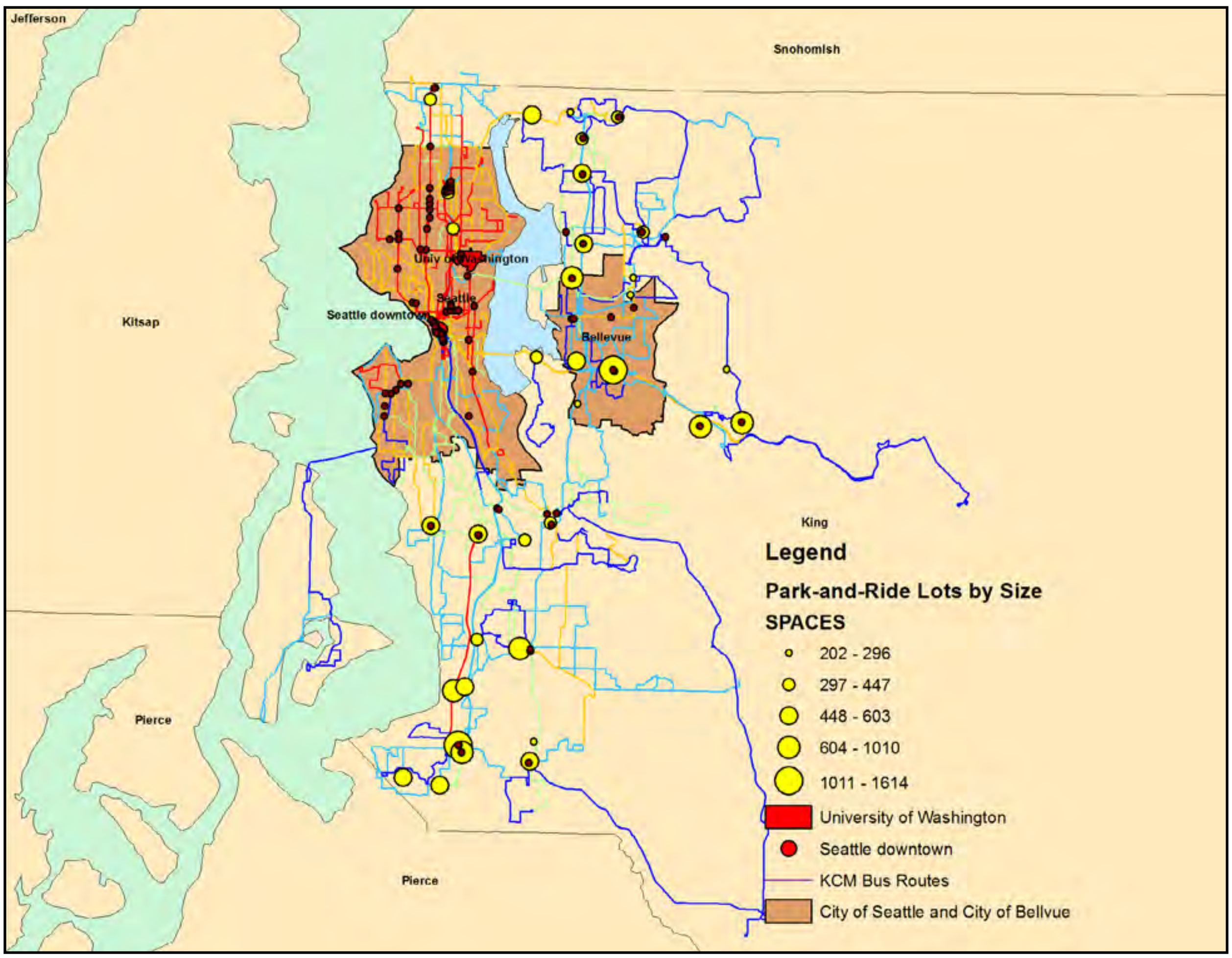

Figure 15. King County Metro Selected Bus Routes and Park-and-Ride Lots

SANTA CLARA VALLEY TRANSPORTATION AUTHORITY (VTA)

Santa Clara VTA is the public transit network for Santa Clara County in California, in which San Jose is the largest city, along with smaller cities such as Palo Alto and Mountain View. This network serves Silicon Valley, one of the US's premier technical industry areas. VTA in 2013 operated 371 motorbuses serving a 326-square-mile urbanized area, and also operated a 42-mile light rail network. VTA serves 40 P&R lots, most of which are operated by the agency, but some of which are operated by the commuter railroad CalTrain.[41]

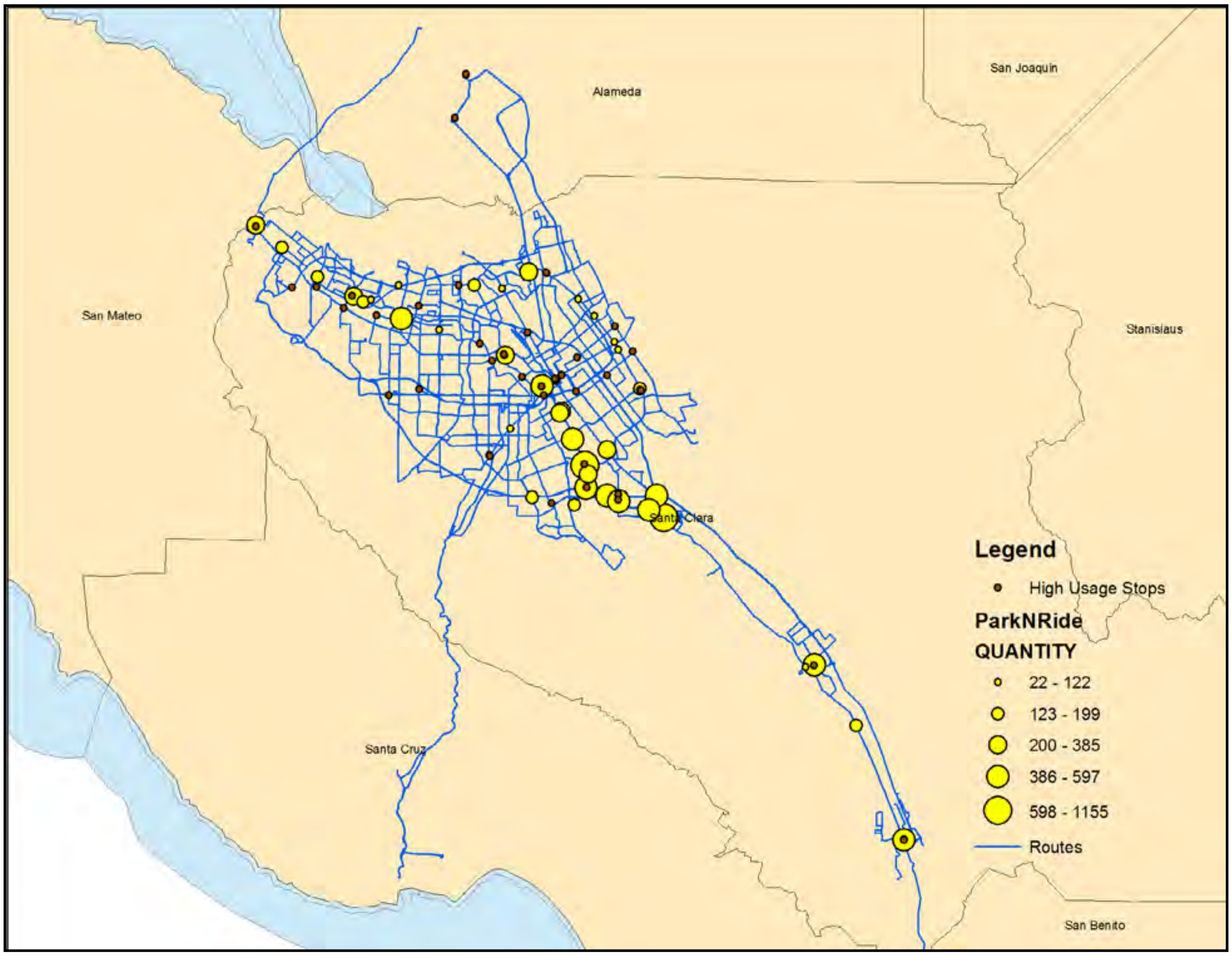

Figure 16. Santa Clara VTA Selected Bus Routes and Park-and-Ride Lots

LOS ANGELES COUNTY METROPOLITAN TRANSPORTATION AUTHORITY

LA Metro is the public transit network for Los Angeles County, in which Los Angeles is the biggest city, while Long Beach and Santa Monica are among prominent smaller jurisdictions. The service area is 1,433 square miles, home to nearly one-third of California residents. LA Metro operates 1,860 motorbuses, as well as commuter trains, a heavy rail subway, and light rail. There are around 150 park-and-ride lots, many of which are located near rail stations.[42]

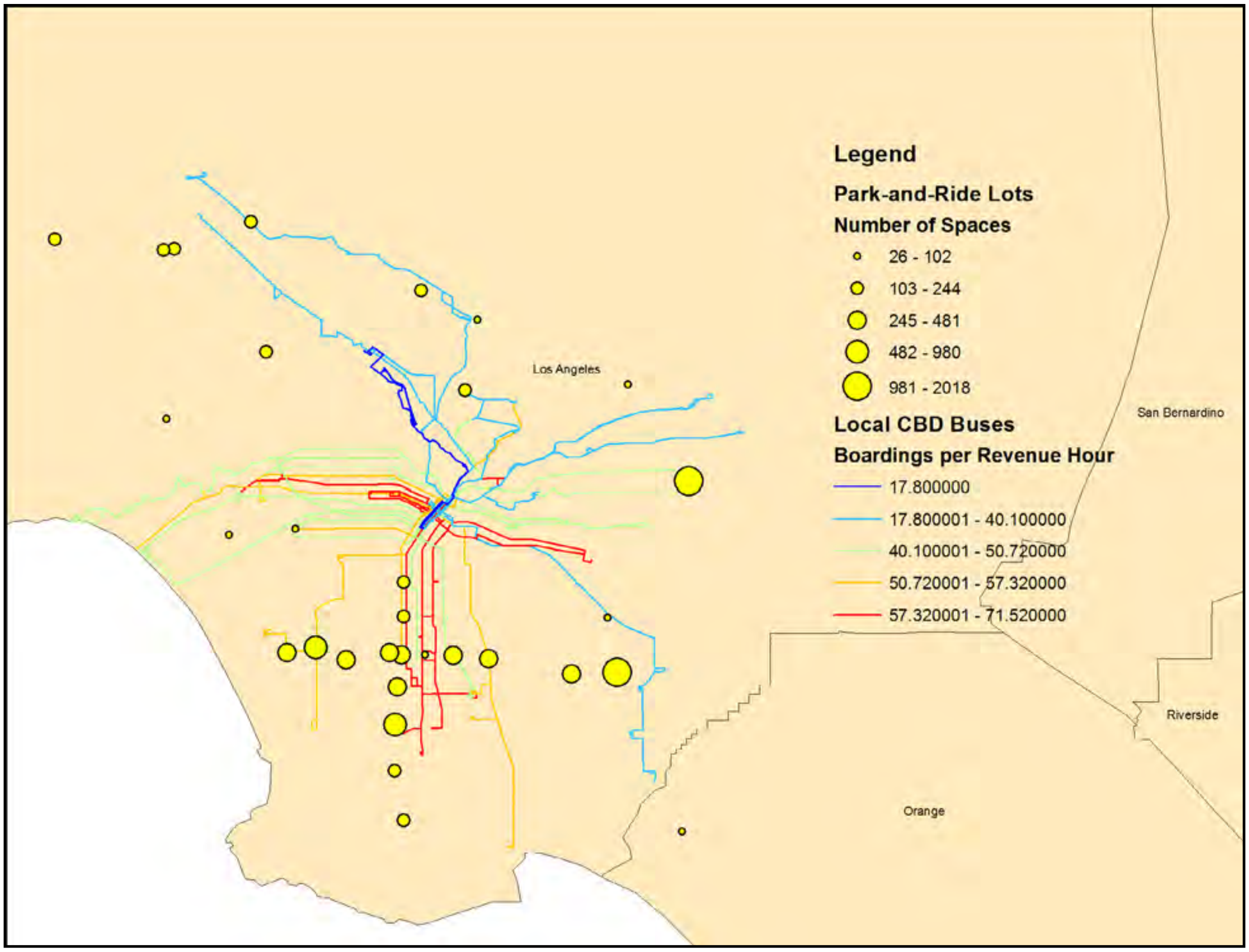

Figure 17. Los Angeles Metro Selected Bus Routes and Park-and-Ride Lots

COMMUNITY TRANSIT (SNOHOMISH COUNTY, WASHINGTON)

Community Transit is one of two public transit agencies serving Snohomish County, the part of the Seattle region adjacent to King County to the north. The City of Everett has its own bus system, which is not part of this research. This study includes all of the 178 buses operated by Community Transit, which includes local service with many bus stops, as well as a fleet of commuter buses that serve 45 P&R lots north of Seattle and end morning runs in downtown Seattle and at the University of Washington campus north of downtown. Some of the buses that Community Transit operates belong to Sound Transit's Regional Express 500 series service into downtown Seattle and downtown Bellevue.[43]

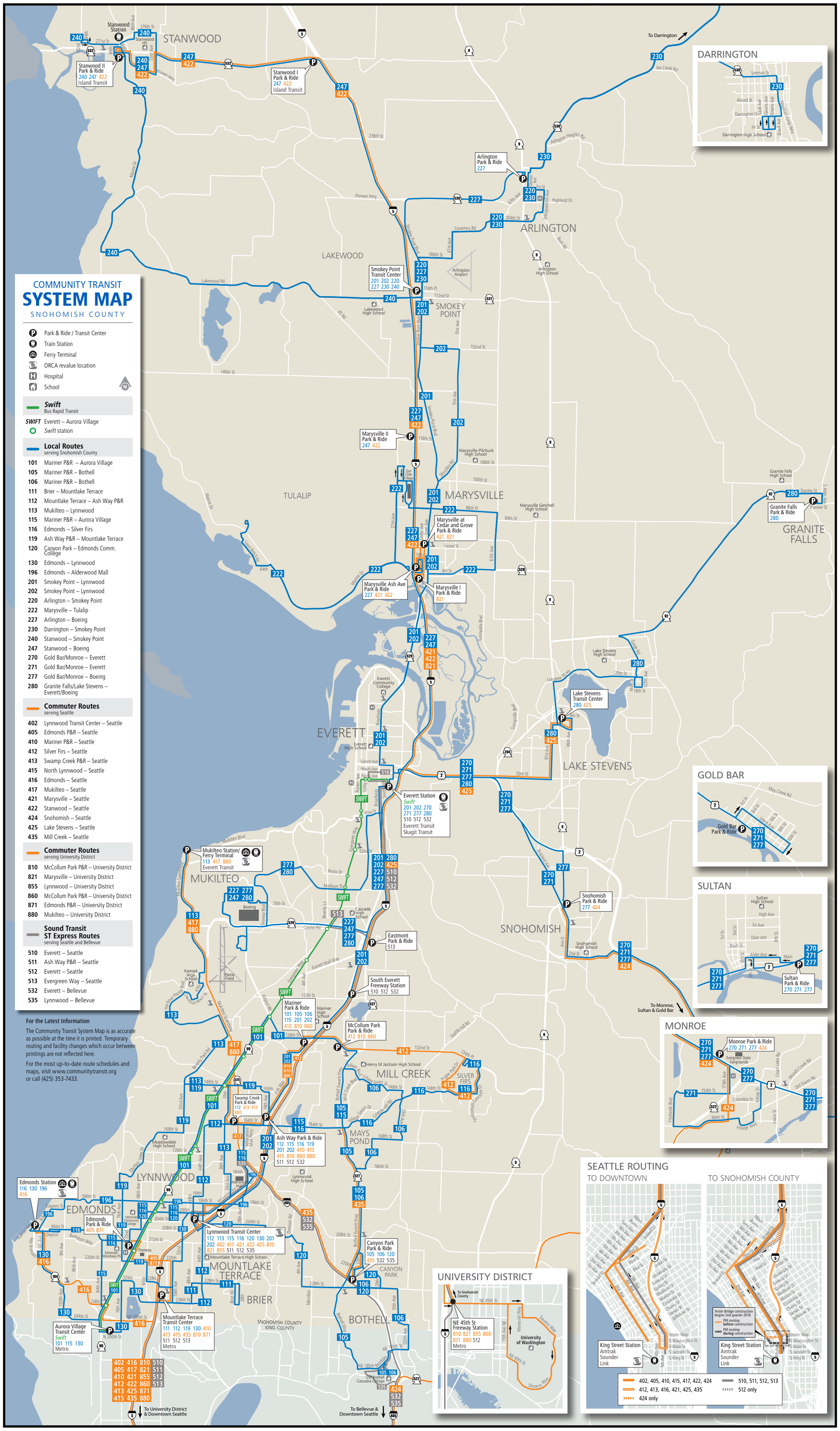

Figure 18. Map of the Community Transit System

Source: Community Transit, Snohomish County, Washington[44]

PIERCE TRANSIT (TACOMA, WASHINGTON AND VICINITY)

Pierce Transit is the public transit agency operating south of Seattle that serves Pierce County, in which the largest city is Tacoma. The Pierce Transit operates a fleet of 106 motorbuses serving local routes in the urbanized parts of the County. In addition, as is the case with King County Metro and Community Transit, Pierce operates some of the Sound Transit Regional Express 500 series buses that take morning commuters to downtown Seattle and downtown Bellevue. The agency serves 30 P&R lots.[45]

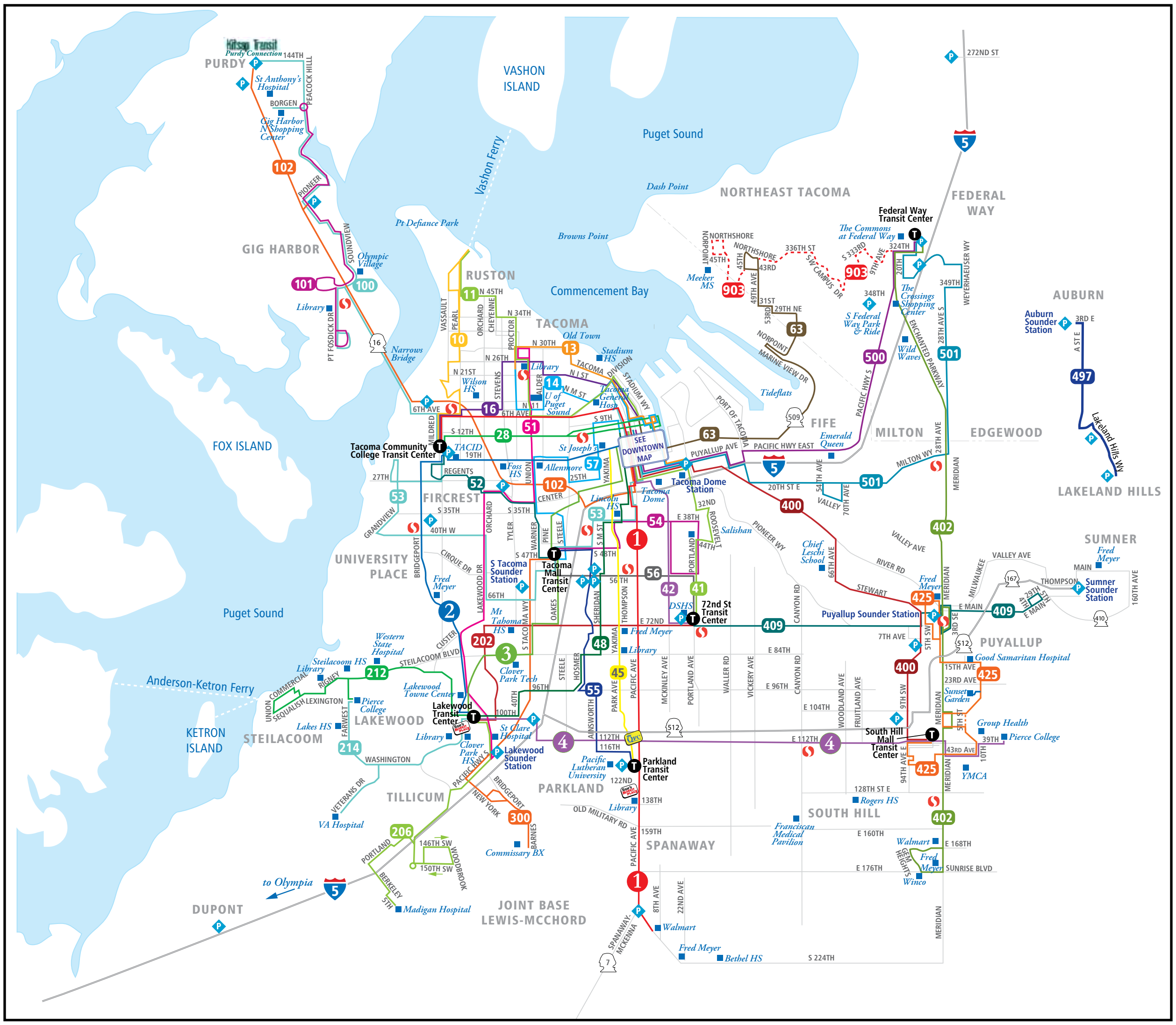

Figure 19. Map of the Pierce Transit System

Source: Pierce Transit, Lakewood, Washington[46]

APPENDIX B. A HEURISTIC EXAMPLE OF ROUTE-LEVEL AND STOP-LEVEL ANALYSIS

To conceptualize our empirical analysis, consider the following heuristic example (Figure 20).

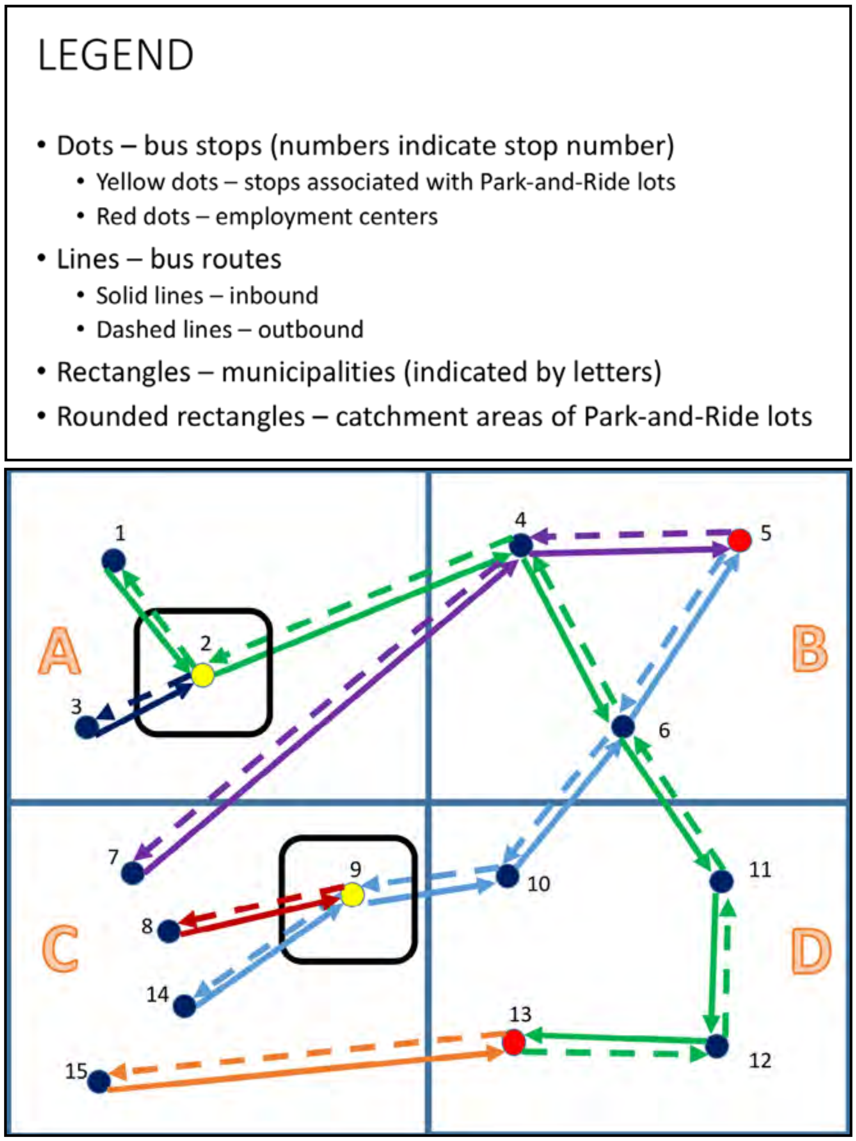

Figure 20. Heuristic Public Transit System

Figure 20 shows six bus routes (green, dark blue, purple, red, light blue, and orange) in each of two directions: inbound and outbound. All the routes except two (dark blue and red) connect directly to an employment center. Two of the routes (green and light blue) are served directly by P&R lots. Because of transfers, P&R lots may affect ridership on all routes except orange.[47] The clientele of stops associated with P&R lots may come from car commuters from the catchment area of the P&R lot, or from “feeder” lines. There are 15 stops, some serving more than one line. For a given route, time, and direction, each stop on a route has a sequence number, i.e., the order in which that stop appears in that route, time, and direction. (Typically, inbound and outbound buses use different stops – usually on opposite sides of the street. The authors have eliminated that complication in our heuristic model.)

This heuristic framework yields the following data concerning sequence numbers:

Table 18. Inbound and Outbound Sequence Numbers Implied by the Heuristic Public Transit System

INBOUND SEQUENCE NUMBERS

STOPS	Green	Dark Blue	Purple	Red	Light Blue	Orange
1	1					
2	2					
3		1				
4	3	2	2			
5			3		5	
6	4				4	
7			1			
8				1		
9				2	2	
10					3	
11	5					
12	6					
13	7					2
14					1	
15						1

OUTBOUND SEQUENCE NUMBERS

STOPS	Green	Dark Blue	Purple	Red	Light Blue	Orange
1	7					
2	6	1				
3		2				
4	5		2			
5			1		1	
6	4				2	
7			3			
8				2		
9				1	4	
10					3	
11	3					
12	2					
13	1					1
14					5	
15						2

For the framework outlined above, assume that the following represents boardings data for the morning commute.

Table 19. Hypothetical Boardings Data for the Heuristic Public Transit System

HYPOTHETICAL INBOUND BOARDINGS DATA

STOPS	Green	Dark Blue	Purple	Red	Light Blue	Orange	Total Boardings per Stop	P&R Dummy	P&R Capacity	Number of Lines Serving Stop
1	10						10	0	0	1
2	150	0					150	1	70	2
3		45					45	0	0	1
4	15		19				34	0	0	2
5			0		0		0	0	0	2
6	12				65		77	0	0	2
7			25				25	0	0	1
8				47			47	0	0	1
9				0	100		100	1	45	2
10					23		23	0	0	1
11	17						17	0	0	1
12	6						6	0	0	1
13	0					0	0	0	0	2
14					49		49	0	0	1
15						120	120	0	0	1
LENGTH	11.5	1	6	1	6.5	4				
NUMBER OF STOPS	7	2	3	2	5	2				
STOPS PER LENGTH	0.608695652	2	0.5	2	0.769230769	0.5				
SPEED	20	45	40	45	30	45				
REVENUE HOURS	0.575	0.022222222	0.15	0.022222222	0.216666667	0.088888889				
TOTAL BOARDINGS	210	45	44	47	237	120				
BOARDINGS PER REVENUE HOUR	365.2173913	2025	293.3333333	2115	1093.846154	1350				
P&R Influence	0.714285714	0	0	0	0.421940928	0				
P&R Dummy	1	0	0	0	1	0				
P&R Capacity	70	0	0	0	45	0				

The basic data in the table (blue background) is the hypothetical inbound boardings data. The data, while entirely hypothetical, nonetheless reflect some assumptions. First, only commuting toward employment centers occurs. Thus, there are zero boardings at the terminus of each route. Second, boardings at P&R affiliated stops are larger than at other stops (and roughly proportional to the capacity of each P&R lot). The length of the routes (gold background) is a given (and corresponds roughly to the lengths of the routes indicated in Figure 20).

The values with a green background are “computed values” – values computed from the basic boardings matrix and length variables. Summing by rows gives aggregates by route. These route-level variables appear in the cells with a green background below the gold-highlighted row. Stop-level variables are computed for each stop based on data in each row of the blue background data. The stop-level variables appear in the green background area to the right of the blue background boardings data. Basically, route-level analysis deals with row aggregates, and stop-level analysis deals with column aggregates. There are possibilities for introducing some row-aggregate data into column aggregates, and vice versa, as discussed later in this report.

The hypothetical data illustrate the two kinds of analysis employed in this paper: route-level analysis and stop-level analysis. Route-level analysis examines the characteristics of routes. In the heuristic illustration there are six routes. Based on the data represented above for these routes, stop data can be aggregated for routes to obtain the route-level data set, indicated below.

Table 20. Boardings per Revenue Hour and Related Data for the Heuristic Public Transit System

Route	BOARDINGS PER REVENUE HOUR	LENGTH	SPEED	NUMBER OF STOPS	P&R Influence	P&R Dummy	P&R Capacity
Green	365.2173913	11.5	20	7	0.714285714	1	70
Dark Blue	2025	1	45	2	0	0	0
Purple	293.3333333	6	40	3	0	0	0
Red	2115	1	45	2	0	0	0
Light Blue	1093.846154	6.5	30	5	0.421940928	1	45
Orange	1350	4	45	2	0	0	0

Using this data, a regression model can be estimated with Boardings per Revenue Hour as the dependent variable, and the remaining variables as independent variables. The dependent variables may include two of the three variables indicated in red font, and one of the variables indicated in blue font. Speed is determined by Length and Number of Stops, so it cannot be included in a regression with either of the other two because of collinearity. (Length and Speed are used.) Similarly, any two of the variables in blue font are collinear. (P&R Influence is used in this example.)

The estimates for the route-level regression are:

Table 21. Route-Level Regression Result for the Heuristic Public Transit System

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.998142229
R Square	0.996287909
Adjusted R Square	0.990719773
Standard Error	75.4882644
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	3058828.549	1019609.516	178.9266371	0.005562966
Residual	2	11396.95612	5698.478062		
Total	5	3070225.505			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-3387.714696	1324.629012	-2.55748188	0.124884277	-9087.133331	2311.703938	-9087.133331	2311.703938
LENGTH	-225.6807971	28.11961344	-8.025743229	0.015172496	-346.6697286	-104.6918656	-346.6697286	-104.6918656
SPEED	125.8014856	28.7534669	4.375176252	0.04847369	2.085302697	249.5176684	2.085302697	249.5176684
P&R Influence	5310.361941	735.9338116	7.215814597	0.01866951	2143.894317	8476.829564	2143.894317	8476.829564

Each of these variables has the expected sign and significance. Boardings per Revenue Hour decline with the length of the route, and increase with speed along the route. The P&R influence variable (the percentage of total boardings occurring at a stop associated with a park-and-ride lot) is positive and strongly statistically significant.

Exactly the same data can be used to estimate an alternative regression equation, using stop-level data (based on column sums). The dependent variable is Boardings per Stop. Possible independent variables include a P&R Dummy variable or a P&R Capacity variable, and the Number of Routes serving a particular stop. The P&R Dummy and the P&R Capacity are collinear. P&R Capacity is employed in the example. Looking at Boardings per Stop in the hypothetical data referred to above allows estimating the stop-level regression given by:

Table 22. Stop-Level Regression Result for the Heuristic Public Transit System

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.73030262
R Square	0.533341917
Adjusted R Square	0.455565569
Standard Error	33.72753303
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	15601.17552	7800.587761	6.857379341	0.010327442
Residual	12	13650.55781	1137.546484		
Total	14	29251.73333			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	48.64165931	27.99442367	1.737548159	0.107861189	-12.35295013	109.6362688	-12.35295013	109.6362688
P&R Capacity	1.711738747	0.490879892	3.487082635	0.004487406	0.642203341	2.781274153	0.642203341	2.781274153
Number of Lines Serving Stop	-10.64165931	20.11232445	-0.529111358	0.6063775	-54.46264987	33.17933124	-54.46264987	33.17933124

The P&R Capacity variable has the expected sign and significance. Because the units of P&R Capacity are spaces, it is possible to interpret the coefficient on the P&R Capacity variable as the marginal impact of an additional space on boardings. Thus, an additional space at a P&R lot would increase boardings at the associated stop by 1.7 riders.

APPENDIX C. DESCRIPTIVE STATISTICS OF THE SAMPLES

Stop -Level Analysis

KCM

Variable	Obs	Mean	Std. Dev.	Min	Max
AM Boardings	6,321	10.11004	27.98965	0	733.8668
Number of Bus Lines	6,321	1.582503	1.256957	1	19
Quarter Mile Dummy	6,321	0.0930233	0.290488	0	1
Quarter Mile Capacity	6,321	24.07926	121.5429	0	1614
Population Density within a quarter mile of a stop	6,321	5839.187	4617.272	1.114756	35207.31
Median Household Income within a quarter mile of a stop	6,321	52993.28	25041.8	3520	190417
Total Number of Employed Persons within a quarter mile of a stop	6,321	1013.021	313.0951	46	2820
Natural logarithm of Median Household Income within a quarter mile of a stop	6,321	10.75773	0.5213081	8.166216	12.15697
Natural logarithm of Total Number of Employed Persons within a quarter mile of a stop	6,321	6.871508	0.3335464	3.828641	7.944492
Natural logarithm of Population Density within a quarter mile of a stop	6,321	8.289489	1.181536	0.1086359	10.46901
Natural logarithm of the number of spaces in the nearest park-and-ride lot	6,321	4.509727	1.343232	2.197225	7.386471
Natural logarithm of the distance to the nearest park-and-ride lot	6,321	8.46682	0.9990408	2.960813	10.15481

VTA

Variable	Obs	Mean	Std. Dev.	Min	Max
AM Boardings	2,373	2.210282	3.160282	0	51
Number of Bus Lines	2,373	1.217025	0.5271836	1	5
Quarter Mile Dummy	2,373	0.0670038	0.2500813	0	1
Quarter Mile Capacity	2,373	22.66035	110.0352	0	1155
Population Density within a quarter mile of a stop	2,373	7599.162	4254.235	0.7843507	28508.55
Median Household Income within a quarter mile of a stop	2,373	92208.61	35075.4	22776	250001
Total Number of Employed Persons within a quarter mile of a stop	2,373	879.0719	271.038	228.5	2525.25
Natural logarithm of Median Household Income within a quarter mile of a stop	2,373	11.36173	0.3781453	10.03346	12.42922
Natural logarithm of Total Number of Employed Persons within a quarter mile of a stop	2,373	6.733751	0.3015335	5.431536	7.834095
Natural logarithm of Population Density within a quarter mile of a stop	2,373	8.645622	1.094975	-0.242899	10.25796
Natural logarithm of the number of spaces in the nearest park-and-ride lot	2,373	5.258127	0.8872343	3.091043	7.051856
Natural logarithm of the distance to the nearest park-and-ride lot	2,373	8.546036	0.9646226	3.665396	10.9175

Route-Level Analysis

KCM

Variable	Obs	Mean	Std. Dev.	Min	Max
Boardings Per Revenue Hour	177	49.01291	22.86366	4.302027	109.1164
MPH	177	15.77912	5.066547	6.845767	31.03317
Total spaces in park-and-ride lots along the route	177	468.2712	472.0876	0	1614
Total spaces in park-and-ride lots along the route squared	177	440885.4	716346.3	0	2604996
Seattle Core Dummy	177	0.6497175	0.4784117	0	1

VTA

Variable	Obs	Mean	Std. Dev.	Min	Max
Boardings Per Revenue Hour	57	21.73158	7.100909	6.1	36.8
Total spaces in park-and-ride lots along the route	57	358.3158	298.3434	0	1155
Total spaces in park-and-ride lots along the route squared	57	215837.4	324912.2	0	1334025
Core Dummy	57	0.3157895	0.4689614	0	1
Limited Dummy	57	0.0701754	0.2577131	0	1

LA

Variable	Obs	Mean	Std. Dev.	Min	Max
Boardings Per Revenue Hour	30	48.14233	11.71403	17.8	71.52
Average Daily Ridership	30	11826.33	6285.569	1338	25365
Total spaces in park-and-ride lots along the route	30	494.5667	1041.938	0	4036
Total spaces in park-and-ride lots along the route squared	30	1294043	4106357	0	1.63E+07
Count of number of park-and-ride lots along the route	30	0.7333333	0.980265	0	4
Route length in miles	30	31.10802	8.954876	12.54851	53.64589

APPENDIX D. DENSITY VS. PARK-AND-RIDE

The authors were interested in looking at the relative strength of housing density and P&R as influenced on bus transit ridership. The cleanest way to make the comparison (both in terms of comparing P&R to density and in terms of comparing one system to another) is to cast everything in terms of elasticities (i.e., percentage changes in density vs. percentage changes in park-and-ride), and then compare the percentages between P&R and density, and compare these elasticities between the two systems. For this to be read off directly from the Poisson regression equation, the independent variables need to be logarithmic transformations of the original variables. The problem is that all the P&R variables are essentially dummy variables. The Quarter Mile Dummy is a dummy variable, equal to either 0 or 1. The logarithm of zero is undefined, whereas the logarithm of density is perfectly fine. So one is left with comparing an elasticity of density (1% change in density leads to a small percent change in boardings), to an absolute change in P&R (there is or is not a P&R lot within a quarter mile) with a percent change in boardings. That's what the "regular" Poisson gives us.

That said, some good results can be shown.

Table 23. King County Poisson Regression Using QMDummy

Poisson regression			Number of obs	=	6,321		
			Wald chi2(5)	=	564.25		
			Prob > chi2	=	0		
Log pseudolikelihood	=	-71429.715	Pseudo R2	=	0.2224		

ROUNDON	Coef.	Robust Std. Err.	z	P>z	[95% Conf.	Interval]
COUNTTOTAL	0.157815	0.0200694	7.86	0	0.1184798	0.1971503
QuarterMileDummy	**1.05605**	0.1076717	9.81	0	0.8450175	1.267083
lnPopDens	**0.4770794**	0.0543236	8.78	0	0.3706072	0.5835517
lnMin_B19013e1	-0.1290285	0.0706135	-1.83	0.068	-0.2674284	0.0093715
lnMax_B23025e4	0.5071294	0.1614605	3.14	0.002	0.1906726	0.8235861
_cons	-4.365956	1.25215	-3.49	0	-6.820125	-1.911787

The presence of a P&R lot within a quarter mile of a stop leads to a 1.05% increase in boardings at that stop. Recall that for KCM there is an average of 5.9 stops within a quarter mile of a P&R lot, while for VTA there is an average of 7.8 stops within a quarter mile of a P&R lot. A 1% increase in density results in a 0.48% increase in boardings. Both results are highly statistically significant (z-values/t-stats of 9.81 and 8.78, respectively).

Table 24. VTA Poisson Regression Using QMDummy

Poisson regression			Number of obs	=	2,373	
			Wald chi2(5)	=	326.58	
			Prob > chi2	=	0	
Log pseudolikelihood	=	-5264.4094	Pseudo R2	=	0.1116	

TOTALRIDERS	Coef.	Robust Std. Err.	z	P>z	[95% Conf.	Interval]
TOTALCOUNT	0.4663701	0.0454978	10.25	0	0.377196	0.5555443
QuarterMileDummy	**0.7546589**	0.1062149	7.11	0	0.5464816	0.9628362
lnAvg_B19013e1	-0.3351254	0.074623	-4.49	0	-0.4813837	-0.188867
lnAvg_B23025e4	0.3458637	0.1059983	3.26	0.001	0.1381109	0.5536166
lnPopDens	**0.1952375**	0.0476164	4.1	0	0.1019111	0.288564
_cons	-0.1468349	1.280329	-0.11	0.909	-2.656233	2.362563

By comparison, for VTA the presence of a P&R lot within a quarter mile of a stop leads to a 0.75% increase in boardings at that stop. A 1% increase in density results in a 0.2% increase in boardings. Both results are highly statistically significant (z-values/t-stats of 7.11 and 4.1, respectively) but less statistically significant than for KCM.

Table 25. KCM Poisson Regression Using Distance-Decay Function

Poisson regression			Number of obs	=	6,321	
			Wald chi2(6)	=	498.54	
			Prob > chi2	=	0	
Log pseudolikelihood	=	-71934.821	Pseudo R2	=	0.2169	

ROUNDON	Coef.	Robust Std. Err.	z	P>z	[95% Conf.	Interval]
COUNTTOTAL	0.1702552	0.0207485	8.21	0	0.1295889	0.2109216
lnREG_SPACES	**0.0725646**	0.024395	2.97	0.003	0.0247512	0.120378
lnNEAR_DIST	**-0.2987086**	0.0409151	-7.3	0	-0.3789008	-0.2185165
lnPopDens	**0.5289155**	0.0549829	9.62	0	0.4211511	0.63668
lnMin_B19013e1	-0.1674258	0.0671871	-2.49	0.013	-0.2991102	-0.0357414
lnMax_B23025e4	0.5615903	0.1649103	3.41	0.001	0.238372	0.8848086
_cons	-2.485067	1.251699	-1.99	0.047	-4.938352	-0.0317833

The authors define a distance-decay variable of the form (Capacity/Distance$^{\gamma}$). With a logarithmic transformation of the right-hand side of the Poisson equation, this gives two new variables, *ln*Capacity and *ln*Distance. These are defined for all observations, and have standard elasticity interpretations. For KCM, the results of incorporating the distance-decay formulation are as follows.

For each 1% increase in spaces, the number of boardings at a stop at the average distance from a P&R lot increases by 0.07%. The effect of increasing the number of spaces at a P&R lot by 1% is strongly influenced by the distance of the stop from the P&R lot. For each 1% increase in distance, the percent change in ridership at such a stop decreases by 0.3%. The effect of a 1% increase in population density is about a 0.53% increase in boardings at a stop within a quarter mile of a P&R lot. All the results are statistically significant, the results for distance and density especially so, suggesting that these variables are the most significant in determining the result.

Table 26. VTA Poisson Regression Using Distance-Decay Function

Poisson regression			Number of obs	=	2,373
			Wald chi2(6)	=	328.18
			Prob > chi2	=	0
Log pseudolikelihood	=	-5321.3844	Pseudo R2	=	0.102

		Robust				
TOTALRIDERS	Coef.	Std. Err.	z	P>z	[95% Conf.	Interval]
TOTALCOUNT	0.4668109	0.0455926	10.24	0	0.3774509	0.5561708
lnQUANTITY	**0.0457416**	0.0292318	1.56	0.118	-0.0115516	0.1030347
lnNEAR_DIST	**-0.1742338**	0.0450712	-3.87	0	-0.2625717	-0.0858959
lnAvg_B19013e1	-0.2537793	0.0731053	-3.47	0.001	-0.397063	-0.1104956
lnAvg_B23025e4	0.3664808	0.1197535	3.06	0.002	0.1317683	0.6011934
lnPopDens	**0.1808069**	0.0449739	4.02	0	0.0926596	0.2689542
_cons	0.220165	1.502881	0.15	0.884	-2.725427	3.165757

For each 1% increase in spaces, the number of boardings at a stop at the average distance from a P&R lot increases by 0.04%. The effect of increasing the number of spaces at a P&R lot by 1% is strongly influenced by the distance of the stop from the P&R lot. For each 1% increase in distance, the percent change in ridership at such a stop decreases by 0.17%. The effect of a 1% increase in population density is about a 0.18% increase in boardings at a stop within a quarter mile of a P&R lot. The results for distance and density are statistically significant, suggesting that these variables are the most significant in determining the result. The result for the number of spaces in a P&R is of the expected sign but not statistically significant.

The upshot of these estimations is that both proximity to a park-and-ride lot and population density in the neighborhood of a stop are strongly significant influences on ridership. Generally, both proximity to a park-and-ride lot and the capacity of the park-and-ride lot are strongly significant influences, with proximity the greater influence. The estimates involving the quarter-mile dummy variable suggest that the influence of the park-and-ride variable is marginally greater than the influence of the population density variable.

ABBREVIATIONS AND ACRONYMS

ACS	American Community Survey
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
CT	Community Transit
ESRI	Environmental Systems Research Institute
FTA	Federal Transit Administration
GIS	Geographic Information System
KCM	King County Metro
LA	Los Angeles
MPO	Metropolitan Planning Organization
NTD	National Transit Database
OLS	Ordinary Least Squares
P&R	Park and Ride
PT	Pierce Transit
QM	Quarter Mile
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
USDOT	U.S. Department of Transportation
VMT	Vehicle Miles Traveled
VTA	Santa Clara Valley Transportation Authority

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ENDNOTES

1. The variable Boardings Per Revenue Hour is defined as the number of people who board all the buses on a particular route over a defined period of time divided by the number of hours that these buses are operating in service on the route. Hours of service include only the periods where customers are able to board the bus and ride, not the time before and after the minutes when the bus is actually running the route in service to customers.

2. Both King County Transit and Santa Clara Valley Transit Authority also deploy non-bus transit (light rail). These non-bus options are not included in the data on which our regressions are based.

3. Poisson regression is used because the data are integer counts, for which Poisson regression is the most appropriate technique and because Poisson regression is robust to many violations of underlying assumptions, as explained in the section.

4. Federal Transit Administration, 2013 Annual Database Agency Information, https://www.transit.dot.gov/ntd/data-product/2013-annual-database-agency-information (accessed July 22, 2016).

5. U.S. Census, SELECTED ECONOMIC CHARACTERISTIC American Community Survey (ACS) 5-Year Estimate, 2010-2014.

6. Accounting for differences in regional prices, per capita real personal income is only about 11% greater in the San Jose Metropolitan Statistical Area than in the Seattle Metropolitan Statistical Area. Bureau of Economic Analysis, Real Personal Income [RPI1] by Metropolitan Statistical Area, http://www.bea.gov/regional/ (accessed May 4, 2016).

7. U.S. Census, ACS 2010-2014 5-Year Estimates for Urban Areas, Table S0801.

8. Data obtained from GIS files for King County Metro and Santa Clara Valley Transportation Authority.

9. We made the calculations in Tables 3 and 4 based on Census Urbanized Areas to make the data compatible with statistics in the 2016 Public Transportation Fact Book (American Public Transportation Association, Fall, 2016).

10. Duncan, Michael and David Cook, “Is the provision of park-and-ride facilities at light rail stations an effective approach to reducing vehicle kilometers traveled in a US context?” Transportation Research Part A, 66 (2014): 65-74.

11. These include varieties of dense residential and commercial development that transit can serve well, because origins and destinations of travelers are concentrated, meaning transit vehicles do not have to stop so often to pick up and discharge passengers. When this concentration of origins and destinations exists, multi-passenger transit

vehicles can board and unload multiple travelers in fewer locations, thus making operations efficient compared to serving passengers at low-volume bus stops.

12. See Metropolitan Transportation Commission, “Plan Bay Area 2040,” (2015), http://planbayarea.org/pdf/Project_Update_Call_for_Projects_and_Needs_Assessments_Guidance.pdf (accessed January 20, 2016).

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16. U.S. Census Bureau, “Patterns of Metropolitan and Micropolitan Population Change: 2000 to 2010,” http://www.census.gov/population/metro/data/c2010sr-01patterns.html (accessed July 23, 2016).

17. Spillar, Robert J., Park and Ride Planning and Design Guidelines, (New York: Parsons Brinkerhoff, 1997).

18. 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.

19. Federal Transit Administration, National Transit Database, 2013 Annual Database Operating Expenses, https://www.transit.dot.gov/ntd/data-product/2013-annual-database-operating-expenses (accessed July 23, 2016)

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27. Turnbull, Katherine; John Evans, and Herbert Levinson, "Park-And- Ride/Pool: Traveler Response to Transport System Changes," Chapter 3; Report 95, Transit Cooperative Research Program; Transportation Research Board, 2004; Qian, Zhen (Sean), and Michael Zhang, "The economics of parking provision for the morning commute," Transportation Research Part A, Vol.45(9) (2011): 861-879.

28. Turnbull, Katherine; John Evans, and Herbert Levinson, "Park-And- Ride/Pool: Traveler Response to Transport System Changes," Chapter 3; Report 95, Transit Cooperative Research Program; Transportation Research Board, (2004), 3-2.

29. Consider the example of 40 passengers commuting to a downtown employment center from a sprawling neighborhood in the suburbs. For the bus to serve these passengers close to their residential locations, 30 minutes or more could be easily consumed, in addition to the 30 minutes it required to get all the way downtown from the last bus stop in this example suburb. So the boardings per service hour would be 40 in this scenario. On the other hand, if these 40 passengers made their way to a single pick-up point at a P&R facility, the time assigned to getting these passengers aboard the bus in the morning would be reduced to about 5 minutes, and the bus could then begin the 30 minutes to reach downtown. This means that the boardings per service hour would drop down to 40 passengers divided by 35 minutes, or 69 boardings per service hour, a gain of 71 percent.

30. We chose a quarter mile as the standard distance that people are willing to walk to get the bus. Many transit centers have stops located at the transit center. However, with modern GPS (Geographic Positioning System) technology, stops are typically identified as distinct from the transit centers where they are located. Depending on the layout of the transit center, stops located at the transit center may show up as a few hundred feet away.

31. There are several stops both for KCM and VTA where the count of boardings is zero. This is an important technical point when running Poisson regressions.

32. See Wooldridge, Jeffrey M., Introductory Econometrics: A Modern Approach, 5th edition (South-Western Publishing Company, 2013), 604-609; Wooldridge, Jeffrey M., Econometric Analysis of Cross Section and Panel Data, 2nd edition. (MIT Press, 2010), 723-776

33. Routes 212, 214, 216, 217, 218, 219, 221, 226, 240, 241, 245, and 271.

34. King County Metro Transit, “2014 Rider Survey Final Report Summary,” (April, 2015), http://metro.kingcounty.gov/am/reports/2014/2014-rider-survey-summary.pdf (January 20, 2016), pg. 38.

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36. This is proved by noting 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.

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47. We assume that riders on the orange route commute toward one of the employment centers.

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