Modelling Carpool and Transit Park-and-Ride Lots

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Park-and-Ride (PnR) lots are an increasingly common element of many areas' plans for air quality conformity. By making it easier to carpool or use transit, PnR lots should theoretically reduce the number of persons driving alone, especially to work. However, accessing a PnR lot still requires a vehicle trip (usually a "cold start" trip) and the vehicle-miles travelled (VMT), congestion impact, and emissions of the PnR access trip should be accounted for in order to produce a proper accounting of the potential air quality benefits of PnR lots.

Few, if any, travel models estimate the impacts of carpool PnR lots. If carpool lots are to be reasonably considered as part of a region's air quality conformity strategy, their impacts must be analyzed. Some *ad hoc* manual methods or geographic information system (GIS)-based have been developed, but the author is unaware of any network-based models which are sensitive to such lots. Careful, detailed analysis of carpool lots is important, because such lots are generally not considered to have a major impact on carpool formation (and properly so). Further, given the time and distance necessary to access the lot, it is entirely possible that some carpool PnR lots could actually *increase* VMT. The author contends that in order to accurately assess this trade-off, a more rigorous network-based methodology is needed.

Many travel models in the larger urban areas accommodate transit PnR lots. The analyst must usually manually connect each lot to the appropriate transit stop nodes, although some models have automated all or part of this process. In such cases, lot choice is unaffected by the lot's characteristics or highway conditions. Also, few models account for the vehicle trips and VMT resulting from drive-access transit trips. Although usually small on a regional scale, this VMT can be more significant when comparing air quality scenarios. As with carpool PnR lots, it is not clear that adding transit PnR lots always improves air quality.

The procedure described here addresses these concerns. It permits the rigorous analysis of the impacts of both carpool and transit PnR lots within a network-based model structure. This procedure has been implemented in the travel model recently developed for the Reading, Pennsylvania area (Berks County). Although not a large metropolitan area (urban area population about 330,000), Reading is in moderate non-attainment of air quality standards and is required to develop plans to achieve attainment. The new travel model was developed with the specific goal of being reasonably sensitive to the variety of transportation control measures (TCMs) that are being considered in large and small areas across the country. The methodology described here should be generally applicable to other areas as well.

As noted above, estimating the impacts of transit PnR lots with a regional travel model is not new. However, it is only recently that automated procedures have been developed to account for peak period highway network conditions in modelling PnR lot access, such as in the new model being developed for the Washington, D.C. area. The Seattle area's model reportedly takes advantage of new capabilities in the EMME/2 software package to examine the home-lot and lot-work connections. However, the author believes that the Reading model is the first regional travel model to handle both carpool and transit PnR lots in a consistent manner.

Methodology

The Reading methodology handles PnR lots through changes in three major model components: transit network coding, highway network coding, and the mode choice application program. These are described below.

Transit Network Coding

This procedure, along with certain simplifying assumptions, permits easier transit network coding. The analyst is not required to use judgment in identifying the zones that are in each PnR lot's service area and is not required to code specific zone-lot connector links. In the transit path building and skimming process, no drive-access paths are built and no PnR lots are specified; only walk access is coded.

In transit network coding, the analyst need only ensure that transit routes which serve a PnR lot have walk access connections from the zone in which the lot is located. That is, if there is a transit PnR lot in zone 324, then zone 324 must have a proper walk connection to the nearest transit stop node. In some cases, this may require coding transit routes somewhat differently than they actually operate.

One of the trade-offs of using this procedure is that the exact location of transit PnR lots cannot be specified; only the zone in which the lot is located is specified (this can be viewed as both an advantage and a disadvantage). Thus, this procedure effectively requires zones that are fairly small in area and basically assumes that the PnR lot is in the vicinity of the zone's center. It also assumes that there is never more than one PnR lot in a zone, or that if there are more than one, they effectively function as one lot.

The assumption of small zones also helps the analyst avoid one other tedious task: the calculation of the percent of each zone within walking distance of a transit line. Most models which handle walk and drive access require each zone to be subdivided by market area and this has proven to be a time-consuming and error-prone process (some newer models attempt to automate this via a GIS-like process, but the accuracy of such procedures is questionable). By using small zones, all zones can effectively be classified as either all-walk (100% of the zone's houses and jobs are within walking distance of transit) or all-drive (none of the zone is within walking distance). All-walk zones are defined as those which have a walk-access connection between the zone centroid and a transit stop node. Obviously this is an over- simplification of reality, but it is likely to be sufficiently accurate for all but the largest urban areas.

Highway Network Coding

The Reading highway network follows the increasingly common convention of using an "HOV flag" network variable to identify those links which are restricted to high-occupancy vehicle (HOV) use during certain times of the day. Although no such links currently exist in the Reading area, it is anticipated that they might be planned or built in the future. Thus, the model is set up to handle them. The highway skim process is set up to build and skim single-occupant vehicle (SOV) and HOV paths separately.

Separate SOV and HOV travel times are not essential to this PnR lot procedure, but if they are available, the procedure uses them. All travel times and distances from carpool PnR lots to work zones use the HOV paths.

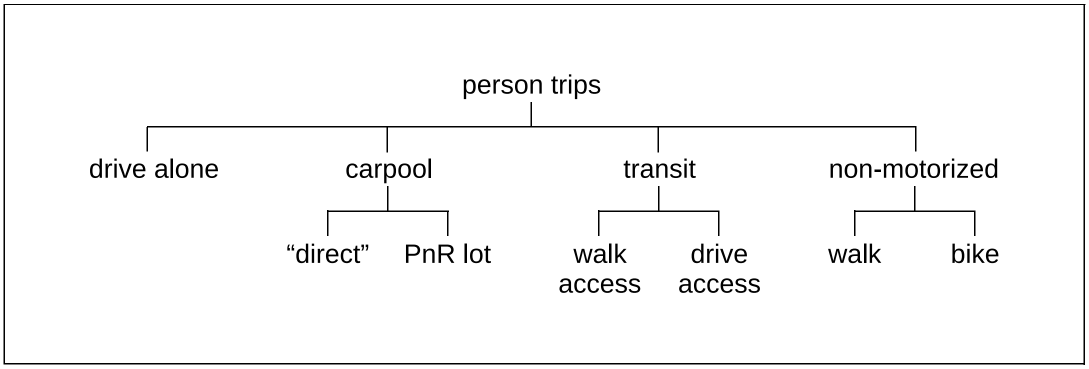

Figure 1: HBW mode choice model structure

Mode Choice Application Program

The Reading model uses a custom-written stand-alone FORTRAN program to apply a nested logit mode choice model. Figure 1 illustrates the structure of the home-based work (HBW) model. In the Reading model, HBW is the only trip purpose for which the PnR lot procedure is applicable, but that assumption could be easily modified.

Carpools (assumed to be HOV2+) are further split into those who travel directly from home to work and those who use a carpool PnR lot. That is, they leave home in low-occupancy vehicles and arrive at a lot, where they form high-occupancy vehicles for the subsequent trip to work. The transit nest is a fairly standard one for models which handle walk- and drive-access. The Reading model also assumes that all drive access to transit is via formal PnR lots. This is likely to be reasonable for all but the largest urban areas. “Informal” drive access is more difficult to handle and cannot be accommodated by the procedure described here.

The locations (zones) of all transit and carpool PnR lots are specified as inputs to the mode choice application program. The Reading model’s program permits up to 50 lots of each type to be specified. Inside that program, Step 1 is to derive the time and cost for the two types of carpool paths: PnR and direct. The direct path is described as follows for the production zone to the attraction zone:

- time = time on the HOV path plus about 1.8 min to account for the assumed additional time to pick up a passenger
- cost = distance on the HOV path, multiplied by the auto operating cost/mile, divided by the observed (surveyed) average HBW carpool occupancy of 2.674 to get a cost per person trip

The PnR path is described as follows:

- time = SOV path time for the production zone to each PnR lot zone plus HOV path time from each PnR lot zone to the attraction zone
- cost = SOV path distance for the production zone to each PnR lot zone, multiplied by the auto operating cost/mile, divided by an assumed average occupancy of 1.05, plus the HOV path distance from each PnR lot zone to the attraction zone, multiplied by the auto operating cost/mile, divided by 2.674

- the number of spaces in the PnR lot and the lot quality also influence this calculation (see below)

All possible production zone-PnR lot-attraction zone paths are evaluated and the one with the lowest total impedance (i.e., weighted combination of time, cost, and lot characteristics) is chosen. In future applications, this calculation could probably be modified to estimate the probability that each of several different lots might be chosen.

Step 2 is to do essentially the same calculation for the transit path. All zones potentially have a PnR path, constructed as follows:

- auto access time = SOV path time for the production zone to each PnR lot
- run time = walk-access transit path time from the PnR lot to the attraction zone
- out-of-vehicle time = wait time at the PnR lot, plus access walk time from the PnR lot's centroid to the nearest stop node (this serves as a surrogate for the time to walk from one's car to the transit stop), plus egress walk time at the attraction zone, plus any transfer wait time from the PnR lot to the attraction zone
- cost = SOV path distance for the production zone to each PnR lot, multiplied by the auto operating cost/mile, divided by an assumed 1.05 auto occupancy, plus half the daily cost of using the PnR lot divided by 1.05, plus the one-way transit fare from the PnR lot to the attraction zone
- transfers = the number of transfers required to travel from the PnR lot to the attraction zone

As with the carpool lot, all possible production zone-PnR lot-attraction zone paths are evaluated and the one with the lowest total impedance (i.e., weighted combination of time and cost) is chosen.

Step 3 is to perform the carpool split. A binary logit model is used to calculate the total carpool split between direct and PnR paths. The utilities of these choices is calculated as follows:

$$U(\text{direct}) = -0.0160 * (\text{HOV time}[P\text{-}A] + 1.1 * (2.674-1)) - 0.0015 * \text{HOV distance}[P\text{-}A] * \text{op cost/mi} / 2.674 \tag{1}$$

$$U(\text{PnR}) = -0.0160 * (\text{SOV time}[P\text{-}L] + \text{HOV time}[L\text{-}A] + 1.1 * (2.674-1)) - 0.0015 * (\text{SOV distance}[P\text{-}L] * \text{op cost/mi} / 1.05 + \text{HOV distance}[L\text{-}A] * \text{op cost/mi} / 2.674) + 0.0320 * \text{lot type} + 0.00032 * \text{spaces} - 2.8 \tag{2}$$

where:

P = production zone
L = PnR lot zone
A = attraction zone
- all times are in minutes (AM peak period), distances are in miles, and costs are in cents (1994 $)
- the auto operating cost is 8.7 ¢/mi

The type of lot is defined using an index of 1 to 5, approximately indicated as follows:

1 = unpaved lot, with “trailblazer” signs
2 = signs + gravel paving
3 = signs + asphalt paving
4 = signs + asphalt paving + lighting
5 = signs + asphalt paving + lighting + fencing (or other similar amenities)

It must be emphasized that no formal carpool PnR lots currently exist in the Reading area and no observed data was available to calibrate the coefficients on lot type or number of spaces. The lot type coefficient was synthesized by assuming that each “step” improvement in lot quality would be perceived as equivalent to 2 minutes of time savings. It seems logical to assume that improvements to the parking surface and the security of the lot should make the lot more attractive, thereby slightly increasing its usage.

Similarly, the coefficient on number of spaces was synthesized by assuming that every 50 additional spaces would be perceived as equivalent to 1 minute of time savings. As noted below, tests of these coefficients produced reasonable results. It was judged very important for the model to be responsive to changes in carpool PnR lot quality and size, because the plans of several Pennsylvania jurisdictions for air quality conformity include such improvements.

Equations (1) and (2) are not only used to determine the split between direct and PnR lot carpooling, but are subsequently combined in a log sum calculation to derive the total carpool utility for the prime mode choice calculation, as shown below:

$$U(\text{carpool}) = \ln\left(e^{U(\text{direct})} + e^{U(\text{PnR})}\right) \tag{3}$$

According to equation (3), the mere presence of a viable carpool PnR lot will always increase the carpool mode share for a given O-D pair. This model will estimate that adding a carpool PnR lot will reduce the direct carpool sub-mode’s share of the total carpool market, but will also increase the total carpool share. Both effects are related to the location, quality, and size of the lot, compared to a direct carpool trip from production to attraction zone.

Step 4 is to perform the walk- vs. drive-access split for transit in an analogous manner. The utilities are as follows:

$$\begin{aligned} U(\text{walk acc.}) = & -0.0250 * OVT[P\text{-}A] - 0.0250 * IVT[P\text{-}A] - 0.0031 * FARE[P\text{-}A] - \\ & 1.0 * XFER[P\text{-}A] \end{aligned} \tag{4}$$

$$\begin{aligned} U(\text{drive acc.}) = & -0.0250 * OVT[L\text{-}A] - 0.0250 * IVT[L\text{-}A] - 0.0031 * (FARE[L\text{-}A] + \\ & 0.5 * LotCst + SOV\ distance[P\text{-}L] * op\ cost/mi / 1.05) - 1.0 * \\ & XFER[L\text{-}A] - 0.0250 * (DACC[P\text{-}L] + 1.1 * (1.05-1)) + bias(inc) \end{aligned} \tag{5}$$

where:

OVT = out-of-vehicle time (= access walk + egress walk + initial wait + transfer wait), min.
IVT = bus running (in-vehicle) time, min.
XFER = no. of transfers
FARE = one-way transit fare, cents
DACC = drive access time, min. (from AM peak SOV highway paths)
LotCst = daily cost of parking at the PnR lot, cents

bias(inc) = bias coefficients by household income quartile:

Income	Coefficient
low	-5.6132
low-mid	-1.2457
high-mid	-0.7789
high	-0.7450

If walk-access transit service is unavailable for a given O-D pair, U(walk acc.) = 0. Also, if DACC exceeds 30 minutes, U(drive acc.) = 0. Finally, if the total unweighted transit travel time (OVT + IVT + drive acc. time) exceeds 120 minutes for either access mode, the U for that access mode is 0. According to equations (4) and (5), the walk vs. drive-access split is sensitive to the relative level of transit service via either access mode, the cost of parking in the PnR lot, the time and cost involved in driving to the lot, and income level. Higher income travellers are much more likely to drive to transit than lower income travellers. Unlike the carpool model, some observed data on transit PnR usage was available for the Reading area, and the transit PnR coefficients are based on that data.

As with the carpool mode, equations (4) and (5) are not only used to determine the split between walk- and drive-access transit, but are subsequently combined in a log sum calculation to derive the total transit utility for the prime mode choice calculation, as shown below:

$$U(\text{transit}) = \ln(e^{U(\text{walk acc.})} + e^{U(\text{drive acc.})}) \qquad (6)$$

Results

The Reading model's mode choice application program produces a report such as the one shown in Figure 2. On the transit side, the report shows the number of persons boarding transit in each zone's PnR lot and the number of cars entering the lot. On the carpool side, "vehicles in" is the number of SOVs entering the lot, "vehicles out" is the number of HOVs exiting the lot, and "vehicles parked" is the number of vehicles remaining in the lot during the day.

Table 1 shows the results of varying the quality of a carpool parking lot. The base case represents a situation with no carpool lots at all. The remaining rows show the results from adding one hypo-

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      Report 7: Park-and-Ride Lot Activity

            Transit                         Carpool

      Persons   Vehicles    Persons   Vehicles   Vehicles   Vehicles
Zone  In/Out    In          In/Out    In         Out        Parked
---------------------------------------------------------------------
63         87         83          0          0          0          0
432         0          0        105        100         39         61
466        63         60          0          0          0          0
```

Figure 2: PnR lot report

Table 1: Carpool PnR sensitivity

Scenario	Regional Daily HBW Carpool Person Trips			Vehicles Parked
	Direct	PnR	Total	
Base	38,761	0	38,761	0
Type 1, 100 Spaces	38,714	105	38,819	61
Type 2, 100 Spaces	38,712	110	38,822	64
Type 3, 100 Spaces	38,710	116	38,826	67
Type 4, 100 Spaces	38,707	121	38,828	70
Type 5, 100 Spaces	38,704	127	38,831	74
Type 5, 25 Spaces	38,706	123	38,829	71
Type 5, 50 Spaces	38,706	124	38,830	72
Type 5, 200 Spaces	38,701	134	38,835	77
Type 5, 500 Spaces	38,692	155	38,847	90

thetical carpool PnR lot in zone 432, which is located about 10 minutes from downtown Reading, about 1.5 mi from a moderately heavy arterial leading into town.

The results of this analysis suggest that there is a “natural” market for about 100-120 carpool PnR lot users and that this estimate is not very sensitive to the quality of the lot - improving the lot from “worst” to “best” produces a 21% increase in lot usage. The estimate is also rather insensitive to the size of the lot and indicates an additional feature of this procedure: lot usage is influenced by lot size, but is not constrained to the lot’s capacity.

Table 1 also indicates that as the PnR lot is improved or expanded in size, the PnR share of total carpool trips increases but the total carpool usage also increases. This hypothetical PnR lot draws about half its users from direct carpooling and the rest from the other travel modes. In this example, it would appear that a carpool PnR lot in zone 432 could be sized at around 100 spaces to accommodate current demand and allow for modest future growth.

Table 2 presents a similar analysis for the existing lot in zone 63. This lot is located at a local sports stadium about 10 min. north of the Reading CBD and is served by two local bus lines with headways of 22 and 15 min.

According to these results, PnR usage at this location is extremely insensitive to a fee that might be charged for PnR use. Charging a $2/day fee reduces the lot’s usage by only 21%, which seems rather low. Either the coefficient on PnR lot cost should be revisited, or perhaps there is a natural market of transit users for this PnR lot also, which might be relatively unaffected by fee increases. Changing the frequency of transit service from this lot also has a fairly minor effect on ridership and lot usage. These results similarly indicate that the likely near-term demand for parking at this location is about 100 spaces.

Table 2: Transit PnR sensitivity

Scenario	Regional Daily HBW Transit Person Trips			Vehicles Parked
	Walk Access	Drive Access[a]	Total	
Base	5,890	150	6,040	83
50 ¢/day fee	5,893	141	6,034	74
$1.00/day fee	5,896	133	6,029	66
$2.00/day fee	5,900	119	6,019	52
no fee, double headways	5,840	137	5,977	70
no fee, halve headways	5,924	162	6,086	95

[a] Total for all existing transit PnR lots.

The model’s results are shown in Tables 1 and 2 to the nearest trip. This should not be interpreted as a

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          Report 8: Grand Integer Trip Totals

Table   Mode                                                Trips
-------------------------------------------------------------
1       Drive Alone Person/Vehicle                        270762
2       Carpool Person (direct)                           389761
3       Carpool Vehicle (direct)                           14496
4       Carpool PNR Orig.-Dest. Person (HBW)*                  0
5       Carpool Origin-to-PNR Lot Vehicle (HBW)*               0
6       Carpool PNR Lot-to-Dest. Vehicle (HBW)*                0
7       Walk-Acc. Transit Person                            5890
8       Drive-Acc. Transit Orig.-Dest. Person (HBW)*         150
9       Drive-Acc. Transit Orig.-PNR Vehicle (HBW)*          143
10      School Bus Person (SCH)                                0
11      Walk/Bike Person                                   15969

      (* Defined as zero for non-HBW purposes.)
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Figure 3: Modal trip table total report

claim that this (or any) model is accurate to the nearest trip. In fact, the "error band" of this model undoubtedly exceeds the small differences among the scenarios shown here. However, it is believed that these results provide a reasonable indication as to the model's relative sensitivity to the different scenarios.

The mode choice application program outputs 11 modal trip tables for each trip purpose. Figure 3 provides a sample of a report listing the total trips on each table. Output tables 2 and 3 are those carpoolers who travel directly to their workplace. Output table 4 includes linked carpool person trips who use a PnR lot, but the trips are stored in this table in the production-attraction zone cell, to facilitate subsequent evaluation. Output tables 5 and 6 represent the unlinked home-lot and lot-work segments of carpool PnR lot users. Similarly, output table 8 includes the linked drive-access transit users, stored in the production-attraction zone cell. Output table 9 represents the home-lot vehicle trip that constitutes the drive-access portion of the trip. This is necessary to account for the VMT that transit PnR lots create.

Conclusions

This paper documents a new implementation of a procedure that handles both carpool and transit PnR lots in a consistent manner. The presence of these lots is modelled in terms of the trade-offs among travel time, cost, and lot characteristics. Due to a lack of observed data, some of the relationships and sensitivities have been synthesized. These coefficients should be updated in the future when observed data on PnR usage becomes available.

This procedure provides a reasonable accounting of the effects of PnR lots. These lots can be expected to increase carpool and transit usage slightly, but not by much. This process also accounts for the fact that an increase in PnR carpooling will "steal" trips from direct carpooling and transit, as well as from drive alone. Increases in PnR transit use will steal trips from walk-access transit use and carpooling also. In addition, the VMT arising from home-lot access is explicitly estimated.

Sensitivity testing has indicated that the model’s estimates of potential carpool and transit PnR lot use are conservative, but probably within the bounds of experience in other areas. The model’s output is consistent with the needs of air quality conformity analyses. Although a complex, custom-written computer program was required to implement this procedure, this is merely an extension of efforts currently being done in other areas.

Acknowledgments

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Bibliography

Berks County Travel Model, prepared by Garmen Associates for Pennsylvania Department of Transportation and the Berks County Planning Commission, July 1996.