Generalized Time Transit Assignment in a Multi-Modal/Service Transit Network

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Presentation to the 20th International
EMME Users' Conference
Montreal
October 18, 2006

Presentation Outline

- Modelling complex transit networks
- Options
- Coding fares into transit networks
- Walk access to transit
- Auto access to transit
- Transit assignment parameters
- Mode choice modelling
- Future work

Modelling Complex Transit Networks

The GTA transit network is a complex system consisting of:

- Multiple and overlapping service areas
- Multiple fare systems
- Multiple “sub-modes” (bus, streetcar, subway, etc.)
- Multiple access modes (walk, auto-drive, etc.)
- Competing/parallel services (often provided by the same operator)

Dealing with these complexities requires a coordinated, consistent approach.

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Issue: Multiple fare systems exist within the GTA. These fare systems overlap spatially.

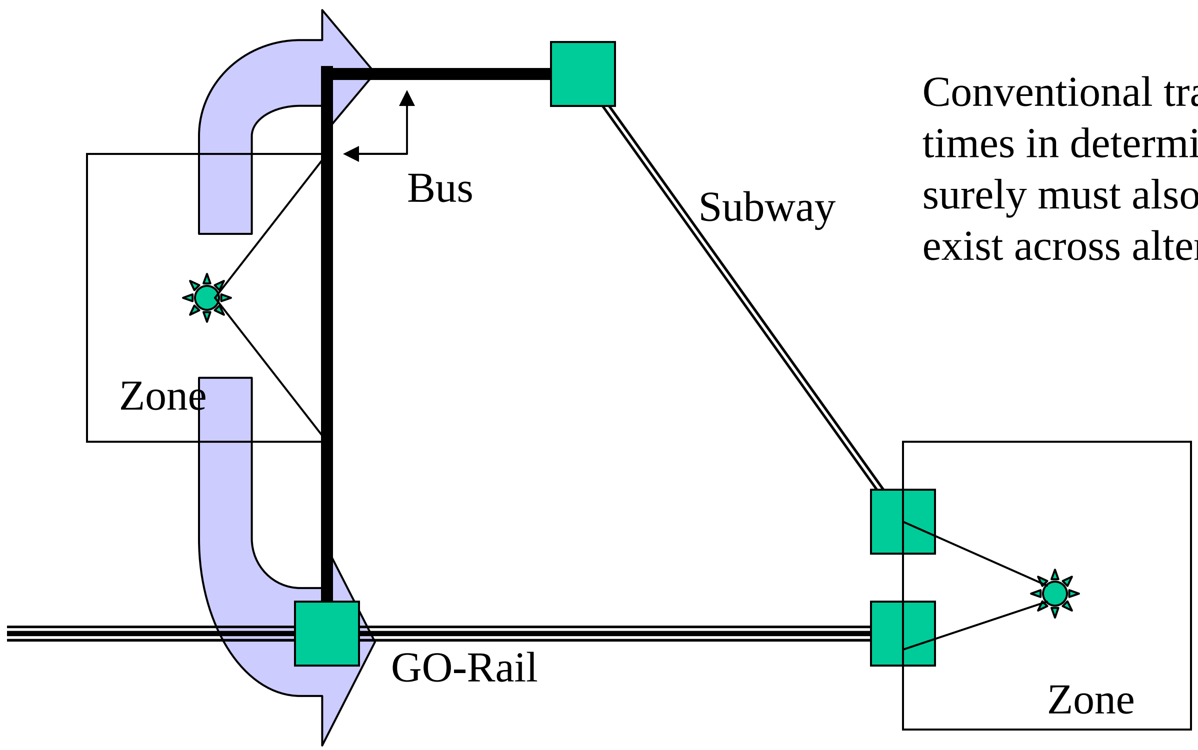
Types of fare policies:

1. Flat fare within a single service area (e.g., TTC).
2. Zone-fare system (e.g., GO Transit).
3. Pure distance-based fare (no current example in the GTA, although the GO zone fare system is loosely based on distance).

Note that with multiple flat fare service areas interconnecting (e.g., TTC with Mississauga Transit or York Transit), this really is a zone-fare system as well when looking at inter-municipality trips.

The key problem is that fare systems overlap spatially. If they did not, then there would be one fare for all paths selected for any given O-D pair. In this case, a simple time-based assignment procedure would find the "correct" path strategy. With overlapping path fares, however, a pure time-based assignment will inevitably over-estimate usage of high-cost, fast services/paths.

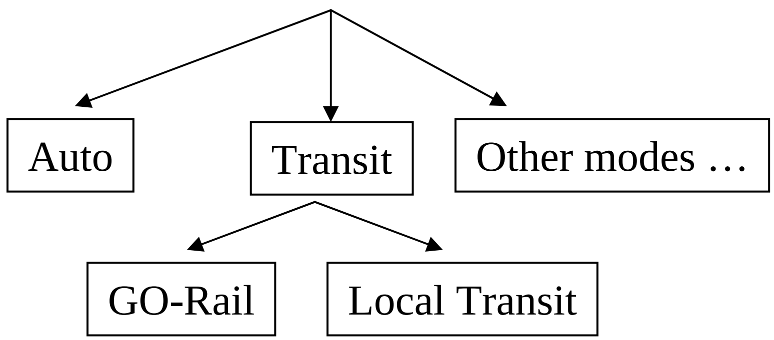
Issue: Multiple paths within a transit strategy for a given O-D pair that have different travel costs.



Conventional transit assignments only consider travel times in determining route choice, but travel cost surely must also play a role when time-cost tradeoffs exist across alternative paths.

Options for Handling The Multiple Path Cost Problem:

1. Treat paths with different costs as separate **sub-modes** and predicting the "path choice" probabilistically within the mode choice model:



$$P(\text{GO-Rail}) = P(\text{GO-Rail} \mid \text{Transit}) * P(\text{Transit})$$

$$P(\text{GO-Rail} \mid \text{Transit}) = \frac{\exp(V(\text{GO-Rail} \mid \text{Transit}))}{[\exp(V(\text{GO-Rail} \mid \text{Transit}) + \exp(V(\text{Local} \mid \text{Transit}))]}$$

$$P(\text{Transit}) = \frac{\exp((V(\text{Transit}) + \phi * \log [\exp(V(\text{GO-Rail} \mid \text{Transit}) + \exp(V(\text{Local} \mid \text{Transit}))]}{\exp(V(\text{Transit}) + \phi * \log [\exp(V(\text{GO-Rail} \mid \text{Transit}) + \exp(V(\text{Local} \mid \text{Transit}))]) + \sum_{m \neq \text{Transit}} \exp(V(m))}$$

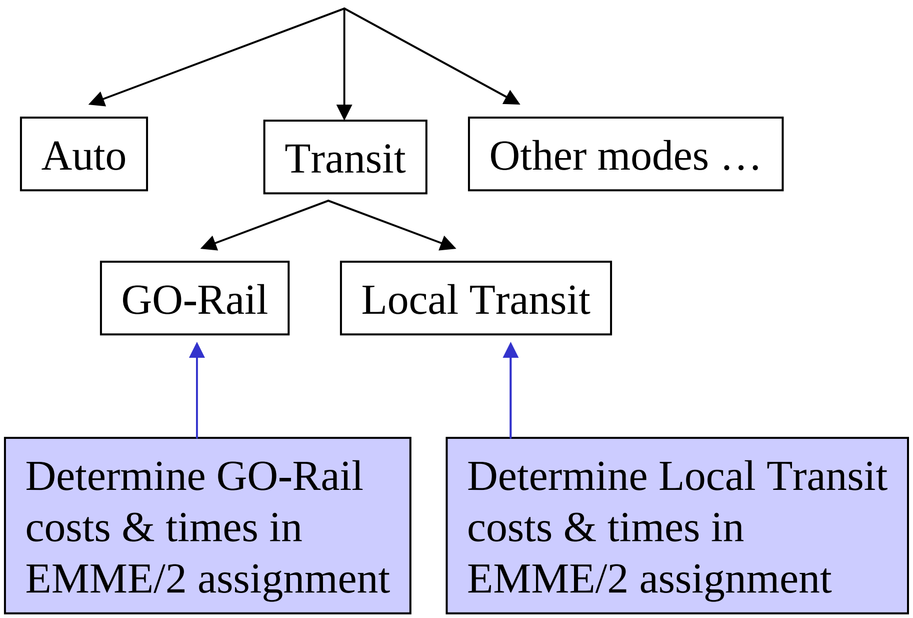
Problems with Option 1 ("Mode Choice") Approach

Several problems exist with this approach as the transit network grows in complexity, including:

- Combinatorics of the calculations involved.
- When does a service become a new sub-mode?
- IIA ("red bus / blue bus") problems with this definition as cost structures change.
- Computing unique cost-time values for each sub-mode can be difficult.
- Handling auto access for non-rail sub-modes.
- Consistency between mode choice & assignment model results

Option 1: Link to Assignment:

Separate assignments need to be run for each sub-mode.

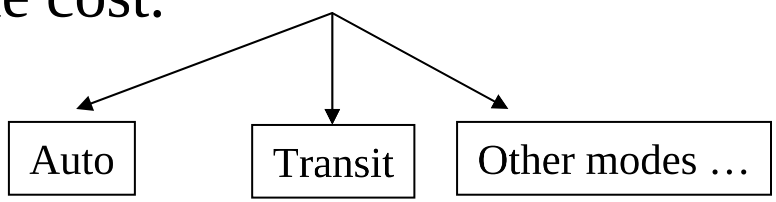


Challenges exist in computing correct times (and costs) for each sub-mode, especially as network complexity increases (e.g., GO-Bus or premium bus services versus local transit). Procedures include:

- Run assignments "with and without" a given sub-mode.
- "Decompose" the trip into access, line-haul and egress trip segments and explicitly "assign" trips to these components outside of EMME/2 (current method used for GO-Rail).
- Use disaggregate assignment to explicitly identify paths by sub-mode within the strategy.

Options for Handling Multiple Path Costs, continued:

2. "Embed" path cost into the path impedance calculations within the transit assignment algorithm, so that path selection is based on a generalized cost or impedance that includes both time and cost. This requires coding the cost terms into the transit network so that these costs are included in the impedance calculations as time equivalents of the cost.



$$P(\text{Transit}) = \frac{\exp((V(\text{Transit}) + \phi * I(\text{Transit}))}{\exp(V(\text{Transit}) + \phi * I(\text{Transit})) + \sum_{m \neq \text{Transit}} \exp(V(m))}$$

I(transit) = overall impedance for selected transit strategy, including costs

Determine average costs & times in for overall transit strategy considering the entire transit network in one EMME/2 assignment

$$I(\text{transit}) = \sum_p P(p)*[\text{Time}(p) + (\beta/\alpha)*\text{Cost}(p)]$$

p = p^{th} path in the strategy

$P(p)$ = proportion of O-D flow using path p

Time(p) = weighted travel time for path p (expressed in units of in-vehicle travel time min.)

Cost(p) = travel cost for path p ($)

(β/α) = time value of money (min/$)

β= in-vehicle travel utility parameter

α = travel cost utility parameter

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Option 2 Strengths & Weaknesses:

Strengths:

1. Simplifies mode choice model.
2. Avoids IIA problems.
3. Mode choice model does not change as services & fare policies change.
4. Extensible to networks of arbitrary complexity (if can code costs correctly and efficiently).
5. Smoothly/consistently adjusts to changes in fare policies.
6. Exploits efficiency of the transit assignment algorithm.
7. Consistent parameters used in mode choice and transit assignment (possibly).

Weaknesses:

1. Assumes deterministic/fixed time-cost trade-offs (but can have "multiple classes" with different parameter sets, if need be).
2. Only probabilistic element in path choice is headway-based.
3. Need to code costs into the network & incorporate these in the impedance calculations.
4. Need to calibrate parameters across mode choice and transit assignment simultaneously (maybe).
5. Need to ensure that headways for low-frequency services are correctly coded and used within the assignment process.

Coding Fares in a Transit Network

Three elements:

1. Initial fare incurred when accessing the first service.
2. Increment in path fare due to transfers from one service to another (or from one fare zone to another).
3. Pure distance-based fares. These can simply be added to the impedance of each link based on its length and the $/km fare rate.

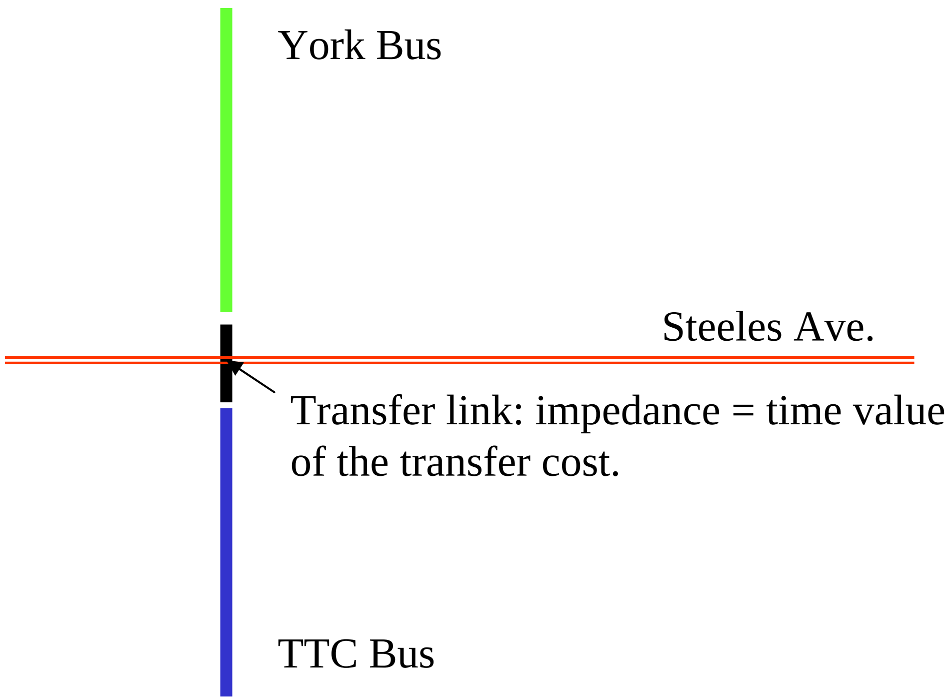
Initial Transit Fare

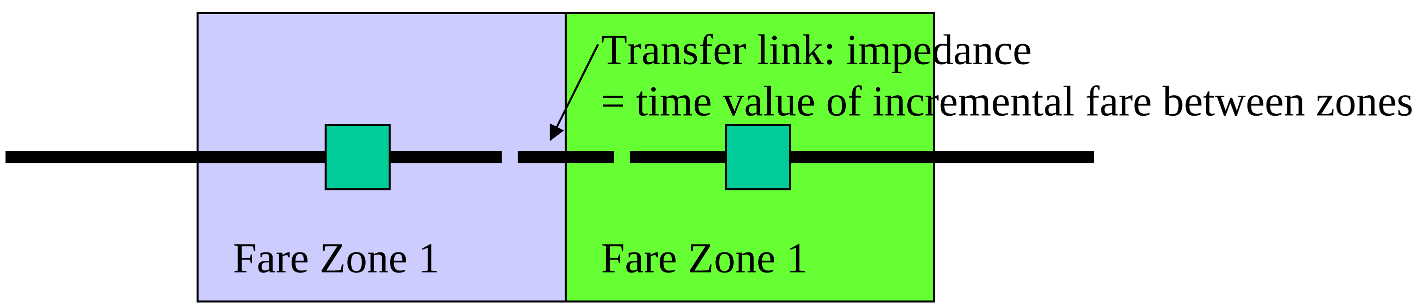
- Ideally, one would want to attach a transit fare to the "first boarding" of a given transit service.
- Unfortunately, EMME/2 does not distinguish between first and subsequent boardings.
- Therefore, centroid connectors in the "access" direction must be coded with the time-value of the initial fare.
- This creates some complications in skimming access walk times and in dealing with walk access representation.

Coding Transfer Fares:

A **transfer link** is coded at <u>each point</u> at which a transfer between two services (or the movement between two fare zones occurs). The increment in fare involved in this movement is then coded onto this link and captured in the path impedance.

Some problems exist with non-additivity of GO fares.

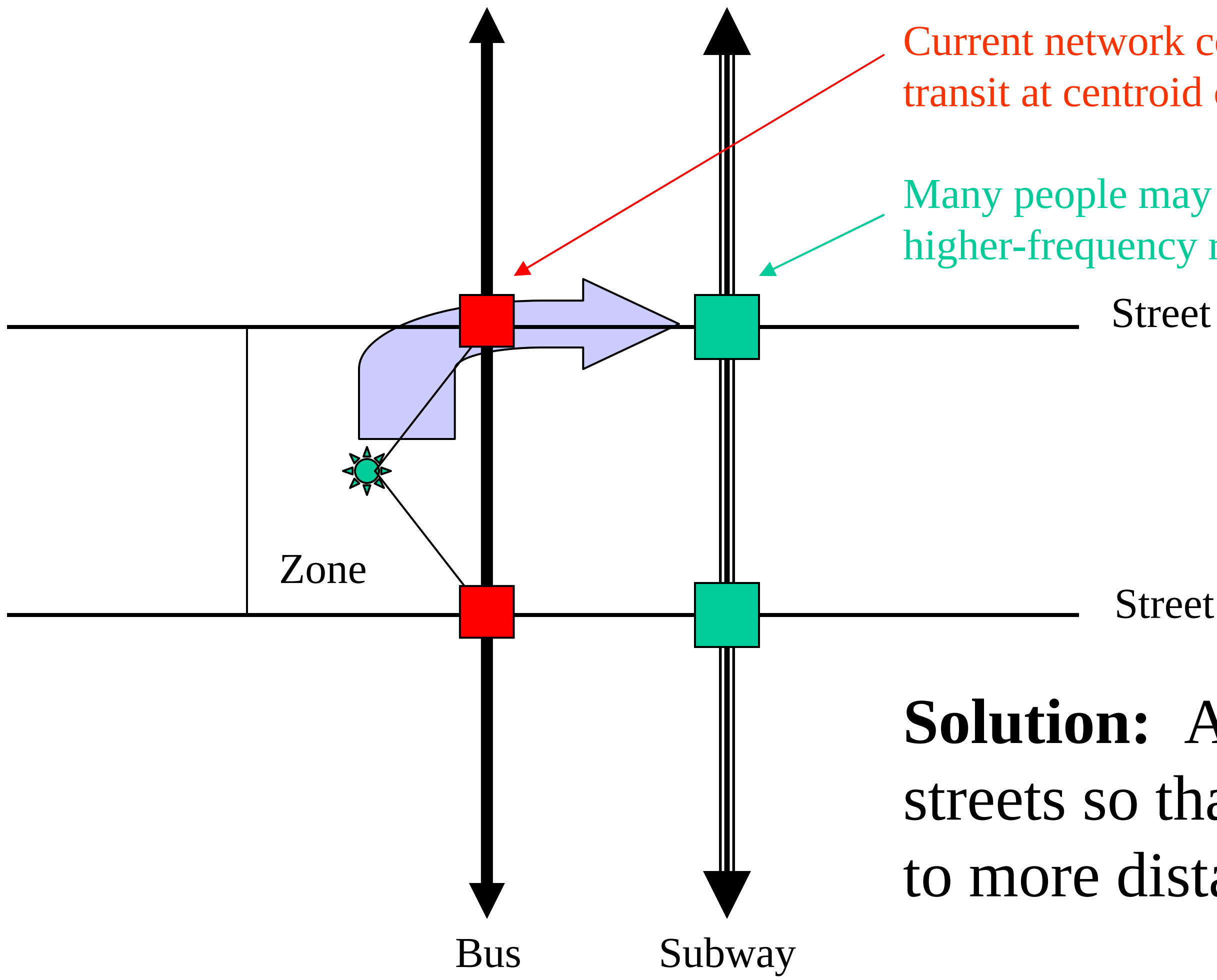




Issue: Trip-makers may “walk past” a low frequency/speed transit line to access a higher frequency/speed line.

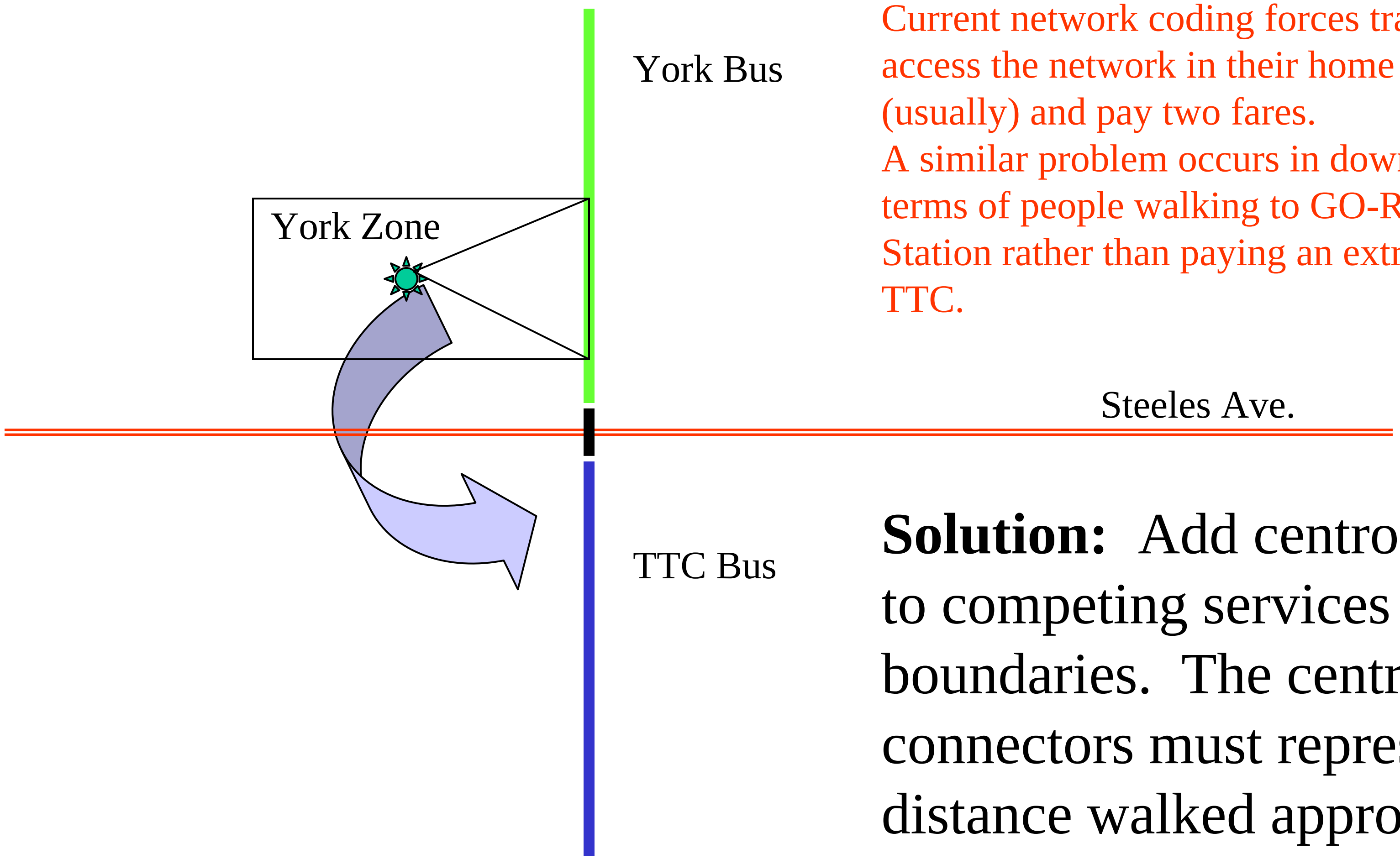
Current network coding forces transit trips to access transit at centroid connector points.

Many people may actually walk to a more distant higher-frequency route



Solution: Allow walk mode on streets so that transit users can walk to more distant transit line.

Issue: Transit riders in zones near service/fare boundaries may "walk across the boundary in order to avoid paying two fares.



Current network coding forces transit users to access the network in their home service area (usually) and pay two fares.
A similar problem occurs in downtown Toronto in terms of people walking to GO-Rail at Union Station rather than paying an extra fare to use the TTC.

Solution: Add centroid connectors to competing services across fare boundaries. The centroid connectors must represent the extra distance walked appropriately.

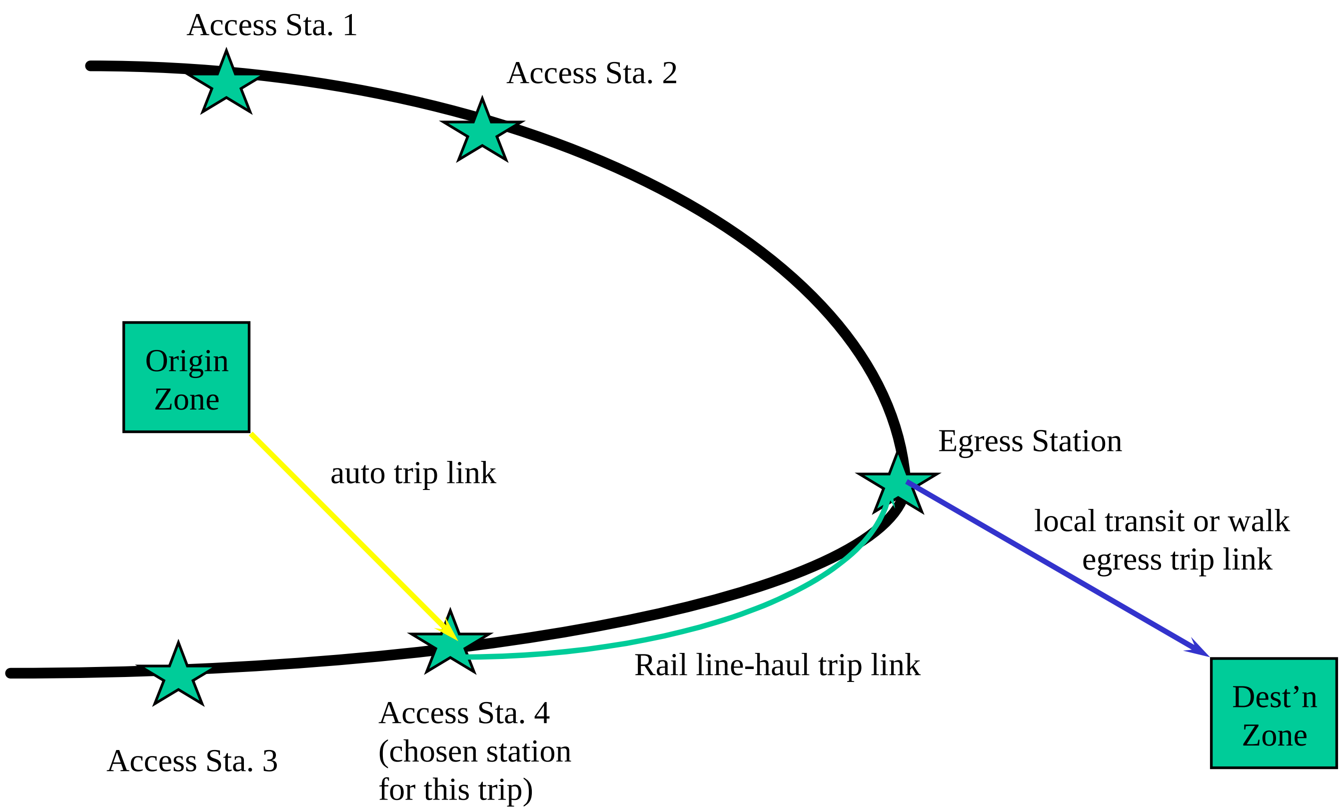
Transit Access Mode

(a) Trips	Access Mode							
Main Mode	Walk	AutoPass	Taxi	Cycle	AutoDrive	Motorbike	Unknown	Total
GO rail only	5492	7441	45	203	27859	0	0	41040
Joint GO rail & public transit	7516	2885	52	81	6839	0	47	17420
Transit excluding GO rail	335157	15338	177	474	15441	20	102	366709
Total	348165	25664	274	758	50139	20	149	425169

(b) Access Mode Share	Access Mode							
Main Mode	Walk	AutoPass	Taxi	Cycle	AutoDrive	Motorbike	Unknown	Total
GO rail only	13.4%	18.1%	0.1%	0.5%	67.9%	0.0%	0.0%	100.0%
Joint GO rail & public transit	43.1%	16.6%	0.3%	0.5%	39.3%	0.0%	0.3%	100.0%
Transit excluding GO rail	91.4%	4.2%	0.0%	0.1%	4.2%	0.0%	0.0%	100.0%
Total	81.9%	6.0%	0.1%	0.2%	11.8%	0.0%	0.0%	100.0%

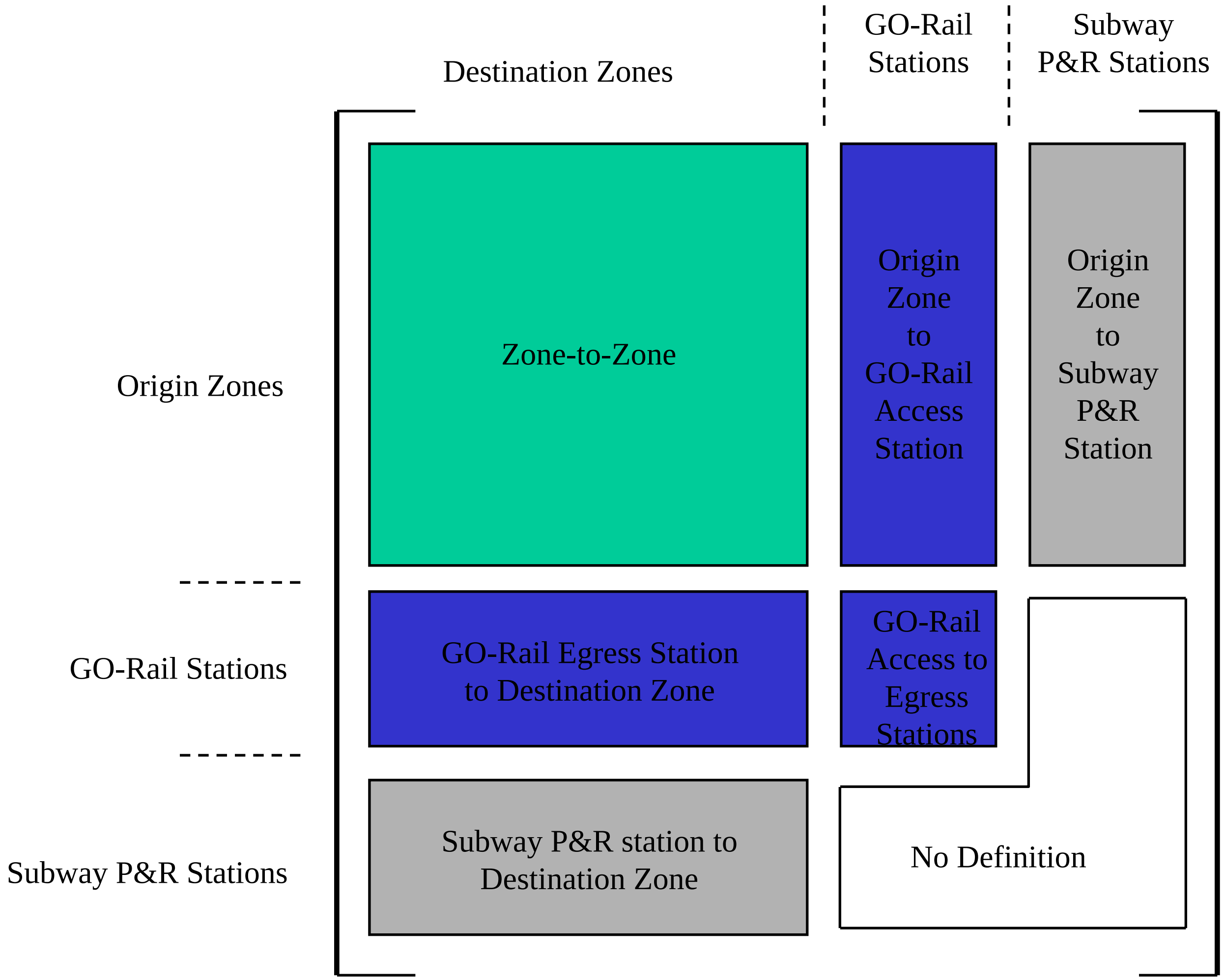
Auto access to GO-Rail is very important – a majority of trips use drive or passenger mode. Local transit and GO-Bus access is predominantly walk, but auto is used by 8.4% of trips and is an important access mode for suburban access to the subway.

Decomposition of Auto Access to Rail Trips



Auto Access to Rail, cont'd

In order to process mixed mode trip links, need to code "station centroids" into the network. This leads to the concept of an "extended O-D matrix".



Transit Parameter Settings

With this approach to transit network modelling, determining the best set of transit parameters is critical, in particular in terms of getting the "right" number of trip-makers on each sub-mode within the network.

This is complicated by the essentially "all or nothing" nature of the EMME/2 transit assignment algorithm, in which parallel routes tend to get either 100% or 0% of the assigned flow.

Transit Parameters, cont'd

We have experimented with using a Genetic Algorithm to search for optimal parameter values. We may return to this approach in the future.

For the moment we have explored alternative parameter settings in a more ad hoc way.

The key concern has been to determine appropriate:
- Time value of money to convert fares into travel time equivalents
- Boarding time penalties to achieve good sub-mode allocations

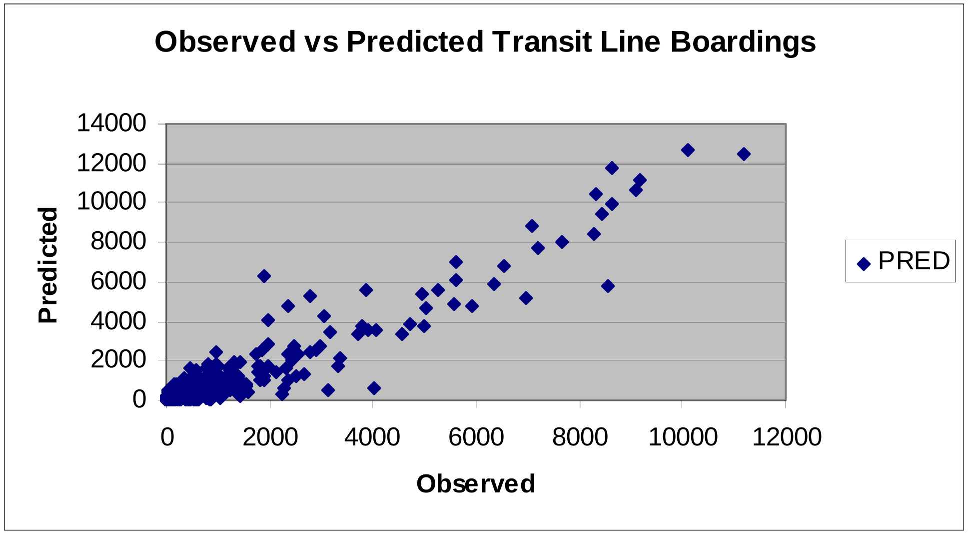
Current Transit Parameter Settings

Transit Assignment Parameters	
Value	**Description**
0.5	Wait factor
8.57	Time value of money (min/$) (=$7/hr)
1	Walk time weight
2.733	Wait time weight
1	Boarding time weight
	Boarding time by sub-mode:
2	TTC regular bus
0	TTC premium bus
2	TTS streetcar/LRT
0	TTS subway
0	GO Train
14	GO Bus
8	York Region Bus
3	Peel Bus
2	Halton Bus
2	Hamilton Bus
2	Durham Bus
Wait-times based on actual line headways.	

Transit Assignment Results 2001 Base Case

Total Boardings by Sub-Mode		OBS	PRED	RMSE	RMS%
Durham Bus		7499	7164	126.1891	1.68%
York Bus		7111	7280	143.0784	2.01%
Peel Bus		38497	40217	332.7368	0.86%
Halton Bus		4536	4990	81.51716	1.80%
HSR Bus		15982	16337	292.8422	1.83%
GO Bus		7172	7353	399.3889	5.57%
GO Rail		13659	13735	645.6756	4.73%
TTC Bus		282084	260041	1038.175	0.37%
TTC Prem Bus		672	101	176.9569	26.33%
TTC Subway		254060	235691	9103.319	3.58%
TTC Streetcar		47097	47097	1201.121	2.55%
Overall		678369	640006	1036.107	0.15%

Final parameter settings with embedded transit fares seem to be providing good assignment of transit trips to lines and sub-modes.



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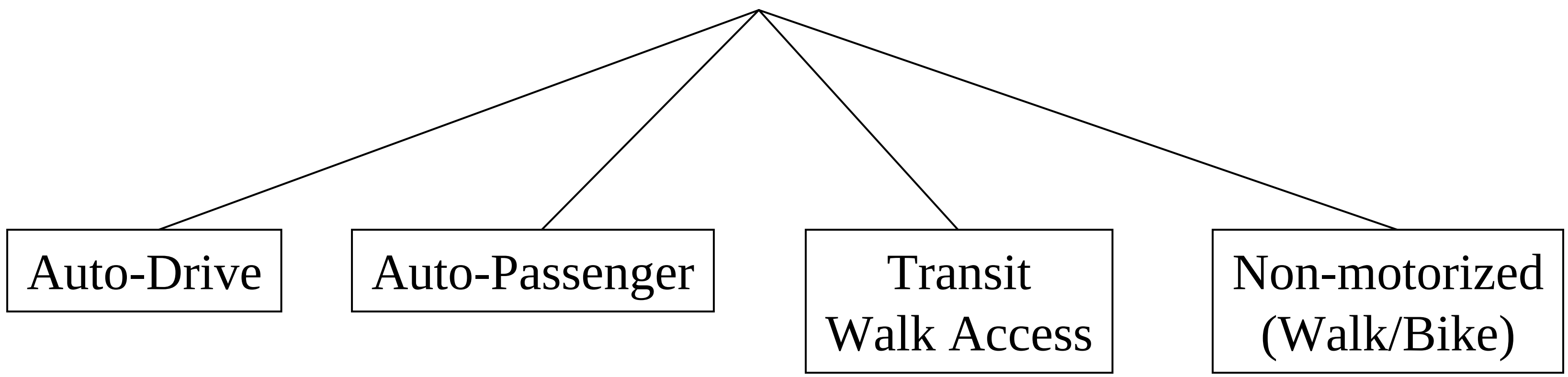
Mode Choice Model Example

Simple logit mode choice model (no auto access to transit).



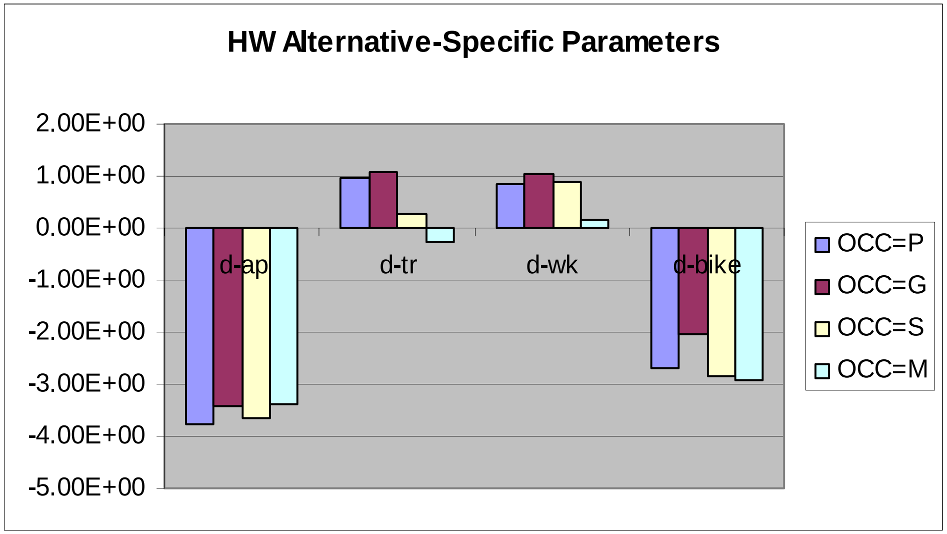
Example Model Results, HW Journeys, Occ=P

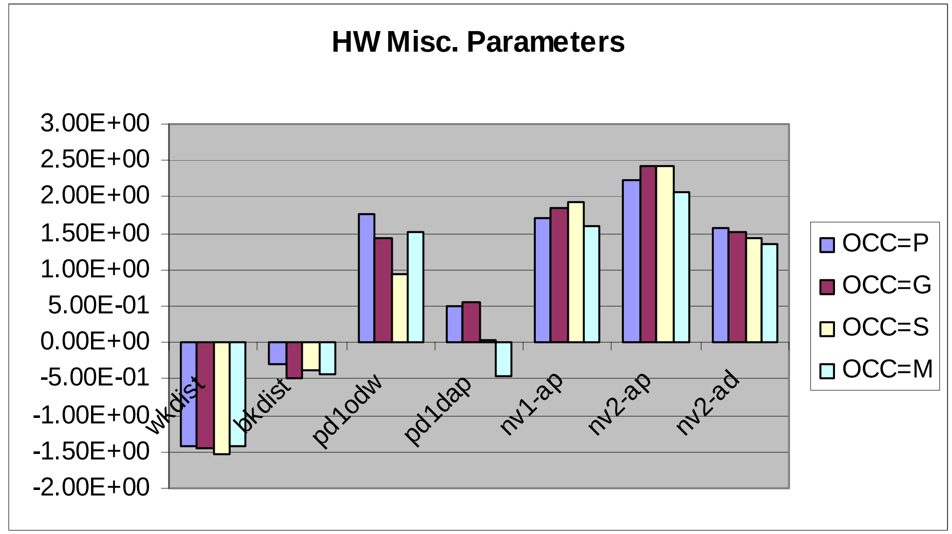
```
*****************************************************************************
*                                                                           *
*                     LOGIT MODEL ESTIMATION VERSION 5.1                    *
*                                                                           *
*             DATA SET: 2001 HW Journeys                                    *
*             MODEL:    wk2g04a: wk2g04 - insign. age terms                 *
*                                                                           *
*                                                                           *
*    PAR:     d-ap   d-tr   d-wk   d-bike wkdist bkdist pd1odw pd1dap       *
*                                                                           *
*    a-drive  0      0      0      0      0      0      0      0            *
*    a-pass   1      0      0      0      0      0      0      pd1nod       *
*    transit  0      1      0      0      0      0      0      0            *
*    walkbike 0      0      wkd3   wkd310 dist3  dist10 pd1od  0            *
*                                                                           *
*    PAR:     nv1-ap nv2-ap nv2-ad a18-ap a25-ap a18-tr a25-tr a30-tr       *
*                                                                           *
*    a-drive  0      0      nveh2  0      0      0      0      0            *
*    a-pass   nveh1  nveh2  0      a16-18 a19-25 0      0      0            *
*    transit  0      0      0      0      0      a16-18 a19-25 a26-30       *
*    walkbike 0      0      0      0      0      0      0      0            *
*                                                                           *
*    PAR:     a25-wk twalk  twait  tboard tivtt  cost   aivtt  apdist       *
*                                                                           *
*    a-drive  0      0      0      0      0      tc-ad  aivtt  0            *
*    a-pass   0      0      0      0      0      0      aivtt  stldst       *
*    transit  0      trauxt trwait trbrdt trivtt tfare  0      0            *
*    walkbike a19-25 0      0      0      0      0      0      0            *
*                                                                           *
*   wk2g04a: HW Journeys; OCC=G                                             *
*   wk2g04 is the base.                                                     *
*   Insignificant age terms deleted:                                        *
*   a30-ap, a18-wk, a30-wk                                                  *
*                                                                           *
*****************************************************************************
```

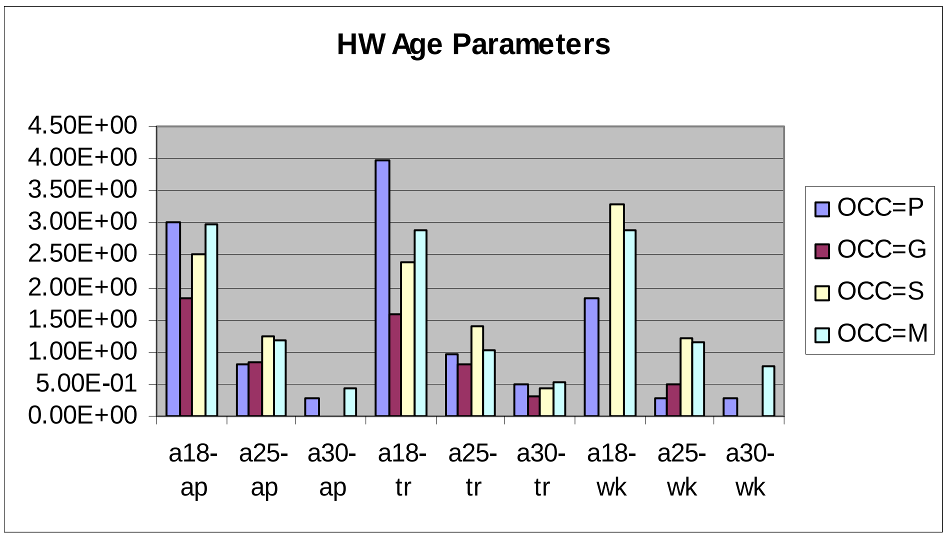
```
*************************************************************
*
*                        FINAL PARAMETER VALUES
*
*             NUMBER         NAME          VALUE         T-STA
*
*                1           d-ap      -.37713E+01    -33.057
*                2           d-tr      0.96369E+00     15.315
*                3           d-wk      0.85276E+00      6.043
*                4           d-bike    -.27042E+01    -11.933
*                5           wkdist    -.14137E+01    -17.919
*                6           bkdist    -.30908E+00     -8.079
*                7           pd1odw    0.17695E+01     17.195
*                8           pd1dap    0.49408E+00      8.042
*                9           nv1-ap    0.17017E+01     15.104
*               10           nv2-ap    0.22412E+01     19.209
*               11           nv2-ad    0.15577E+01     33.965
*               12           a18-ap    0.30063E+01      4.475
*               13           a25-ap    0.81638E+00      9.753
*               14           a30-ap    0.29031E+00      4.149
*               15           a18-tr    0.39747E+01      5.019
*               16           a25-tr    0.97710E+00     11.573
*               17           a30-tr    0.48274E+00      7.801
*               18           a18-wk    0.18410E+01      1.429
*               19           a25-wk    0.28658E+00      1.788
*               20           a30-wk    0.27186E+00      2.387
*               21           twalk     -.67645E-01    -20.924
*               22           twait     -.25162E+00    -20.538
*               23           tboard    -.94008E-01     -7.365
*               24           tivtt     -.31304E-01    -12.837
*               25           cost      -.95607E-01    -12.145
*               26           aivtt     -.63746E-01    -22.010
*               27           apdist    -.30977E-01    -11.636
*
*************************************************************
```

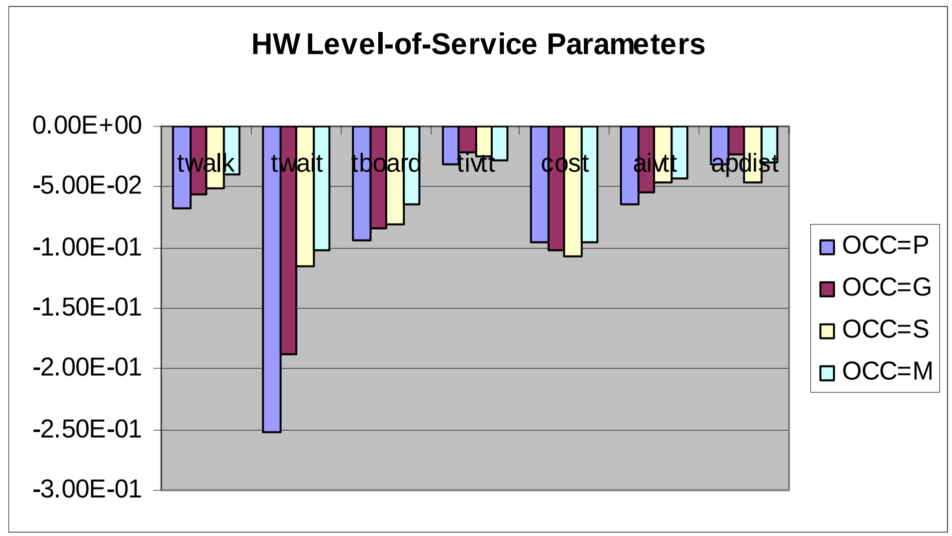
```
*****************************************************************************
*                                                                           *
*                        GOODNESS-OF-FIT STATISTICS                         *
*                                                                           *
*                    No. of weighted observations= 33243                    *
*                    No. of cases=                 74731                    *
*                    No. of parameters estimated=     27                    *
*                    Degrees of freedom=           74704                    *
*                                                                           *
*                    Log likelihood at B=0,=    -38467.7                    *
*                    Log likelihood at conv.=   -14524.8                    *
*                    Log likelihood ratio=       47885.8                    *
*                    RHO-square=                  0.6224                    *
*                    Adjusted RHO-square=         0.6223                    *
*                    Horowitz' RHO-square=        0.6221                    *
*                                                                           *
*                    Expected percent right=        77.2                    *
*                                                                           *
*****************************************************************************
```

HW Mode Choice Model Parameters









Key Parameter Ratios

Ratios with respect to tivtt:					
	OCC=P	OCC=G	OCC=S	OCC=M	HO
twalk	2.16	2.53	1.99	1.46	2.22
twait	8.04	8.55	4.53	3.78	6.83
tboard	3.00	3.83	3.14	2.39	1.47
In-vehicle value of time:					
	OCC=P	OCC=G	OCC=S	OCC=M	HO
tivtt	19.65	12.87	14.37	17.20	16.74
aivtt	40.00	32.22	25.74	26.68	49.37

Conclusions & Future Work

- Finalize assignment & mode choice parameters (currently not the same in the two models).
- Incorporate auto access to transit (nested logit model incorporating access station choice).
- More detailed evaluation of competing route/service assignment results.
- Test sensitivity to introduction of new services.
- Incorporate enhanced sensitivity to transit service technologies?