A Practitioner's Guide to DVRPC's Evans Congestion-Equilibrium Travel Simulation

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Outline

- Methods to Iterate Travel Simulation Model
- Implementing Evans in Existing Simulation Model (Frank-Wolf)
- DVRPC Evans Implementation
- Model Calibration in an Iterative Environment
- Convergence Issues and Transport Alternative Comparability
- Application Experience with Evans
- Recommendations and Conclusions

Notes:

This is a wide ranging presentation that is intended to cover the entire topic of iterative/simultaneous modeling using in practitioner's, rather than academic terminology. Many different topics are presented. A series of outlines and sub-outline slides are included to keep the audience from getting lost.

These topics are presented in terms of the features and design decisions that we made for the DVRPC model. Local issues in other regions might necessitate different modeling approaches.

Clearly, the DVRPC model is not the only way to do equilibrium modeling, but it is the only model that systematically approaches this topic in North America.

Hopefully, we can inspire someone else to try it.

Methods to Iterate Travel Simulation Model

- **Simple Iteration**
  - ~ Doesn't converge to any solution – wanders forever
  - ~ May be OK, if start with actual speeds and don't iterate more than a few times

Notes:

We don't reject simple iteration completely. It is still useful in certain situations where demonstrated convergence is not necessary -- the transit outer loop and new starts modeling.

Simple iteration cannot start with free flow speeds like the DVRPC Evans inner loop because it never converges to a true equilibrium solution Realistic, hopefully observed, speeds must be used as the starting point, followed by one or two iterations of the modeling chain using capacity restrained speeds.

Methods to Iterate Travel Simulation Model

- **Method of Successive Averages (MSA)**
  - Converges to solution using convex combinations with predetermined step sizes (Powel and Sheffi)
  - Less efficient, but compatible with Origin Based Assignment and other methods where optimal step sizes unknown

Notes:

See: Warren B. Powell and Yosef Sheffi, The Convergence of Equilibrium Algorithms with Predetermined Step Sizes, Transportation Science, Vol16. No.1, February 1982.1

Methods to Iterate Travel Simulation Model

- **Evans Algorithm**
  - ~ Converges to optimal solution using convex combinations with optimal step sizes
  - ~ Straightforward extension of Frank-Wolf equilibrium assignment
  - ~ Can generate equilibrium speeds from free-flow speeds

Notes:

Implementing Evans in Existing Simulation Model (Frank-Wolf)

1. **Review objective function**
2. **Review and improve equilibrium highway assignment**
3. **Modify modal split model to calculate transit impedance**
4. **Modify λ search routines**
5. **Make provision for pre-setting of λs**

Notes:

This is a straight forward extension of the Leblanc/UROAD Frank-Wolf equilibrium assignment implementation to consider trip distribution and modal split.

An accurate restart within a well-implemented equilibrium assignment model will capture about 90% of the Evans model variation.

This is "link level" Evans with a linearized search for the optimal λ. It is also possible to do a "trip table" Evans implementation where the λ search is conducted by weighting together trip tables and conducting full assignments at each stage of bisection. Trip table Evans can be implemented without modifying the 4-step simulation software. The disadvantage is that it is much more cumbersome to execute (especially with complex modal split/transit assignment models) and computationally intensive – slower running times and many scratch files.

User Equilibrium Objective Function (MSA & Evans)

MINIMIZE USER TIME AND COST (DISUTILITY):

$$F = \underbrace{\gamma_1 Q \sum_a \int_0^{V_a} c_a(x)}_{\text{IN-VEHICLE AUTO TIME}} + \gamma_2 \Big(\underbrace{\sum_a \int_0^{V_a} k_a(x)}_{\text{AUTO OPERATING COST}} + \underbrace{\sum_i \sum_j T_{ijh} \; s_j}_{\text{AUTO PARKING COST}} \Big) + \underbrace{\gamma_3 \sum_i \sum_j T_{ijh} \; w_{ijh}}_{\text{AUTO TERMINAL TIME}} +$$

$$\underbrace{\gamma_1 \sum_i \sum_j T_{ijt} c_{ijt}}_{\text{IN VEHICLE TRANSIT TIME}} + \underbrace{\gamma_2 \sum_i \sum_j T_{ijt} k_{ijt}}_{\text{TRANSIT FARE}} + \underbrace{\gamma_3 \sum_i \sum_j T_{ijt} w_{ijt}}_{\text{TRANSIT WAIT AND WALK TIME}}$$

Notes:

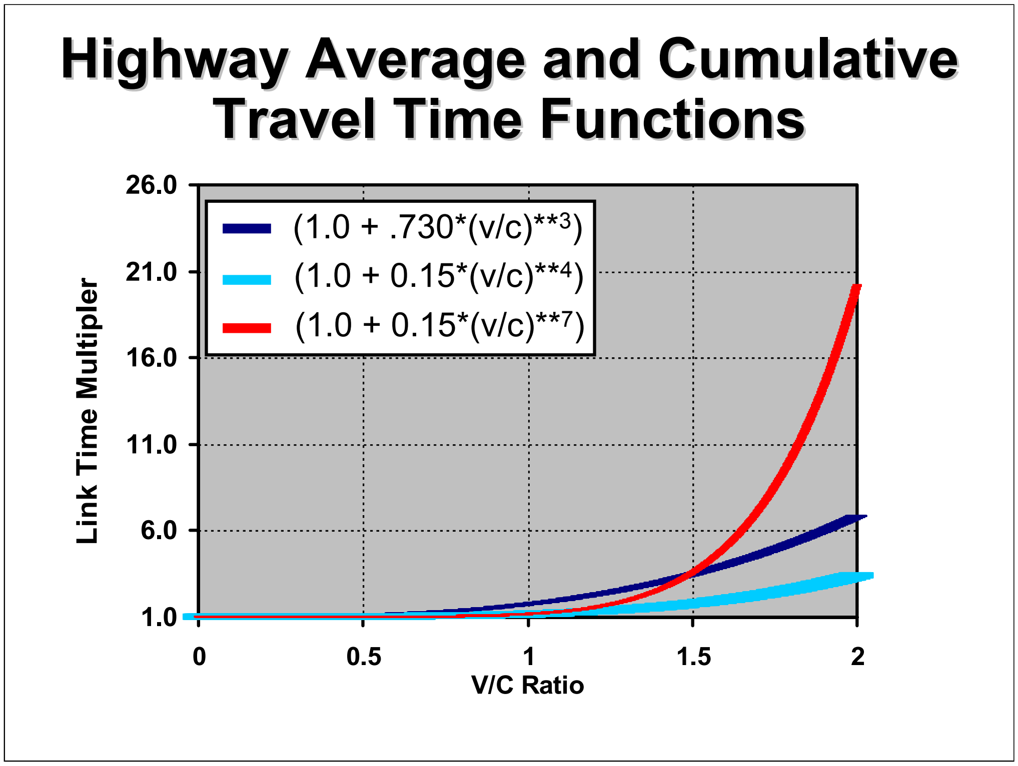
The highway link time functions are integrated to represent cumulative time and produce the user equilibrium highway assignment solution -- ala Beckman.

The Gravity Model and Modal Split aspects of objective function implemented by model construction.

Flow conversation constraints implemented through dynamic programming – highway and transit minimum path/assignment algorithm.

Highway capacity constraint implemented through "hook" on BPR function.

The transit time function is not integrated -- we use summations of average link time from the schedule rather than cumulative time. This is system optimal solution rather than user optimal solution. Transit is operated and optimized as a system with preset scheduled travel times controlled by supervisors. It does not respond directly to user behavior – just indirectly through schedule changes based on prevailing (highway) running times, stop dwell times, vehicle occupancy, terminal times and so forth.



Note:

There is not much difference between average (dark blue)**3, cumulative time **4 (light blue) and cumulative time **7(red) V/C ratios < 1.0.

The **4 and **7 functions clearly represent cumulative time because they are almost perfectly flat between v/c 0 and 1.

The average time is the first derivative of the **4 function. Note that in objective function requires that these formulas be multiplied through by the link volume leading to v**5/c**4 for the **4 curve (the 0.15 value is rounded).

By reverse engineering, the exact calibration reference for the BRP average time function: Figure 3.43 (two lane rural highways) on page 65 of the 1965 Highway Capacity Manual, HRB Special Report 87. Use the 50 MPH speed limit, site distance 60% curve at its limits – 26-45 MPH. (Only two data points are needed to calibrate the BRP function.) With a little finagling, you can also get a similar calibration for multi-lane rural highways and freeways from figures 3.42 and 3.41.

Compatibility with Software Packages

- ✓ **Link Level Frank-Wolf Evans**
  - – Frank-Wolf implementations of Evans compatible with any package that supports 4-step model and equilibrium assignment
- ✓ **Some customization required**
  - – Fine tune equilibrium assignment computation
  - – Calculate transit impedance
  - – Modify λ search to include transit
  - – Make provision to preset λs
- ✓ **Computational efficiency issues**
  - – DVRPC implementation involves 24 passes through the model chain and 66 iterations of equilibrium assignment. TRANPLAN takes about 2.5 hours

Notes:

The computational advantages make it worthwhile to enhance the software to implement link level Evans.

Uniqueness of the Solution

- ✓ **Convex Objective Function with Linear Constraints**
  - – Travel mode cost/time functions monotonically increasing with volume
- ✓ **Sufficient Condition:**
  - – Each mode time/cost function independent of other travel modes
- ✓ **Independence may not be necessary if combined cost function monotonically increasing**

Notes:

Highway Travel Time Curves

BPR curve shown previously is monotonically increasing.

BPR; Unique Solution with constant transit times

Transit Travel Time Curves

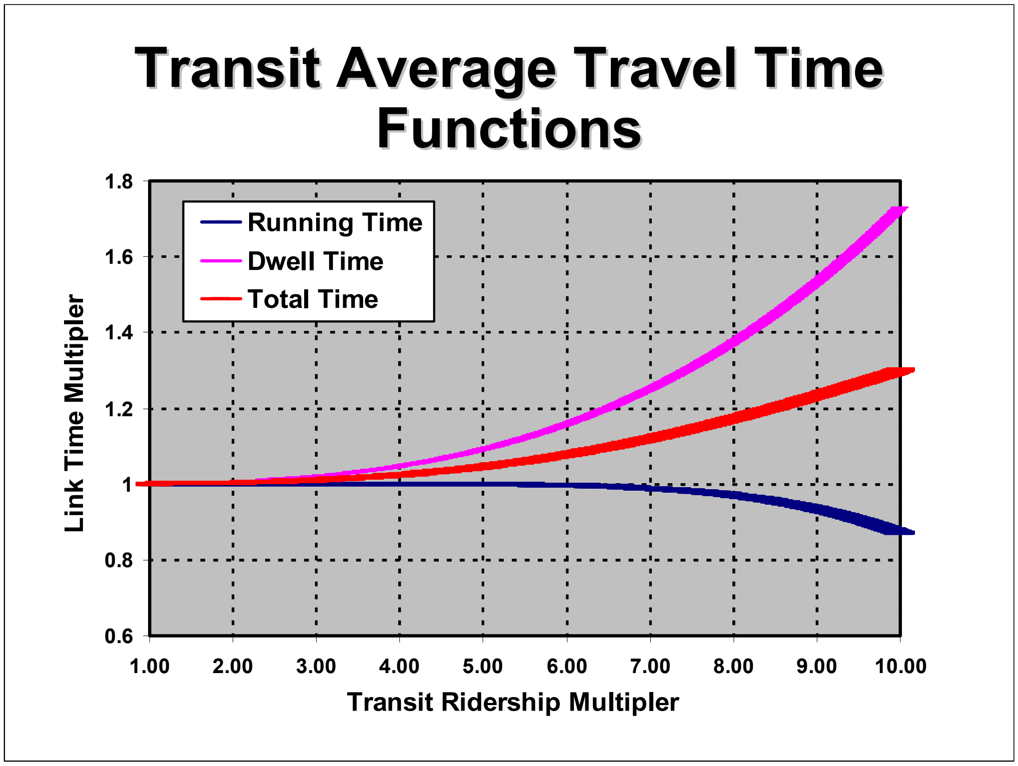
Regional forecasts; probably unique.

INET highway speed only; probably multiple solutions, especially if person trip table fixed.

With transit dwell time; probably unique.

Simple Iteration from Current Transit Speeds

One or two iterations – small changes (<5%)



Notes:

In mixed mode operations, bus running times decrease with ridership because highway link volumes are reduced by the diversion to transit -- especially if the person trip table is fixed. This leads to multiple solutions. Evans will tend to divert trip ends into highway corridors with improved speeds and mitigate this effect.

This effect is counterbalanced by the increase in dwell times resulting from congested boardings and alightings at transit stops.

DVRPC Evans Implementation

- **Evans Diagonalized Iterative Structure**
  - Inner loop on highway time
  - Outer loop on transit time
  - Cannot be used for New Starts Analysis
- **Opening Gambit**
  - 15 Iterations of highway assignment in Evans Iteration 0 to reduce highway free flow speeds to approximate operating speeds
- **Evans Iterations 1 through 7**
- **Preset λs for Opening Gambit and Evans Iterations 1 and 2**

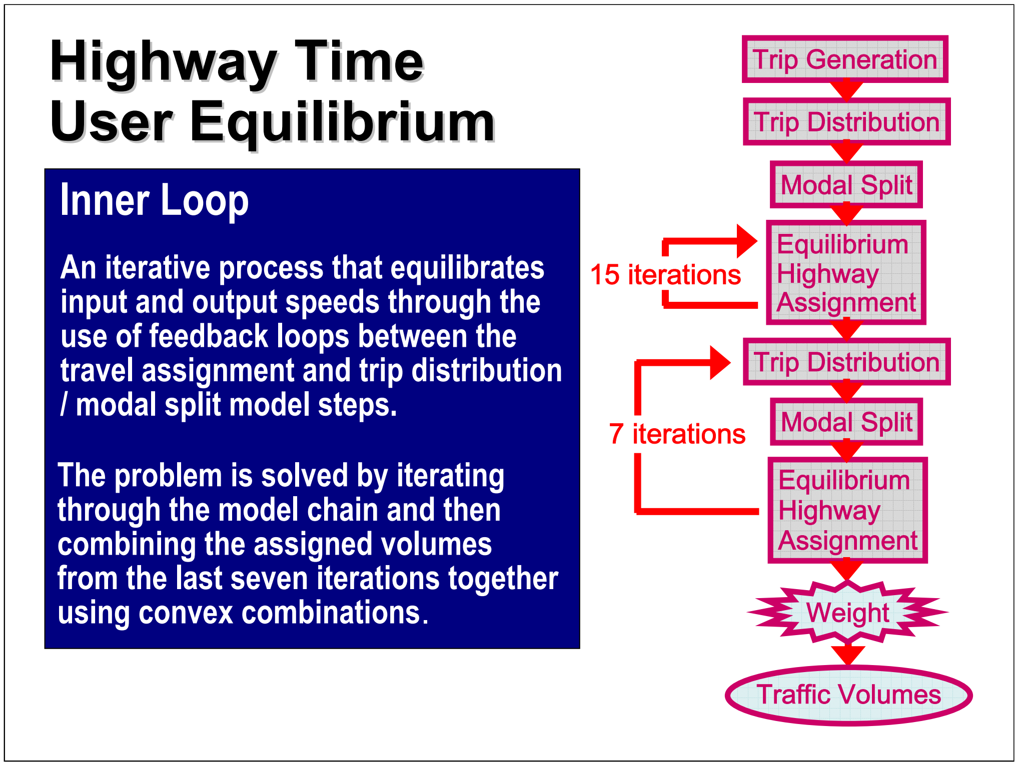
Advantages of diagonalization:

The inner highway loop is convex and single valued. Makes a stable engine on which to hang the algorithm.

The outer transit loop may or may not be convex depending on the treatment of congested transit times. Diagonalization allows the use of scheduled (non integrated) current times and approximate methods to adjust for future transit times, particularly when the anticipated speed changes are not large.

The outer loop is not iterated to convergence, rather 1 or 2 iterations of simple iteration are employed to adjust transit running times to the approximate future values (less than 5 percent reduction for most lines).

The New Starts guidelines do not allow iteration on person trips. Can't use Evans for alternatives analysis except to prepare no-build person trip table.



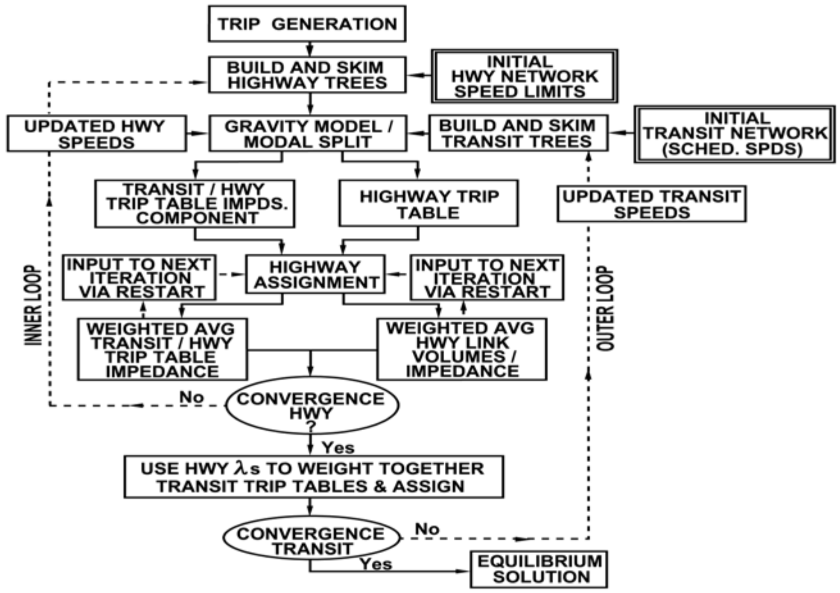
Notes:

Process generates both congested highway speed and volume.

Starts with opening gambit of 15 iterations of equilibrium highway assignment in Evans iteration 0 to reduce input uncongested (speed limits) highway speeds to approximate prevailing speeds. Followed by 7 iterations of Evans from trip distribution through highway assignment.

Opening gambit reduces computation time and increases the attainable degree of convergence.

Evans Diagonalized Iterative Structure



Notes:

We don’t have a completely accurate way of calculation highway times for use in transit running time estimation. Accurate transit times are essential for preparing summaries and evaluation statistics. DVRPC air quality post-processor highway speed curves work better that the BPR curve, but are not based on micro assignment information and therefore are not cognizant of the nuances of highway capacity and travel speed.

Outer transit loop is one iteration of simple iteration with slightly non-convex transit time function -- using the ratio of future to current highway link post-processor time to adjust the corresponding current transit link scheduled time. This typically results in small changes (< 5% in peak period). This methodology is adequate to adjust current scheduled transit speeds for prevailing future highway conditions.

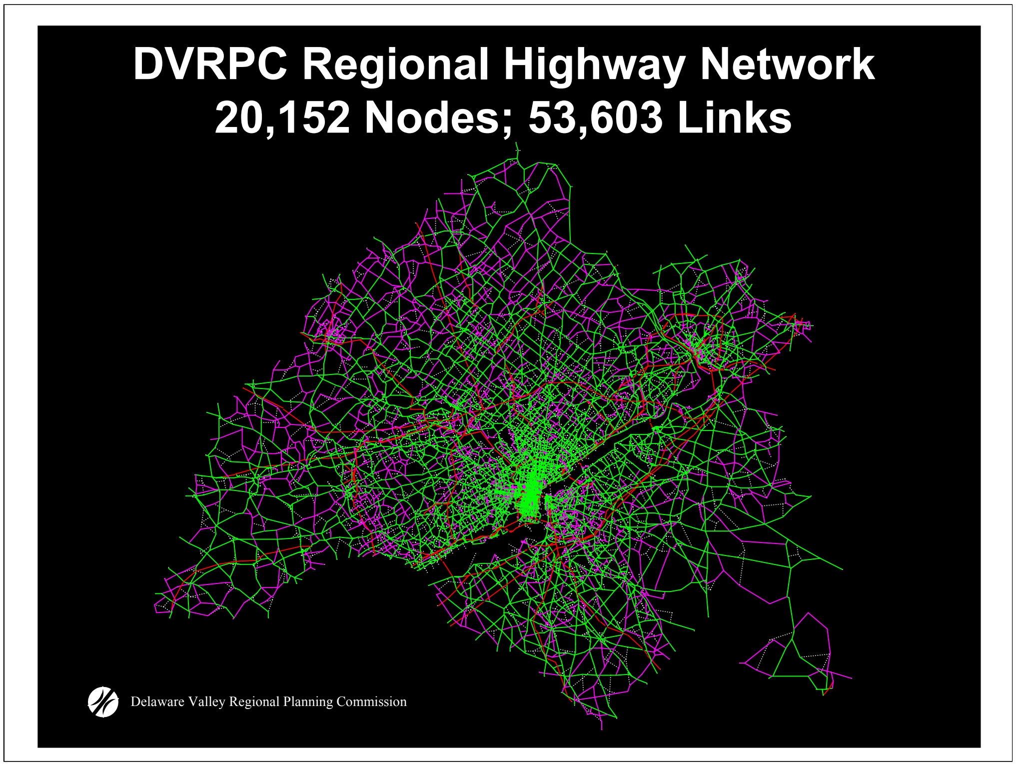
Inner loop always starts with uncongested highway speeds and is convex.

DVRPC Model Components

- **Trip Generation**
  - Cross Classification
- **Trip Distribution**
  - Gravity Model
- **Modal Split**
  - Binary Logit
  - Nested on mode of approach
- **Highway Assignment**
  - Minimum Impedance
  - Equilibrium BPR exponent 7.0
- **Transit Assignment**
  - Minimum Impedance
  - All or nothing

DVRPC Model Characteristics

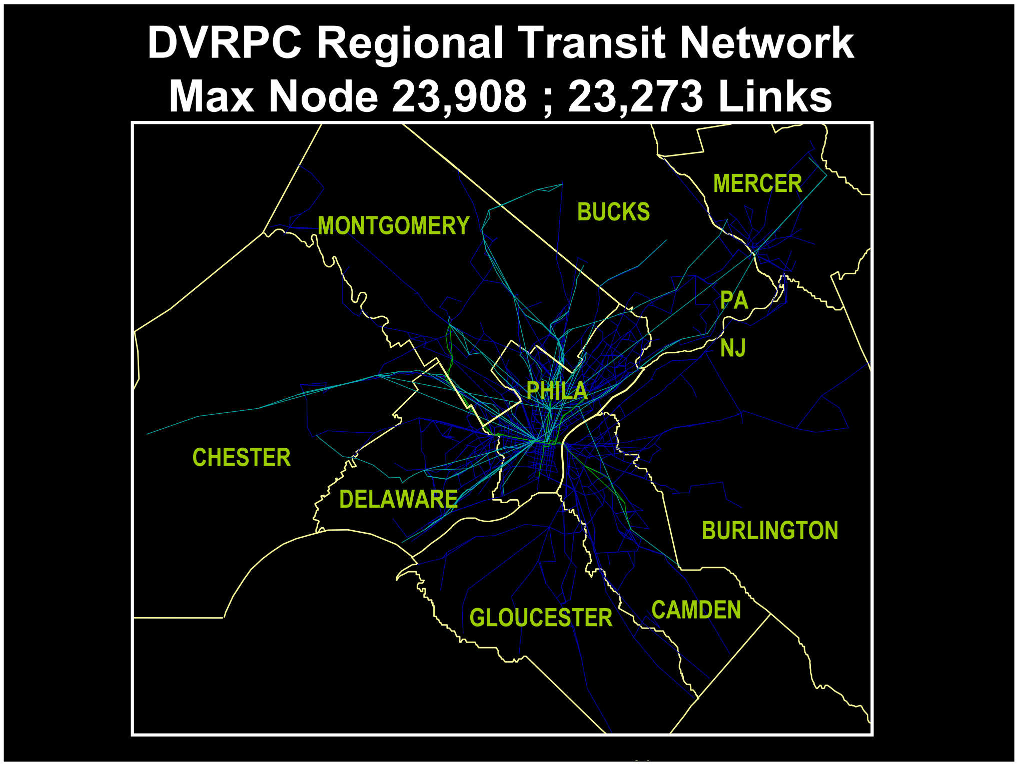
- **Demographics**
  - 5,389,000 Persons
  - 2,718,000 Employees
- **2068 Traffic Analysis Zones (TAZs)**
  - Bi - State: Pennsylvania and New Jersey, 9 Counties, 355 Minor Civil Divisions (MCDs)
- **Three Time Periods:**
  - Peak 7:00 AM to 9:00 AM and 3:00 PM to 6:00 PM.
  - Midday 9:00 AM to 3:00 PM
  - Evening 6:00 PM to 7:00 AM



Notes:

Very large, detailed, networks and number of TAZs. Evans/TranPlan combination very efficient and solves problem in about 45 minutes per time period -- 2:25 hours overall.

Very reasonable computation time for conformity analyses, traffic studies, etc.


DVRPC Regional Transit Network
Max Node 23,908 ; 23,273 Links
MERCER
MONTGOMERY
BUCKS
PA
NJ
PHILA
CHESTER
DELAWARE
BURLINGTON
GLOUCESTER
CAMDEN

Model Calibration in an Iterative Environment

- Simulated travel times a function of simulated volume (BPR isn't perfect)
- Start with free flow highway speeds
- Simulated equilibrium travel times change with model parameter settings
- Equilibrium iterated model turned on its side – minimize calibration error given surveyed travel patterns and simulated speeds
- Simple iteration of model calibration routines doesn't converge to a stable parameter solution
- Use convex combinations of iterated of model parameters using optimal λs.

Notes:

Travel time issues:

Average (table lookup) highway time in survey versus cumulative time in model (minor factor).

Influence of "hook" on BPR curve on simulated travel times (major factor), although the Evans redistribution of GM trips away from congested corridors reduces this effect.

Theoretical issue: Cumulative versus average highway travel time for behavior modeling:

Using average highway time for behavior modeling and cumulative time for evaluating the objective function has great intuitive appeal.

But, is this really correct?

> Remember the GM and Modal Split portions of the objective are included by model construction. This requires cumulative time throughout the model chain.
>
> Also, equilibrium assignment implementations using the BPR curve use cumulative time to build minimum paths as well as to evaluate the objective function. If you have custom average time restraining routines, you are generating the system equilibrium solution.

My view: User equilibrium cumulative time requirements apply to modeling as well as to objective function evaluation.

Model Calibration Methodology

- Initial model calibration based on surveyed highway speeds and scheduled transit times
- Execute Evans iterative model procedure starting from free flow speeds
- Re-estimate model parameters based on simulated equilibrium speeds
- Using convex combinations search for λ value that minimizes calibration error.
- Model fine tuning order -- trip distribution, auto occupancy, modal split, trip generation, highway assignment, and transit assignment

Calibration Results
Average Trip Lengths

Purpose	Surveyed Average Trip Length (Minutes)	Simulated Average Trip Length (Minutes)	Diff.	Percent Diff.
Home-based Work	26.1	26.6	0.5	1.9%
Home-based Non-work	16.7	17.2	0.5	3.0%
Non-home based	17.8	18.3	0.5	2.8%
Freeway Ext-local	41.6	42.7	1.1	2.6%
Arterial Ext-local	35.0	35.7	0.7	2.0%
Local Ext-local	27.9	27.8	-0.1	-0.4%
Turnpike Ext-local	70.1	70.2	0.1	0.1%

Notes:

Good calibration – all predicted ATL's within 5% of surveyed.

Average simulated highway speeds from Evans output comparable with travel time survey.

	Actual	Simulated
Peak	30.1	28.0 MPH
Midday	31.7	32.0 MPH
Evening	NA	33.4 MPH

Calibration Results
Transit Ridership

Company/Division	Submode	2000 Assigned Volumes	2000 Passenger Counts	% Difference
SEPTA City Transit	Subway-Elevated	279,489	286,500	-2.45%
	Bus & Trolley	539,393	559,400	-3.58%
Total		**818,882**	**845,900**	**-3.19%**
SEPTA Suburban				
Victory Division	Heavy Rail	7,594	7,600	-0.08%
Victory Division	Bus & Light Rail	37,263	37,200	0.17%
Fronier Division	Bus	14,837	15,600	-4.89%
Total		**59,694**	**60,400**	**-1.17%**
SEPTA Regional Rail	Commuter Rail	**108,525**	**104,200**	**4.15%**
SEPTA Total		**987,101**	**1,010,500**	**-2.32%**
NJT Southern Division	Bus	34,479	33,700	2.31%
NJT Mercer Division	Bus	14,997	14,800	1.33%
Total NJ Transit		**49,476**	**48,500**	**2.01%**
DRPA	High Speed Rail	39,704	37,300	6.45%
Grand Total		**1,076,281**	**1,096,300**	**-1.83%**

Notes:

Good regional fit. Individual transit lines may need fine tuning.

Calibration Results
Highway Assignment Errors

Link Volume Group	Percent RMS Error
<3,000	101.0%
3,000-4,999	71.5%
5,000-9,999	61.4%
10,000-14,999	37.0%
15,000-19,999	42.5%
20,000-29,999	30.8%
30,000-49,999	25.6%
>50,000	25.2%
Total	**40.2%**
Overall Correlation	**0.89**
Average Screenline Error (16 Screenlines)	**4.6%**

Notes:

Results of regional calibration.

Too many links to fine tune assignment unless links are part of detailed alternatives analysis.

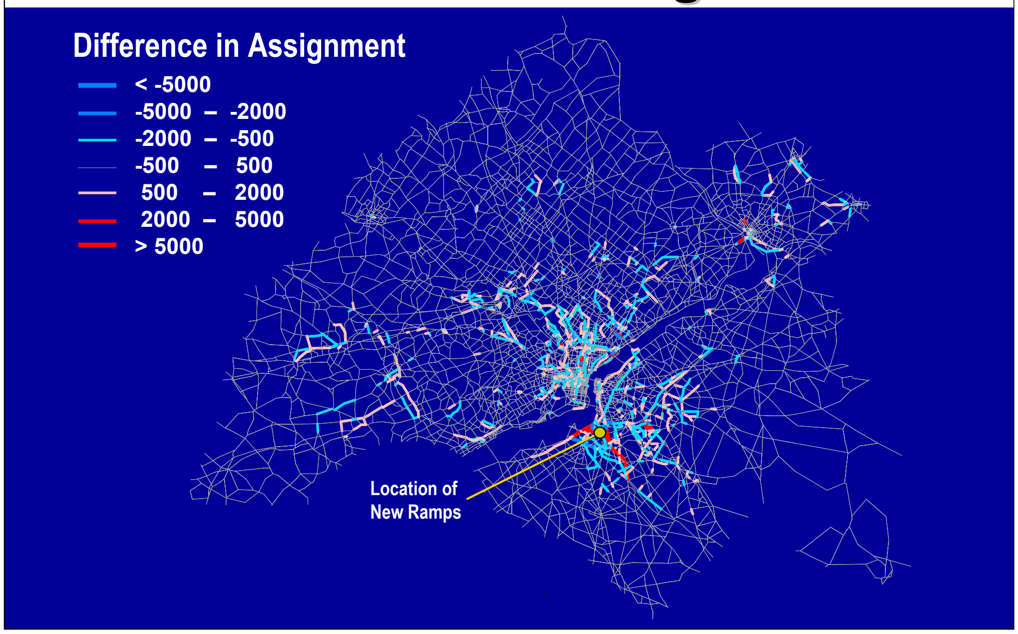
Focus model on study corridor and improve calibration. Corridor extraction is not consistent with Evans.

Must run entire regional model for Evans to work. Not too bad because of reasonable running times.

Convergence Issues and Transport Alternative Comparability

- **Rounding Error and Bisection Search Direction**
  - Summation rounding error
  - Trip table integerization
- **Network Topology**
  - Comparison of similar alternatives
  - Sequencing table sorting inconsistencies
- **Rational for Presetting Iteration Weights (λ)**
  - Opening gambit
  - Evans iterations
  - Attainable convergence level (0.0001) and quality of the simulated link volumes

Iteration 0 Differences in Build and No-Build Traffic Assignments



Notes:

The sort routine only considers impedance when determine the next link to be added to the tree. A few tied impedance links may be switched in the sort simply because of adding two additional links to the build alternative network. Those (young at heart) folks in the audience who used to run and IBM card sorter will know what I mean. You may have also seen this in KEDIT or other visual sort routines.

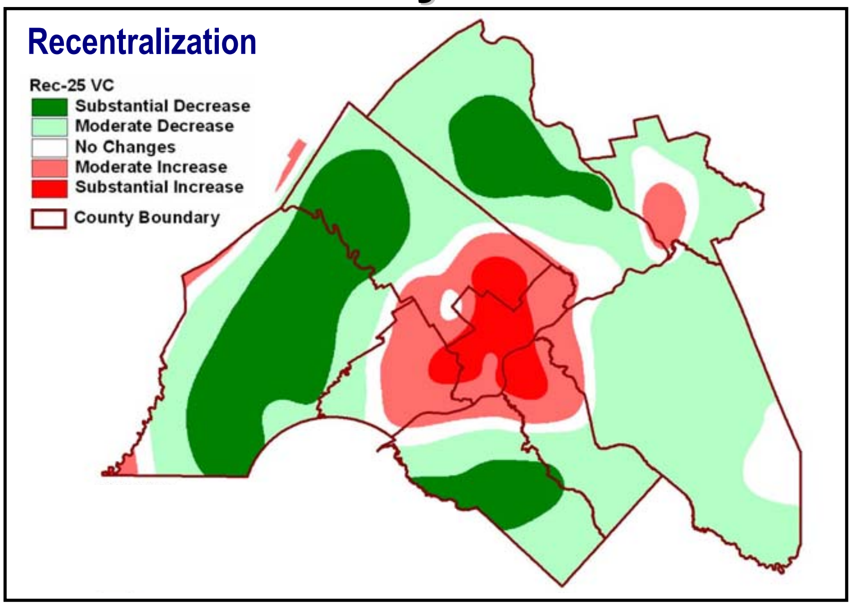
This switching of tied links affects the minimum paths, even though the differences appear rational in the immediate vicinity of the proposed ramps.

The irrational effect is most prevalent (although not common) in iteration 0 because all impedances are in 100ths.

This map shows that the irrational effect is localized in the early going.

However, the lambda values calculated for each iteration can be significantly changed. This spreads the disturbance to all links in the network.

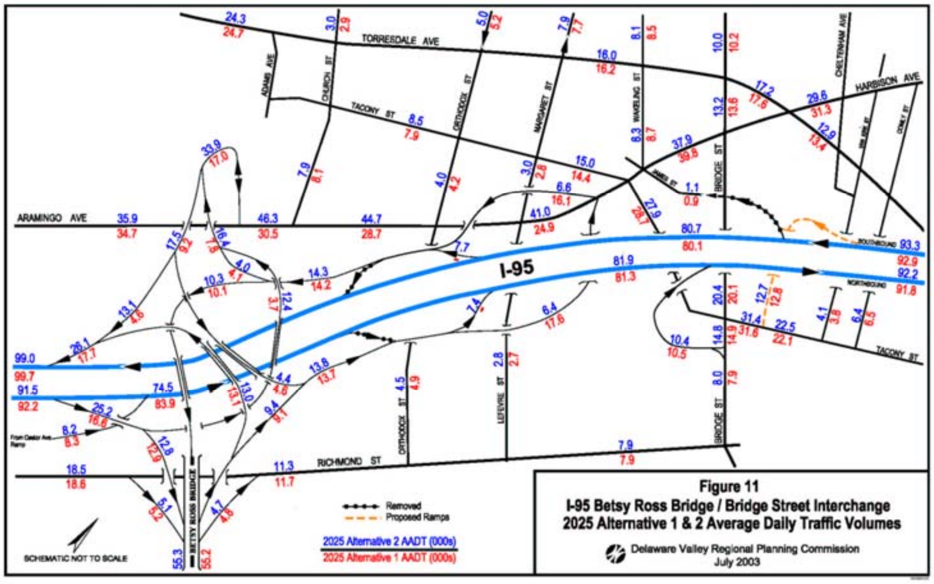
Example: Long Range Plan Scenario Analyses V/C Ratio



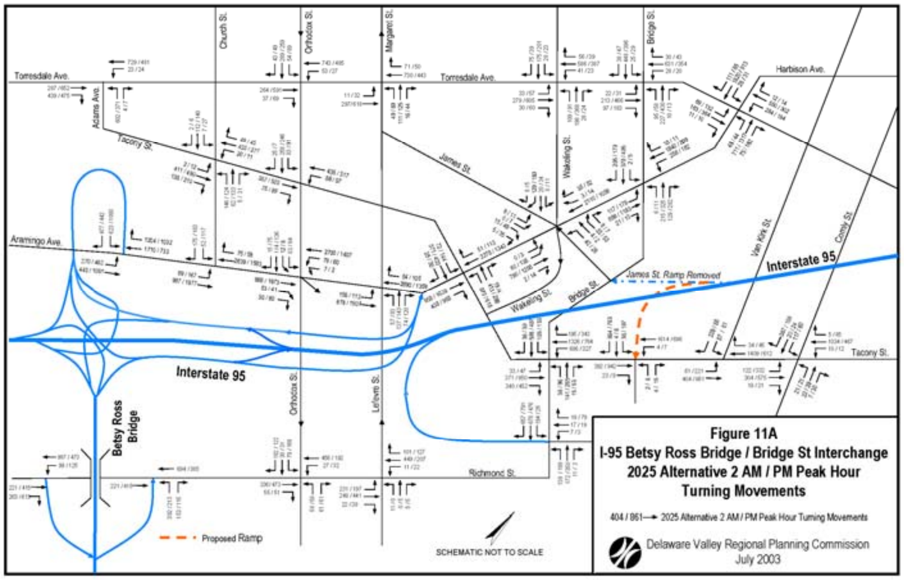
Example: Ozone Conformity Tests

Scenario	Daily VMT	Ave. Speed (mph)	Emissions (tons/day) VOC	NOx	Budgets VOC	NOx	Difference VOC	NOx
2010 Summer								
Pennsylvania	83,758,200	29.8	58.29	88.07	**79.69**	**144.73**	-21.40	-56.66
New Jersey	46,081,300	33.7	21.41	44.91	**42.99**	**63.44**	-21.58	-18.54
2020 Summer								
Pennsylvania	88,665,100	30.1	26.53	27.90	**79.69**	**144.73**	-53.16	-116.83
New Jersey	48,938,800	33.7	12.11	12.97	**42.99**	**63.44**	-30.88	-50.47
2030 Summer								
Pennsylvania	91,361,600	29.9	23.11	16.80	**79.69**	**144.73**	-56.58	-127.93
New Jersey	50,177,400	33.5	11.16	8.37	**42.99**	**63.44**	-31.83	-55.07

Example: Average Daily Traffic Volumes



Example: AM and PM Peak Hour Turning Movements



Example: DVRPC Region Transit Fare Hike Impacts

SEPTA Division	Submode	Current Fares and Service Boardings (Base)	Alternative A (11% Fare Increase) Brdngs	Diff. From Base	% Diff. From Base	Alternative B (31% Fare Increase & 20% Reduction in Service) Brdngs	Diff. From Base	% Diff. From Base
City Transit	Subway-Elevated	284,050	276,002	-8,048	-2.8%	251,709	-32,341	-11.4%
	Bus & Trolley	506,134	495,395	-10,739	-2.1%	458,118	-48,016	-9.5%
Sub Total		**790,184**	**771,397**	**-18,787**	**-2.4%**	**709,827**	**-80,357**	**-10.2%**
Suburban								
Victory Div.	Heavy Rail	7,495	7,265	-230	-3.1%	5,980	-1,515	-20.2%
Victory Div.	Bus & Light Rail	36,078	34,266	-1,812	-5.0%	28,075	-8,003	-22.2%
Frontier Div.	Bus	15,936	15,712	-224	-1.4%	13,210	-2,726	-17.1%
Sub Total		**59,509**	**57,243**	**-2,266**	**-3.8%**	**47,265**	**-12,244**	**-20.6%**
Regional Rail	Commuter Rail	**107,721**	**103,628**	**-4,093**	**-3.8%**	**85,194**	**-22,527**	**-20.9%**
SEPTA Total		**957,414**	**932,268**	**-25,146**	**-2.6%**	**842,286**	**-115,128**	**-12.0%**

Modeling Recommendations

- Simple model components a plus
- Transit volume/time functions should include vehicle dwell and acceleration/deceleration effects
- Software packages, except TRANPLAN, may require revisions to implement Evans
- Newer software packages will require testing to determine computational performance with Evans
- Explore possibility of implementing Evans within network optimizing methods other than Frank-Wolf -- Origin Based etc.
- Implement Evans within tour/activity based models

Overall Conclusions

- **DVRPC model involves many design decisions and compromises, but considers all aspects of equilibrium theory**
  - Focused on current situation and policy environment in the DVRPC Region
- **Represents state of the art in practical equilibrium modeling**
  - Fine grained simulation model
  - Acceptable calibration
  - Computationally practical
  - Successfully used in many long range planning, transportation air quality, and highway alternatives analyses
- **Modeling profession should consider how to incorporate equilibrium factors more effectively**

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