Urban Rail Simulation Model Calibration and Validation

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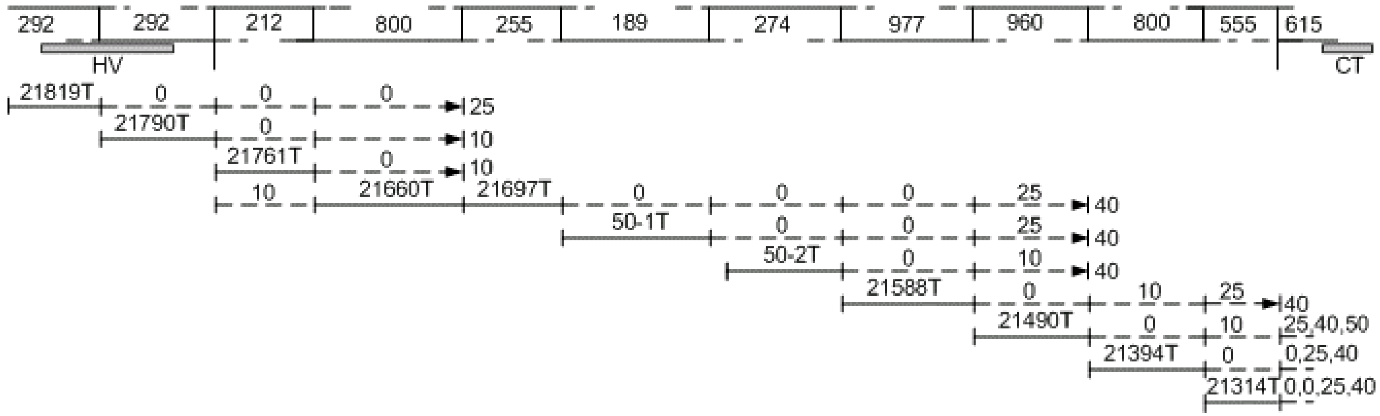
Outline

- Simulation model of rail operations and control
- Calibration and Validation
  - Methodology
- Case study
  - MBTA Red Line

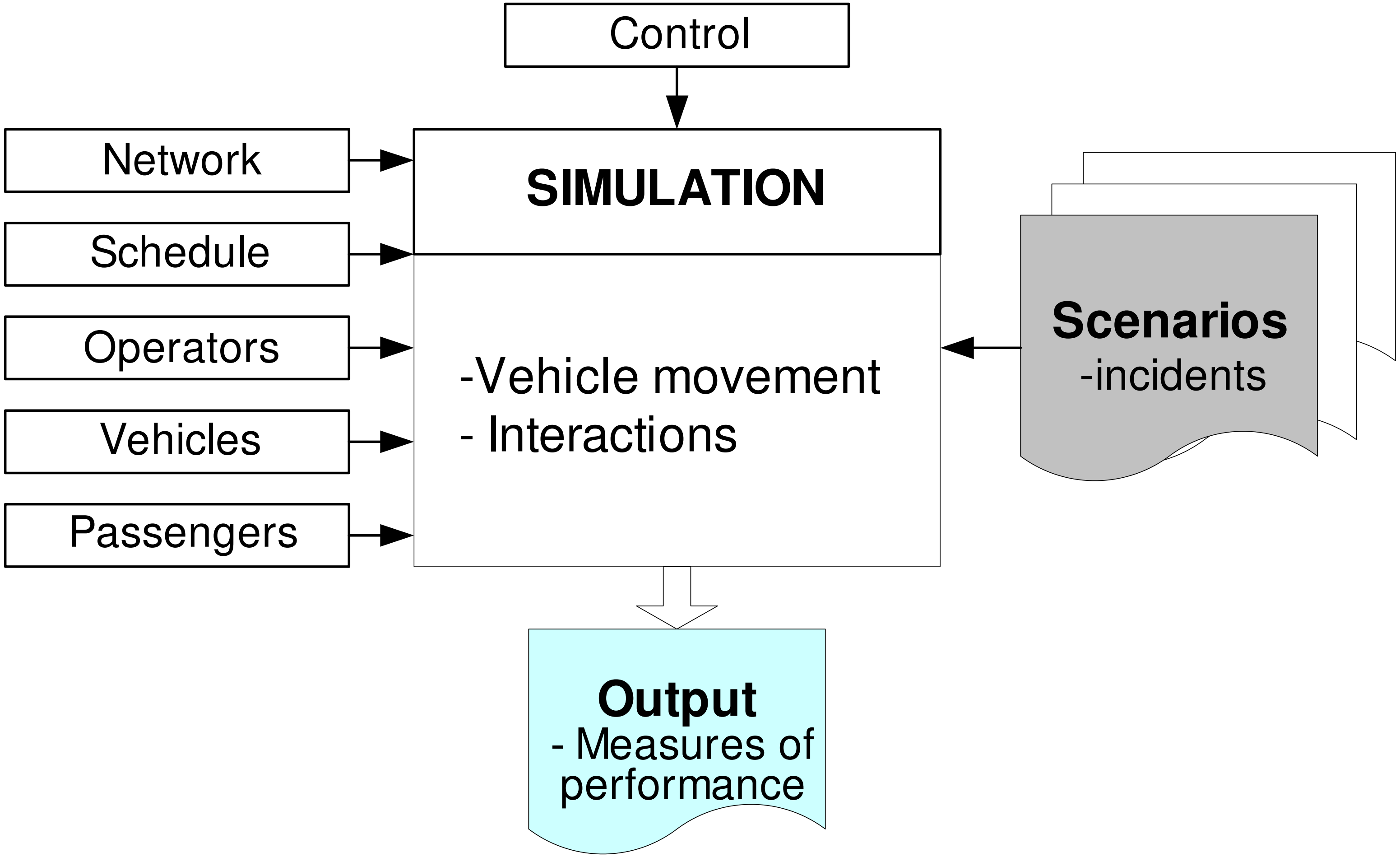
Rail Simulation Model

- Detailed Simulation of Operations for:
  - Evaluation of real time control strategies
  - System performance analysis and operations planning
  - Control system evaluation



  - Capacity analysis
  - Training

Simulation Model Structure



Calibration

- Parameters/Input
  - Dwell time model parameters
  - Acceleration/deceleration rates
  - Demand: arrival/alighting rates
  - Pre-shunt/post-shunt distance
  - Operator variability
- Data Available for Calibration
  - Operational Control System (OCS) records
    - Block on/off time
    - Actual train dispatching records

Calibration Methodology

- Formulated as an optimization problem of minimizing errors and deviation from a-priori values

$$Min \quad Z = \sum_{i=1}^{m} w_1 (Y^{obs} - Y^{sim})^2 + \sum_{j=1}^{n} w_2 (P^a - \hat{P})^2 + \sum_{k=1}^{l} w_3 (I^a - \hat{I})^2$$

$\hat{P}, P^a$ – Calibrated and a-priori system parameters, e.g., dwell time model parameters

$\hat{I}, I^a$ – Calibrated and a-priori system input, e.g. arrival/alighting rates

Y^{sim}, Y^{obs} – Simulated and observed performance measurements, e.g., block occupancy time

w_i – Weights

Goodness-of-Fit Measures

- Root mean square error

$$RMSE = \sqrt{\frac{1}{N}\sum_{n=1}^{N}(Y_n^{sim} - Y_n^{obs})^2} \qquad RMSPE = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\left(\frac{Y_n^{sim} - Y_n^{obs}}{Y_n^{obs}}\right)^2}$$

- Theil's U

$$U = \frac{\sqrt{\frac{1}{N}\sum_{n=1}^{N}(Y_n^{sim} - Y_n^{obs})^2}}{\sqrt{\frac{1}{N}\sum_{n=1}^{N}(Y_n^{sim})^2} + \sqrt{\frac{1}{N}\sum_{n=1}^{N}(Y_n^{obs})^2}}$$

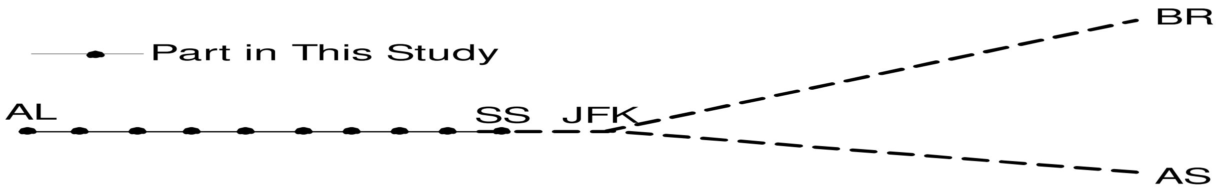
$$U^M + U^S + U^C = 1$$

U^M: Bias; U^S: Variability replication; U^C: Unsystematic error

- Y^{sim}, Y^{obs}: Simulated and Observed Performance Measures
  - Block run time
  - Travel time
  - Headway distribution

Case Study

- Network: Red Line southbound Alewife-South Station



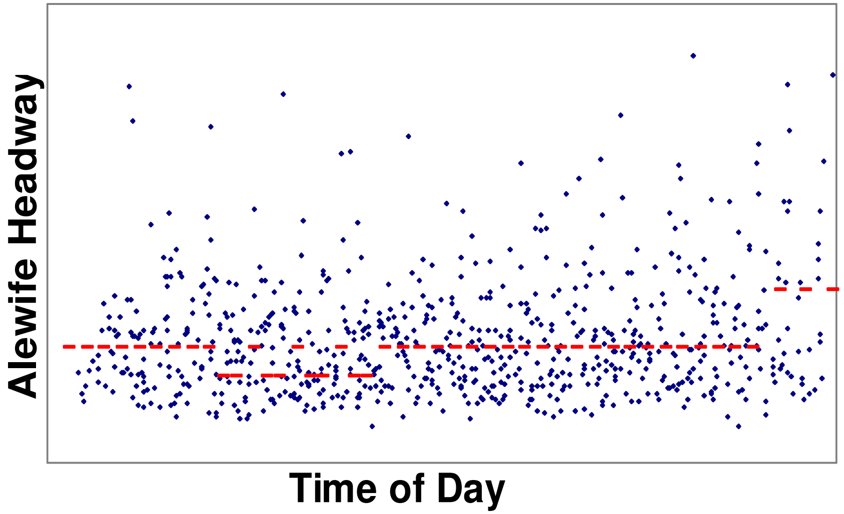
- Data: a-priori parameters and inputs
  - Demand: CTPS 1997
  - ACC/DEC Rates: Theoretical profile, MIT/field data
  - OCS Oct 04 records
    - Block Run Time
    - Dispatching Headway
  - Dwell Time Model: Puong, MIT 2000

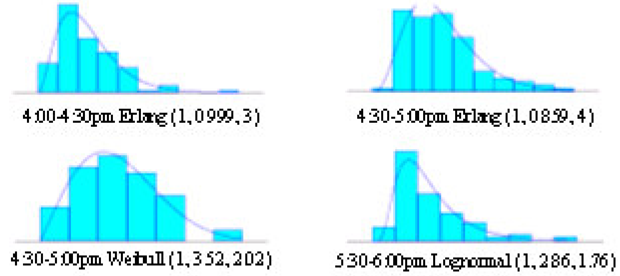
$$DT = 12.22 + 2.27 * B_d + 1.82 * A_d + 6.2 * 10^{-4} * TS_d^3 B_d$$

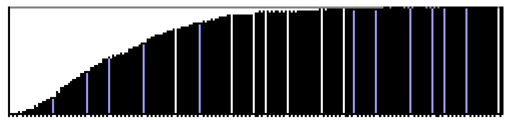
B_d – Boardings per door $\quad A_d$ – Alightings per door

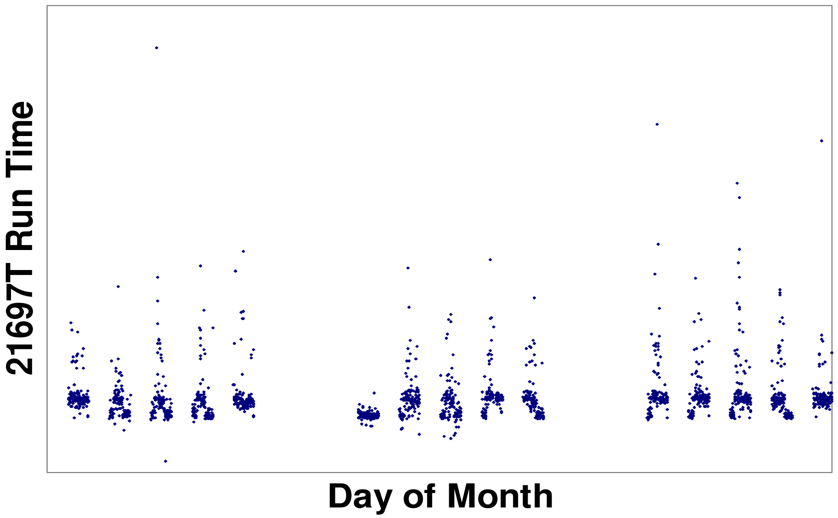
TS_d^3 – Through standees per door

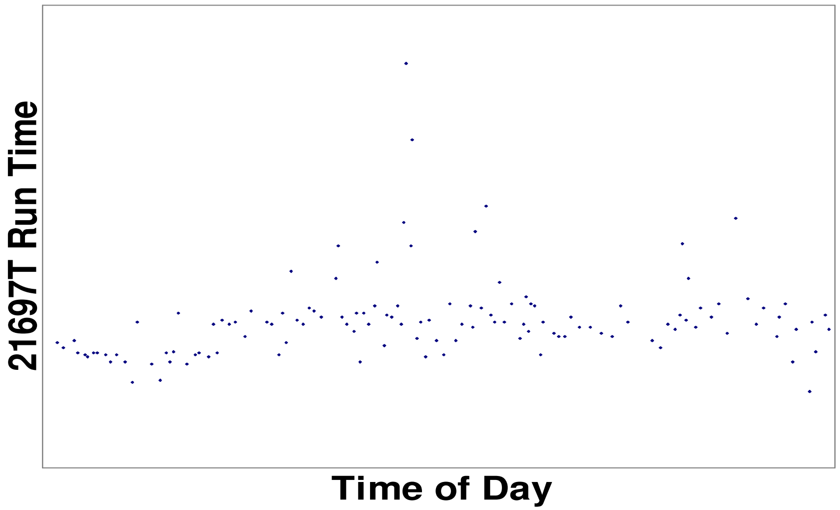
Case Study


Alewife Headway
Time of Day

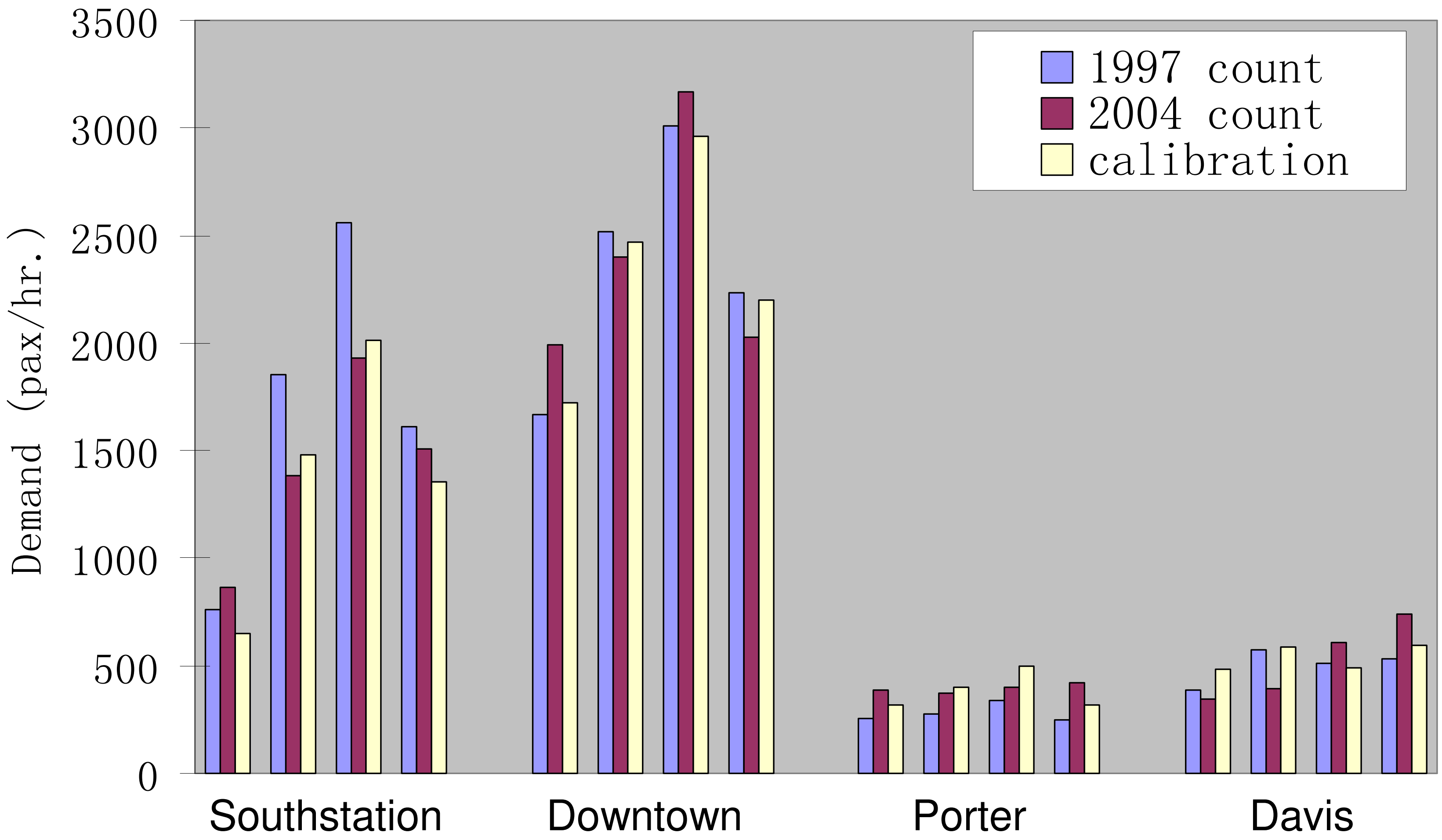

4:00-4:30pm Erlang (1,0.999,3)
4:30-5:00pm Erlang (1,0.859,4)
4:30-5:00pm Weibull (1,3.52,2.02)
5:30-6:00pm Lognormal (1,2.86,1.76)



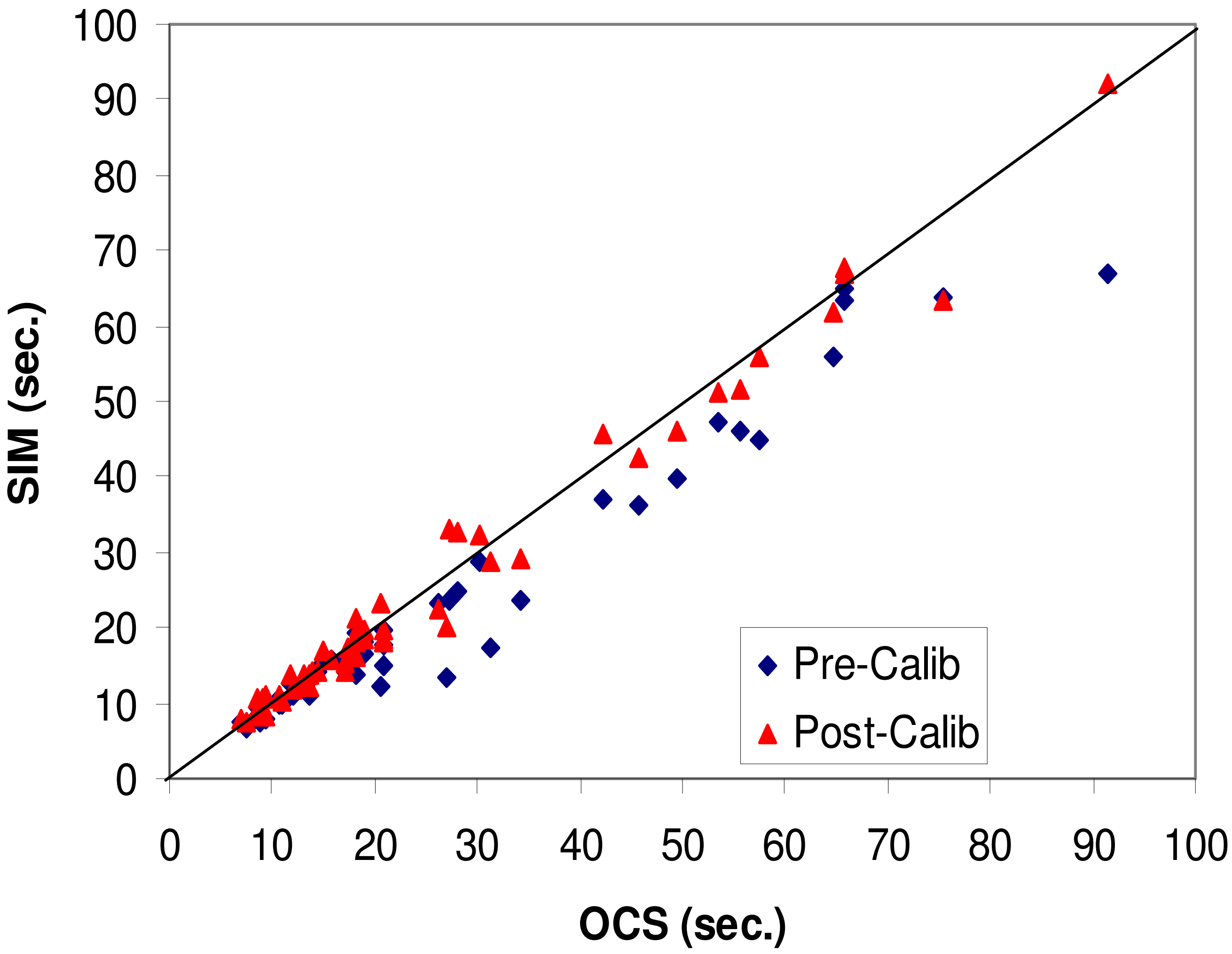

21697T Run Time
Day of Month


21697T Run Time
Time of Day

Calibration-Passenger Demand



Calibration- Block Run Time

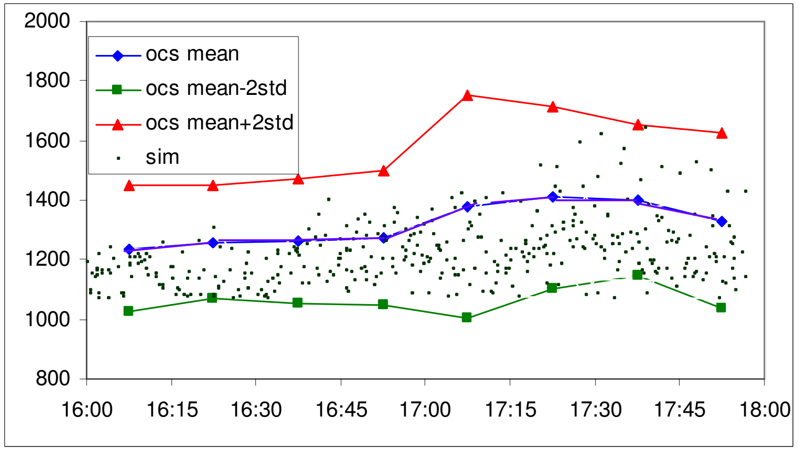


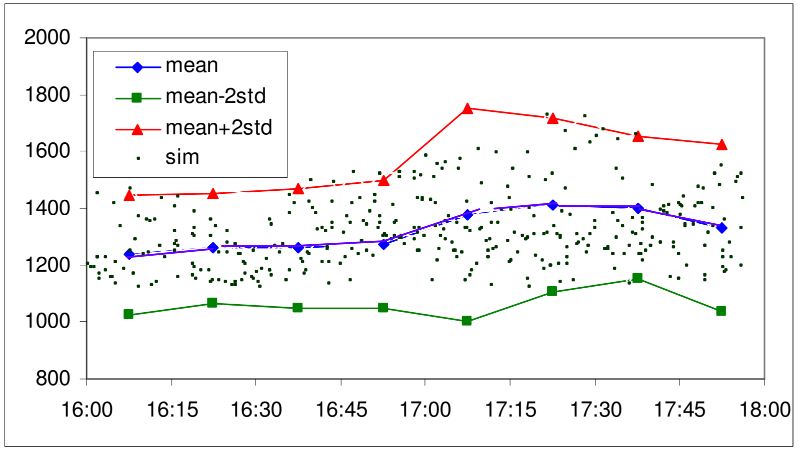
Calibration- Dwell Time Parameters

Station \ Parameter	Constant	Sec./Boarding	Sec./Alighting
a-priori value (Puong, 2000)	12.22	2.27	1.82
Kendall	14.1	2.39	1.86
Central	13.8	2.24	1.96
Park	27.3	2.61	2.02

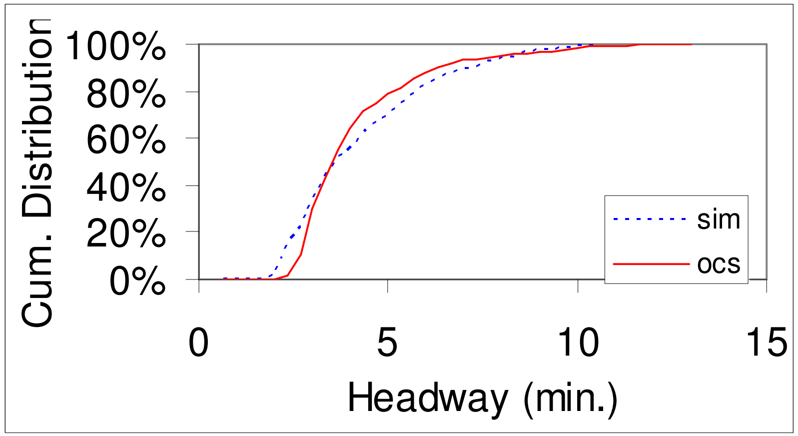
Calibration

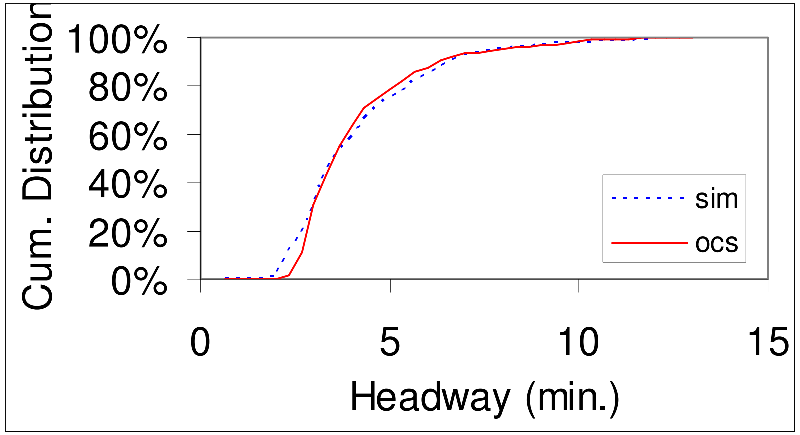
- Travel Time





- Headway Distribution





Calibration- Goodness-of-Fit Statistics

- Block Run Time, Oct 4-22/04, 4-6PM

Statistic	**Before**	**After**
RMSE	5.801	2.255
RMSPE	2.70%	0.92%
U (Theil's statistic)	0.104	0.038
U^M *(bias part)*	0.328	0.0338
U^S *(variance part)*	0.285	0.0002
U^C *(covariance part)*	0.387	0.966

Validation

- Block Run Time, Oct 25-29/04, 4-6PM

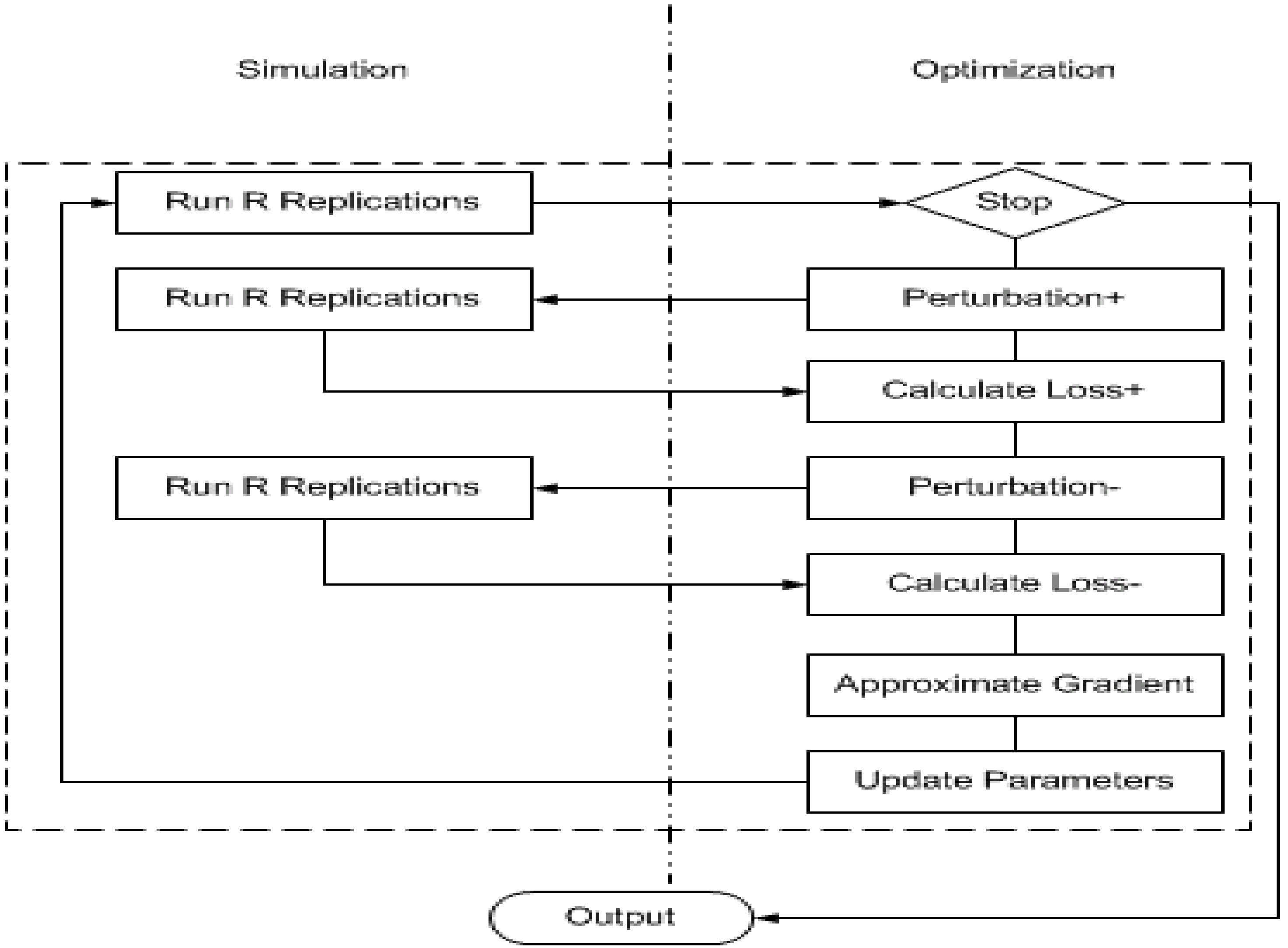
RMSE	2.538
RMSPE	1.08%
U (Theil's statistic)	0.042
U^M *(bias part)*	0.055
U^S *(variance part)*	0.082
U^C *(covariance part)*	0.863

Conclusion

- Rail simulation model is useful for planning and operations
- Calibration and validation of the model is very important before its use
- OCS data facilitate the calibration and validation process
- Proposed calibration method shows promising results

Questions

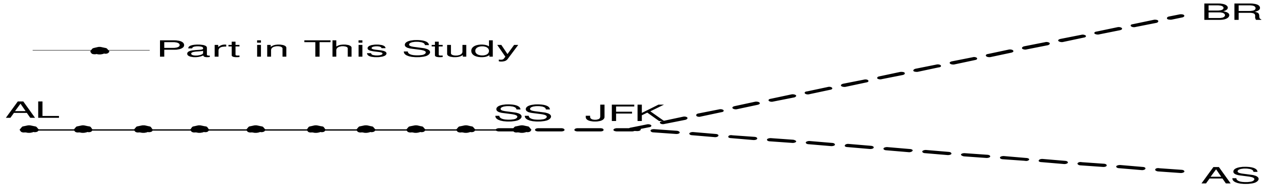
Framework



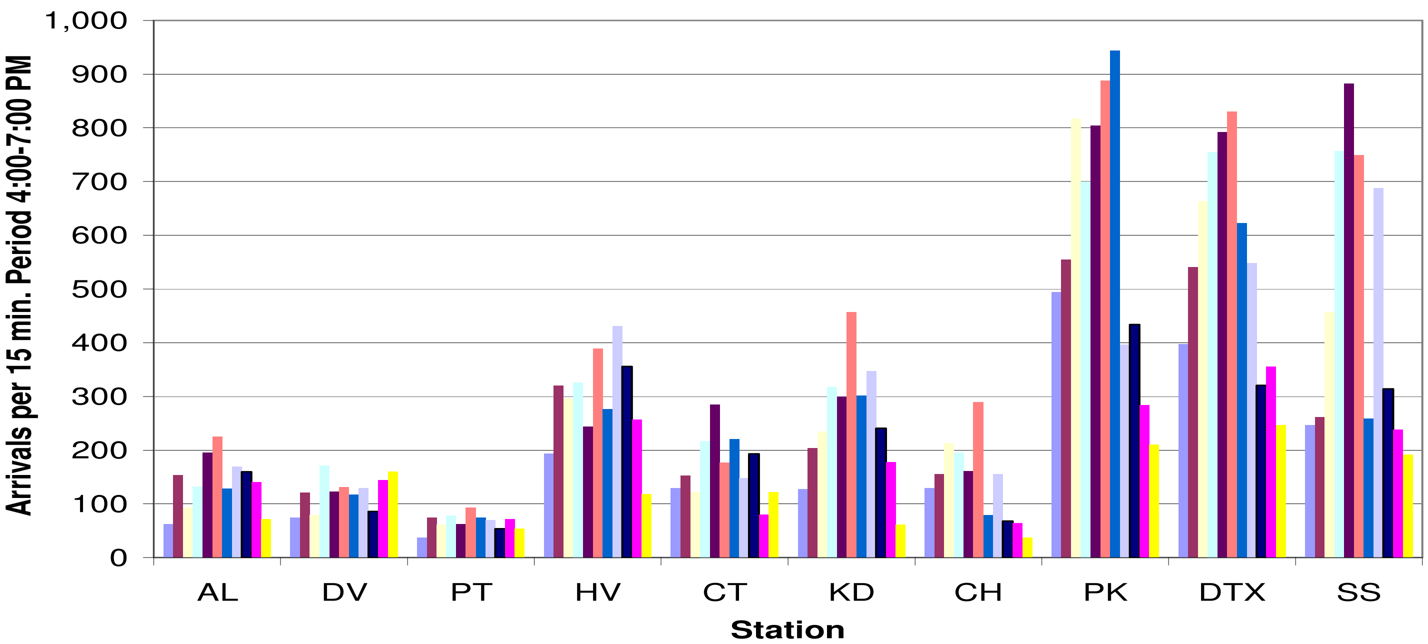
Simulation
Optimization
Run R Replications
Stop
Run R Replications
Perturbation+
Calculate Loss+
Run R Replications
Perturbation-
Calculate Loss-
Approximate Gradient
Update Parameters
Output

Case Study-Input Data

- Network: Red Line southbound Alewife-South Station

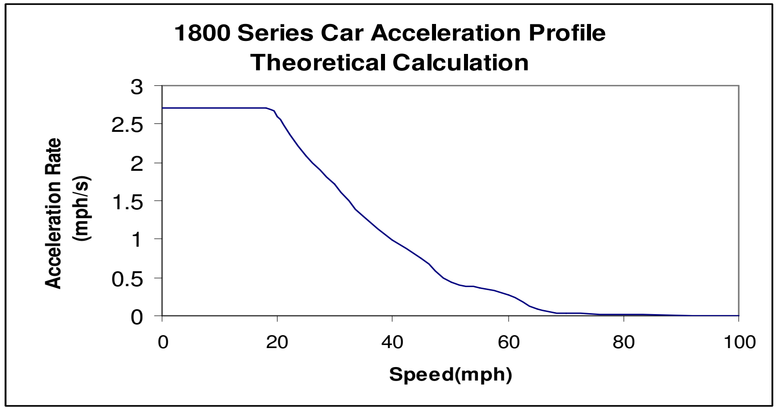


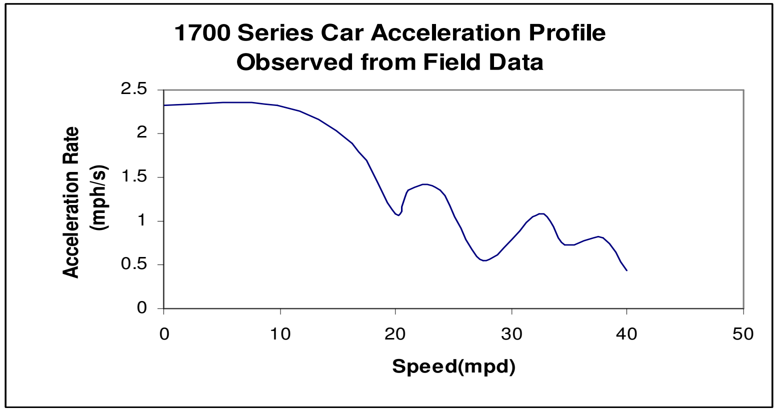
- Demand: CTPS 1997, split and shifted



Input Data-Cont'd

- ACC/DEC: Theoretical profiles, MIT study/field data





- Dwell Parameters: Puong model, non-station specific

$$DT = 12.22 + 2.27 * B_d + 1.82 * A_d + 6.2 * 10^{-4} * TS_d^3 B_d$$

B_d – *Boardings per door*

A_d – *Alightings per door*

TS_d^3 – *Through standees per door*

Calibration-Formulation

$$Min \quad Z = w_t \sum_{i=0}^{p}\sum_{j=1}^{m}(t_{ij}^{sim} - t_{ij}^{ocs})^2 + w_a \sum_{i=0}^{p}\sum_{k=1}^{n}(a_{ik}^{sim} - a_{ik}^{97})^2 + w_f \sum_{i=0}^{p}\sum_{k=1}^{n}(f_{ik}^{sim} - f_{ik}^{97})^2$$

$$+ w_c \sum_{k=0}^{n}(c_k^{sim} - c_k^{mit})^2 + w_\alpha \sum_{k=0}^{n}(\alpha_k^{sim} - \alpha_k^{mit})^2 + \sum_{k=0}^{n}(\beta_k^{sim} - \beta_k^{mit})^2$$

$st.$

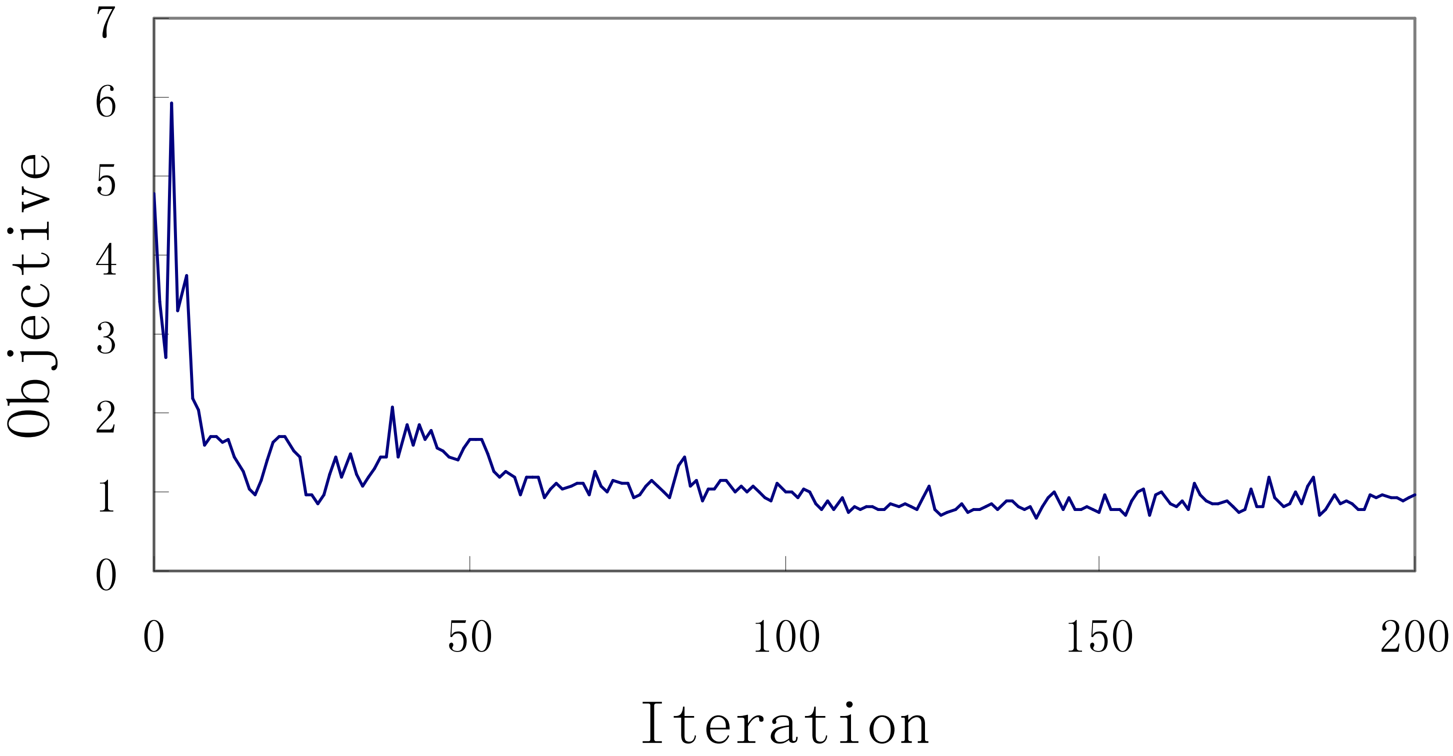
$$l_k^a \le \frac{a_{ik}^{sim}}{a_{ik}^{97}} \le u_k^a \qquad l_k^f \le \frac{f_{ik}^{sim}}{f_{ik}^{97}} \le u_k^f$$

$$l_k^c \le \frac{c_k^{sim}}{c_k^{mit}} \le u_k^c \qquad l_k^\alpha \le \frac{\alpha_k^{sim}}{\alpha_k^{mit}} \le u_k^\alpha$$

$$l_k^\beta \le \frac{\beta_k^{sim}}{\beta_k^{mit}} \le u_k^\beta \qquad t = S(a, f, c, \alpha, \beta, ...)$$

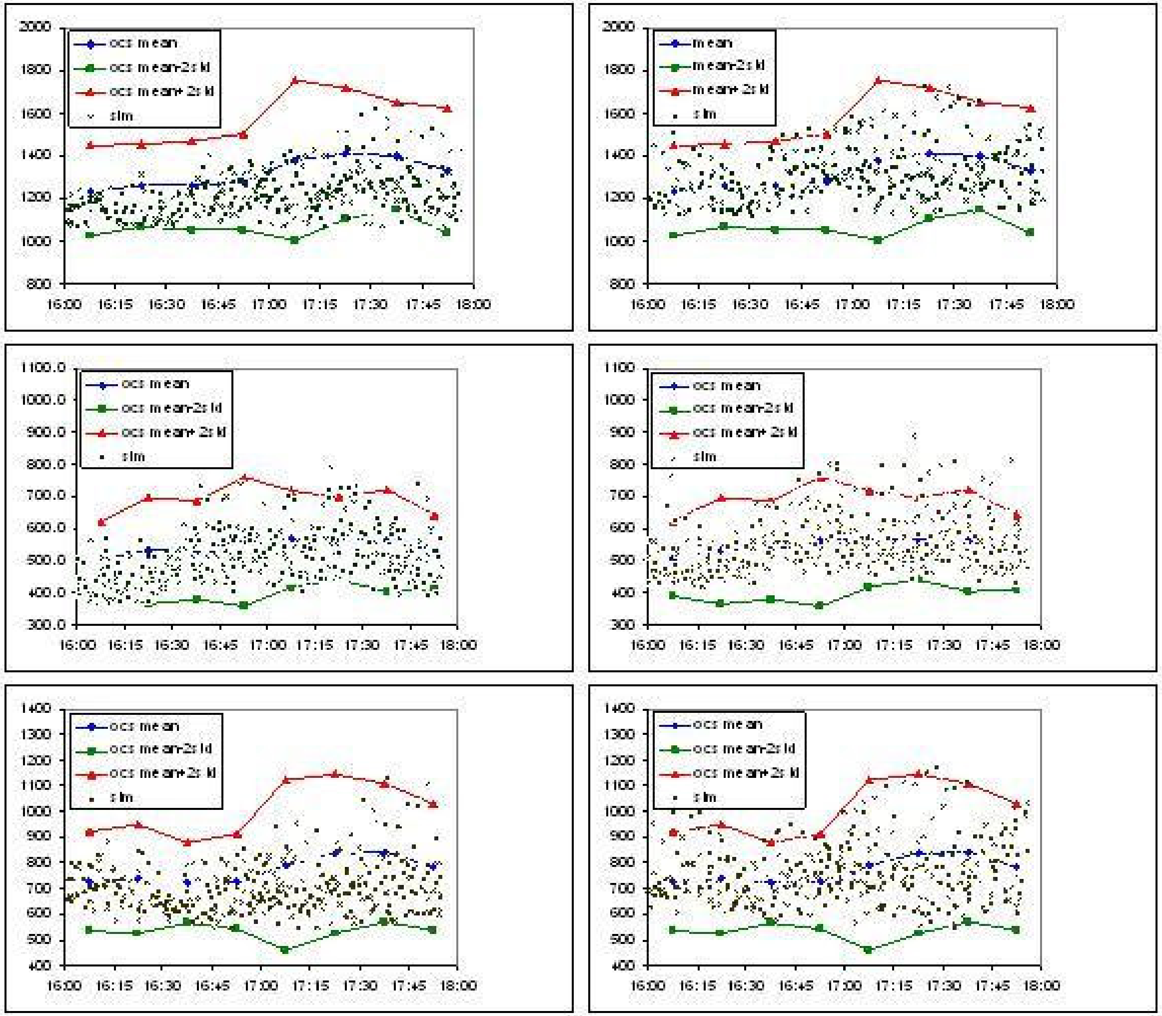
Calibration-Solution

- Convergence of Objective Function

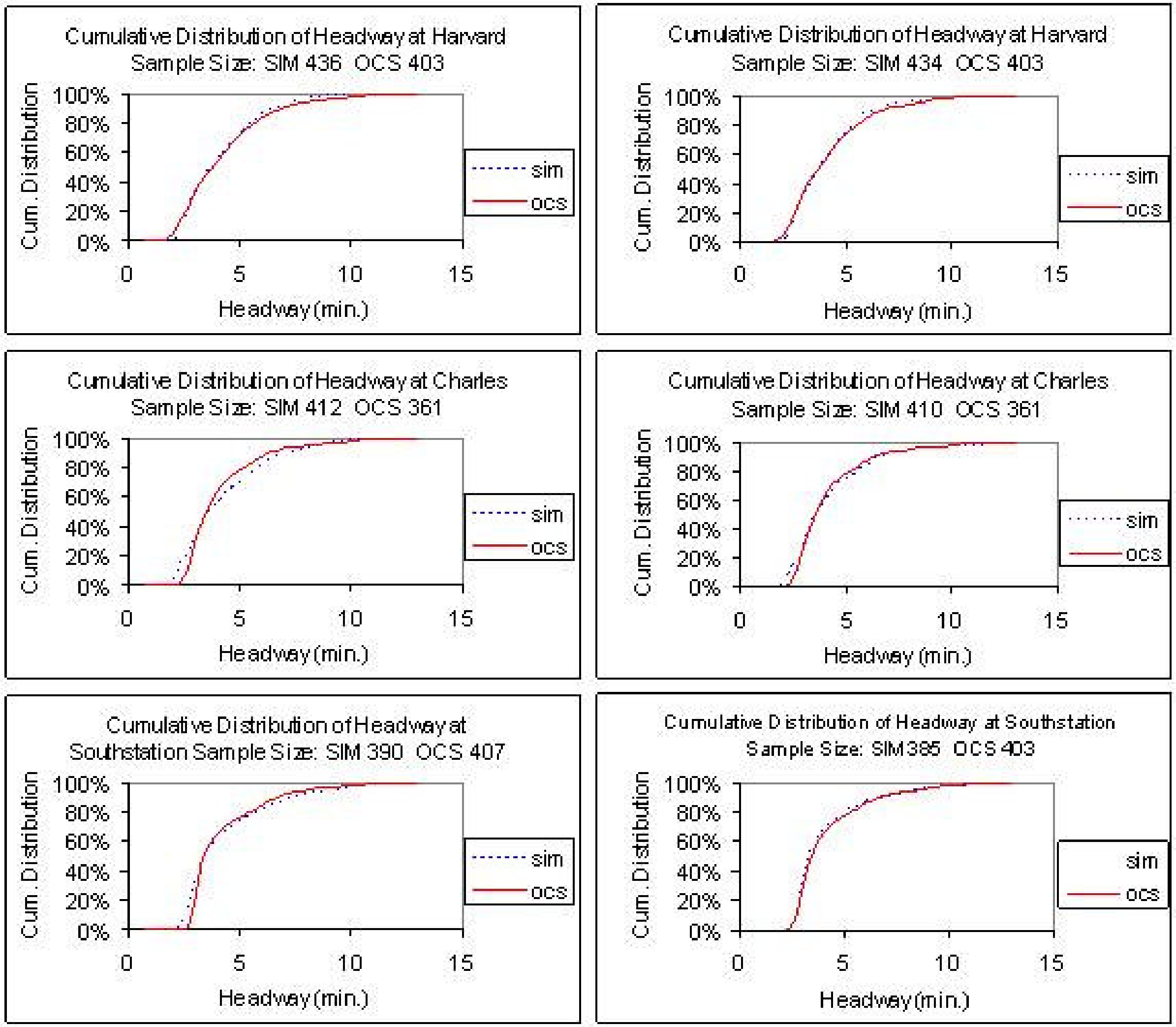


Calibration-Travel Time

Travel Time Pre-Calibration | Travel Time Post-Calibration



Calibration-Headway Distribution



Calibration Result- Dwell Time Parameters

Parameter	C_0	α	β	γ
Puong 2000	12.22	2.27	1.82	0.00062
Alewife	12.2	2.27	-	-
Davis	15.0	2.44	1.67	0.00062
Porter	11.9	2.17	1.93	0.00062
Harvard	17.5	2.27	1.88	0.00062
Central	13.8	2.24	1.96	0.00062
Kendall	14.1	2.39	1.86	0.00062
Charles	14.8	2.42	2.00	0.00062
Park	27.3	2.61	2.02	0.00062
Downtown	14.4	1.87	1.84	0.00062
Southstation	13.8	1.86	1.95	0.00062