



## Disclaimer

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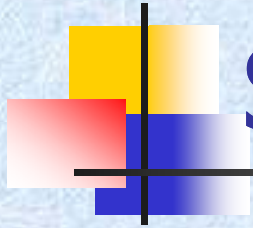
# Reliability in Policy-Sensitive Transportation Models: Insights from SHRP 2

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*New York, NY*



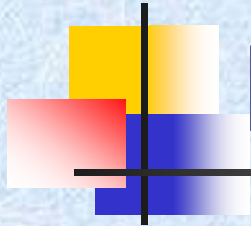
International Meeting on Value of Travel Time Reliability,  
October 15-16, 2009, Vancouver



# SHRP 2 Projects

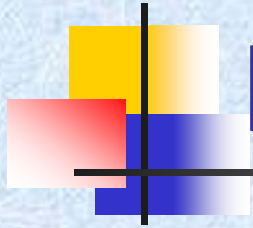
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- C04 “Improving Our Understanding How Highway Congestion and Pricing Affect Travel Demand”
- L04 “Incorporating Reliability Performance Measures in Operations and Planning Modeling Tools”



# Fundamental Challenge

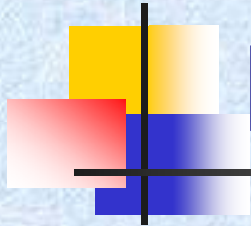
- Random Utility Model (RUM):  
 **$U = \alpha \times \text{Time} + \beta \times \text{Cost} + \dots + \epsilon$**
- Random Coefficients RUM:  
 **$U = \alpha \times \text{Time} + \beta \times \text{Cost} + \dots + \epsilon$**
- Random travel time:
  - **$U = \alpha \times \text{Time} + \beta \times \text{Cost} + \dots$**
  - **$U = \alpha \times \text{Time} + \beta \times \text{Cost} + \gamma \times \text{STD} \dots + \epsilon$**  (RUM)
  - **$U = f(\text{Time}) + \beta \times \text{Cost} + \dots$**  (Risk)



# Four Methods

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- (Indirect) Perceived highway time by congestion levels
- (1<sup>st</sup> direct) Time-distribution-based measures
- (2<sup>nd</sup> direct) Schedule delay cost
- (3<sup>rd</sup> direct) Temporal profiles for activity participation



# Perceived Highway Time

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- Perceived transit time long recognized and used in models
- Highway time is normally considered generic
- Highway time components:
  - Free-flow time
  - Extra time (delay) by congestion levels
- Differential coefficients:
  - Psychological perception
  - Proxy for reliability



# Time Weight By Congestion Levels, Wardman et al, 2009

<b>Travel time conditions</b>	<b>UK</b>	<b>US</b>
Free Flow	1.00	1.00
Busy	1.05	1.03
Light Congestion	1.11	1.06
Heavy Congestion	1.31	1.20
Stop Start	1.50	1.38
Gridlock	1.89	1.79



# Other Evidence

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- SHRP 2 C04:
  - Travel time is broken into free-flow and delay components
  - Delay time weight vs. free-flow time is 1.6-2.5 in mode and route type choice with higher values for toll routes
- NCHRP 431:
  - Recommended mark-up value of 2.5 to VOT savings under congested conditions



# Time-Distribution-Based Measures

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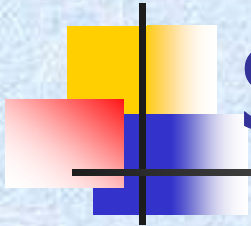
- (**Mean-Variance**) Standard Deviation (symmetric)
- (**Buffer time**) Difference between 80-90-95<sup>th</sup> and 50<sup>th</sup> percentile (asymmetric)
- (**Risk measure**) Probability of delay of certain length (asymmetric)
- (**Lateness measure**) Average delay (asymmetric)



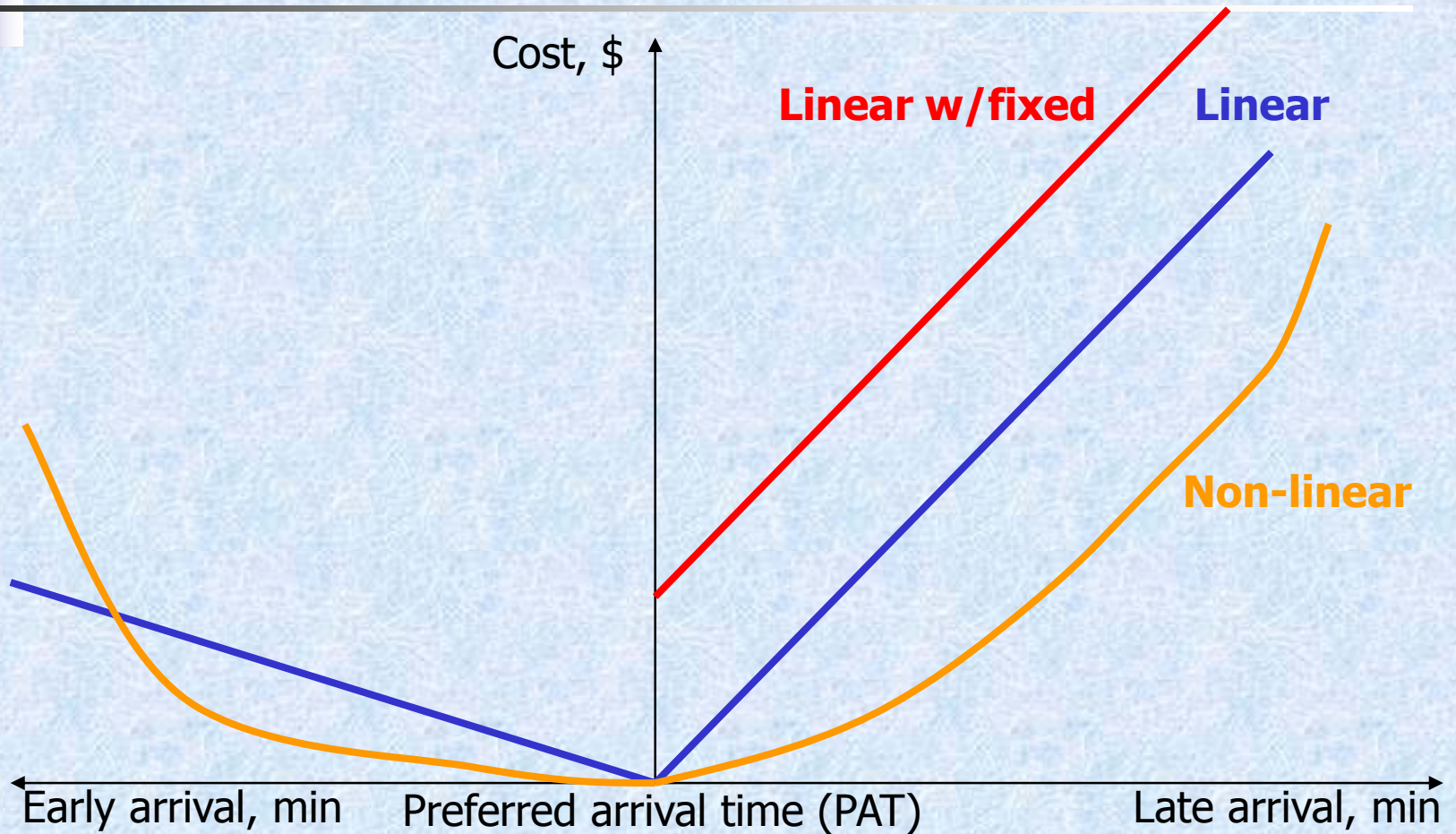
# Reliability Ratio ( $\rho$ )

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- ***$U = b \times \text{Time} + c \times \text{Cost} + d \times \text{STD}$*** 
  - $\text{VOT} = b/c$
  - $\text{VOR} = d/c$
  - $\rho = d/b = \text{VOR}/\text{VOT}$
- Evidence from estimated models:
  - Dutch Ministry of Transport, 2004:  $\rho = 0.80$
  - Hensher, 2007:  $\rho = 0.30-0.40$
  - Eliasson, 2004:  $\rho = 0.30-0.95$
  - NCHRP 431:  $\rho = 0.80-1.10$
  - SHRP 2 C04:  $\rho = 0.40-0.90$



# Schedule Delay Cost



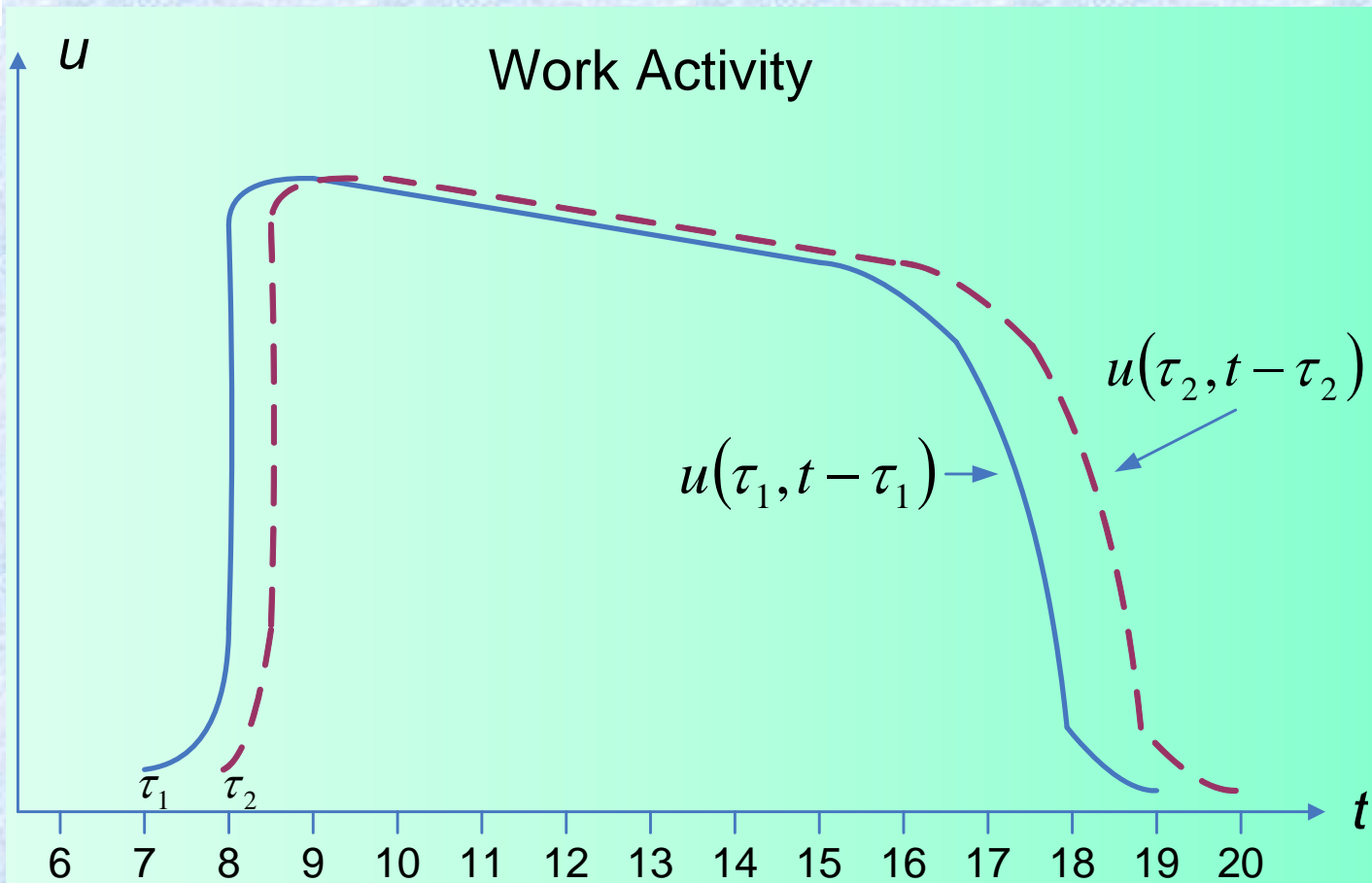


# Schedule Delay Cost

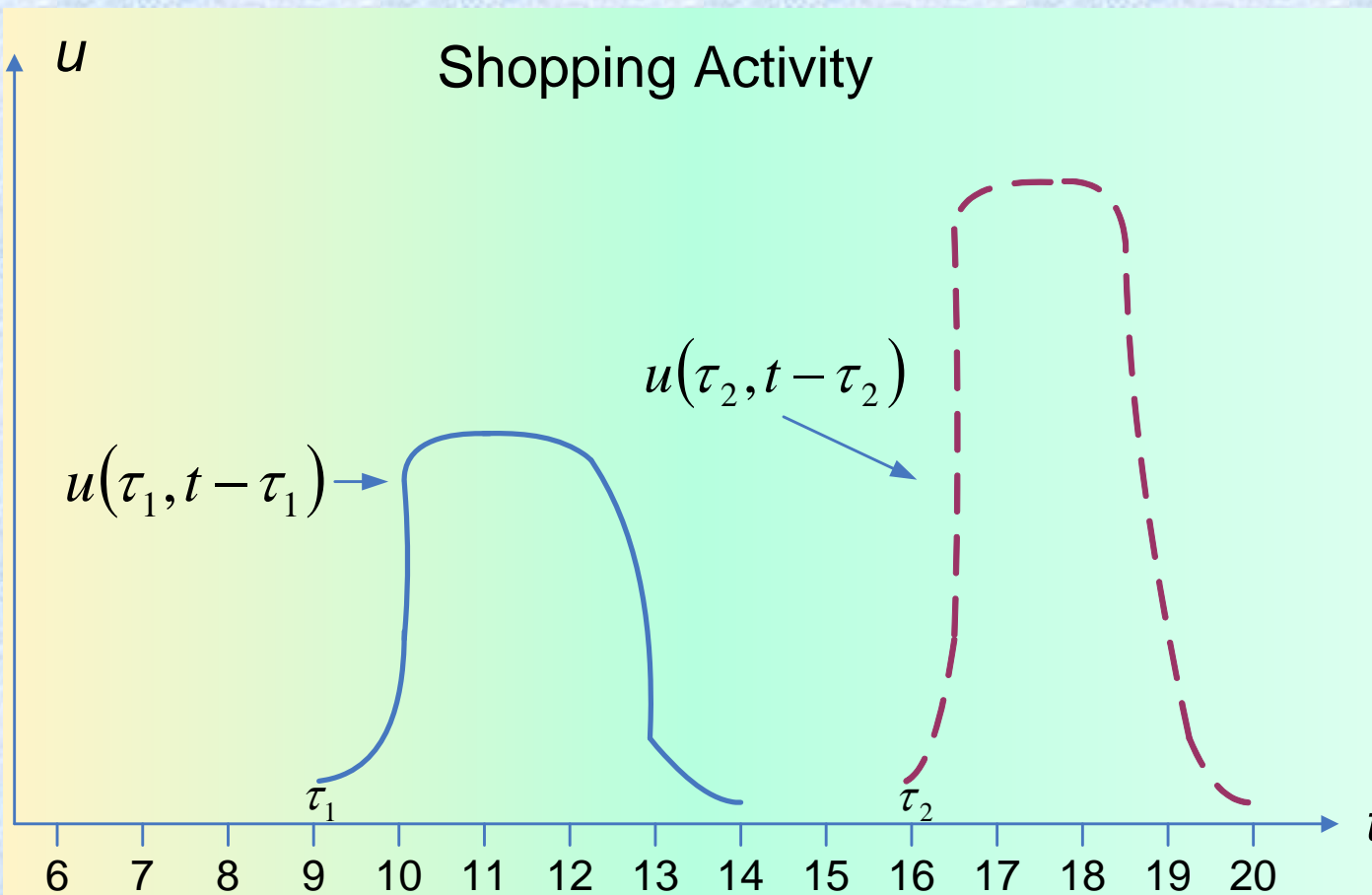
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- **$U = \alpha \times T + \beta \times SDE + \gamma \times SDL + \delta \times L$**
- In presence of random travel times:
  - $f(T)$  – travel time distribution
  - $E(U)$  – expected utility dependent on  $f(T)$  and departure time/ $PAT$
  - Improvement of reliability in terms of  $f(T)$  can be evaluated in terms of  $E(U)$
- Considerable body of literature:
  - SP estimates:  $\gamma \geq \alpha$

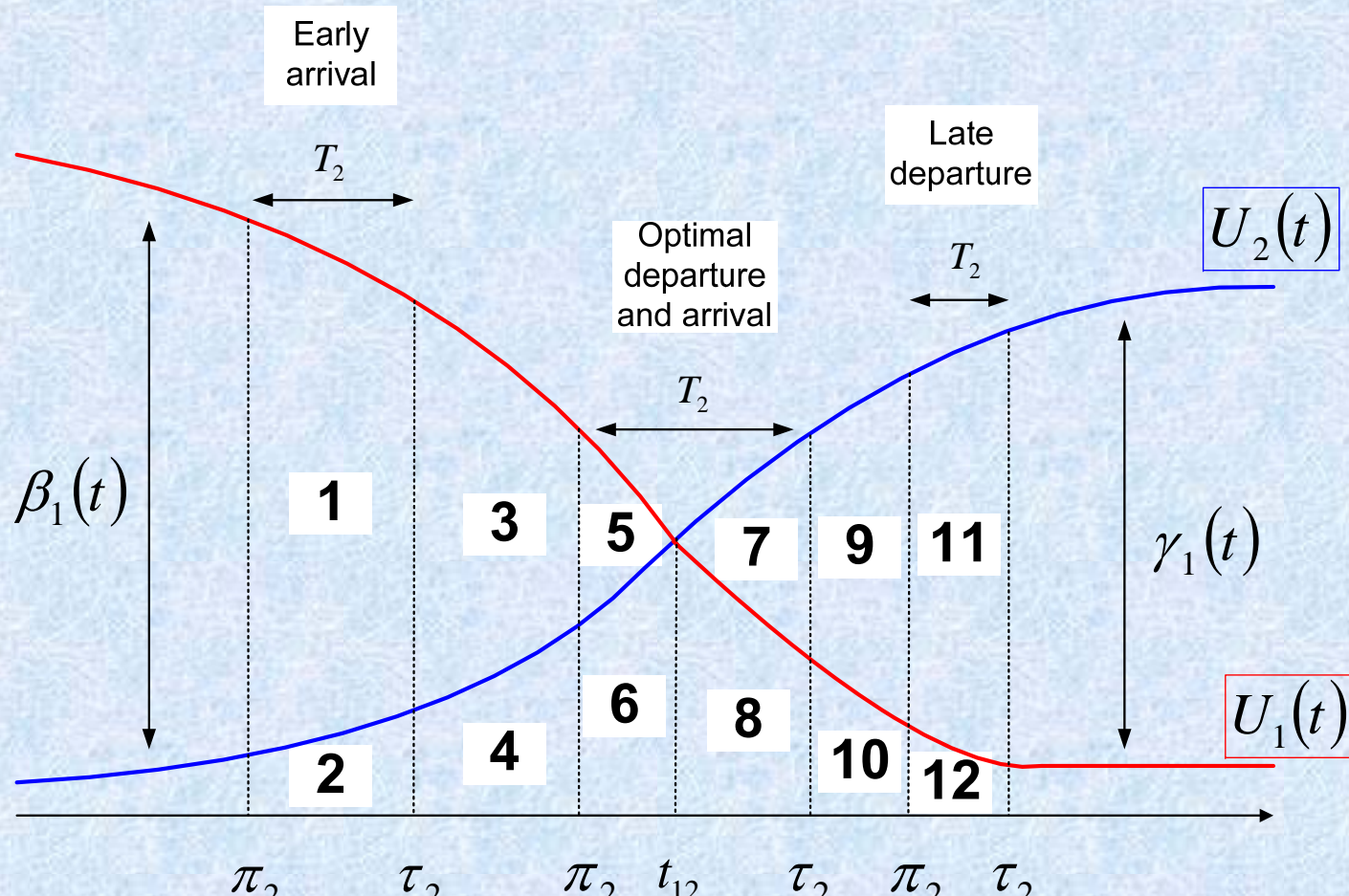
# Temporal Utility Profile for Activity Participation



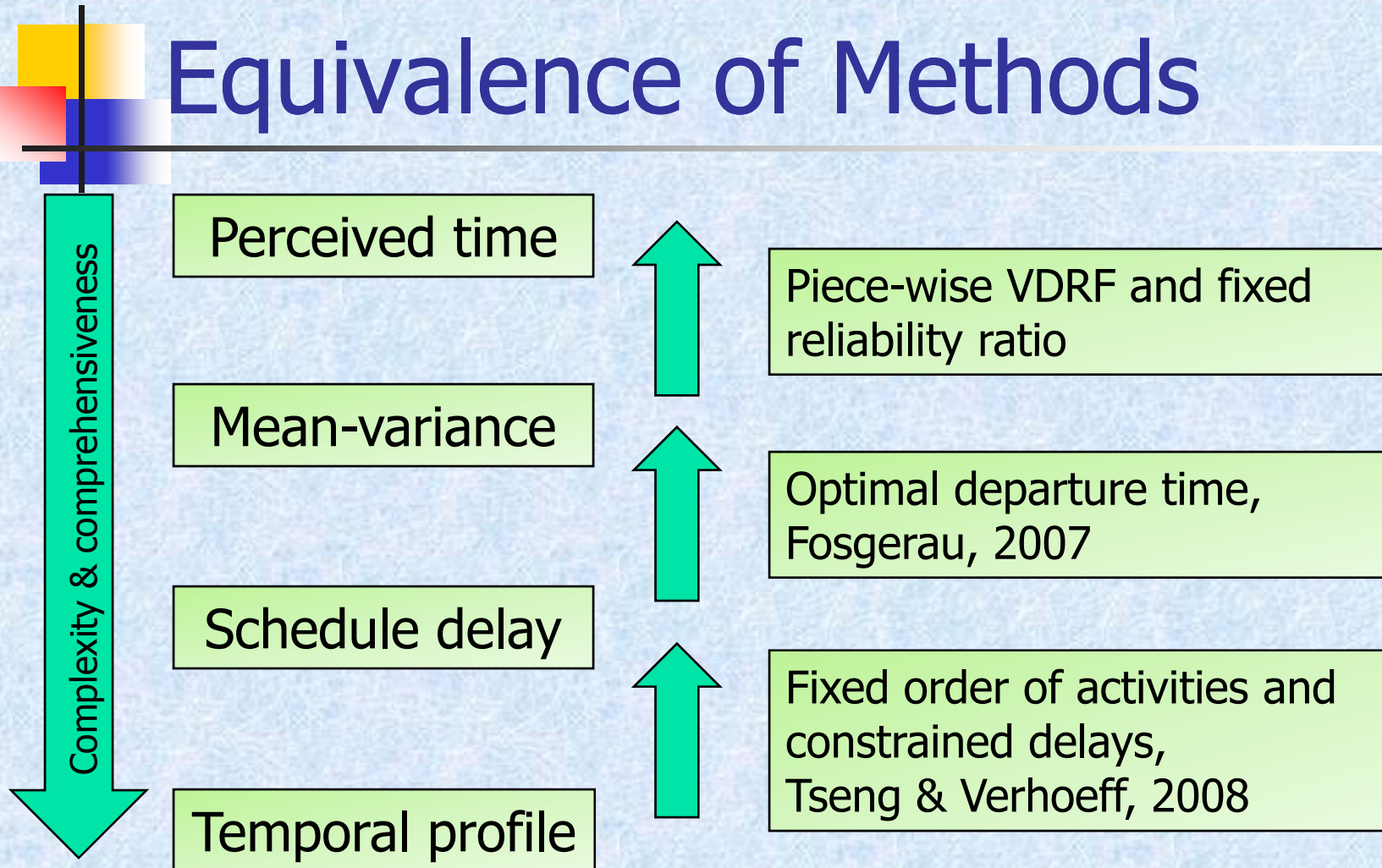
# Temporal Utility Profile for Activity Participation



# Utility Profile and Schedule Delay



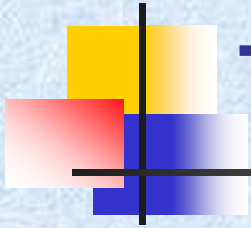
# Equivalence of Methods





# Applicability in Practice

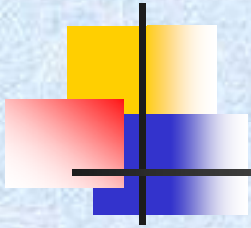
Method	Demand model	Network simulation
Perceived highway time	Easy	Easy
Time distribution (mean-variance)	Easy	Route choice? Generation of OD reliability measures?
Schedule delay cost	Preferred arrival time?	Route choice? Generation of OD time distribution?
Temporal utility profiles for participation in activity	Entire-day schedule consolidation?	Route choice? Generation of OD time distribution?



# Traffic Physics at Link Level

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- Volume-Delay-Reliability Function (VDRF):
  - Average time  $\mathbf{t_a = f(v_a)}$
  - STD (or other Reliability measure):  
 $\mathbf{\sigma_a = g(t_a) = g[f(v_a)]}$  or  $\mathbf{\sigma_a = h(v_a)}$
- Growing number of VDRF estimated:
  - $\mathbf{\sigma_a = g(t_a)}$  – linear, slightly non-linear
  - $\mathbf{\sigma_a = h(v_a)}$  – highly non-linear (convex)



# Mahmassani et al, 2008



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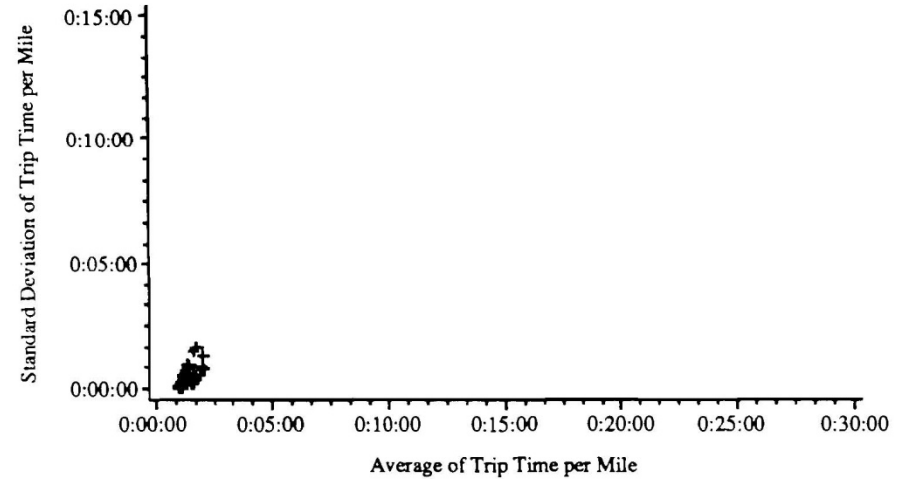


Fig. 52. Standard deviation of trip time per mile vs. average trip time per mile for expressway data. Each data point represents the average and standard deviation of the data collected on one link during one 5-minute observation period.

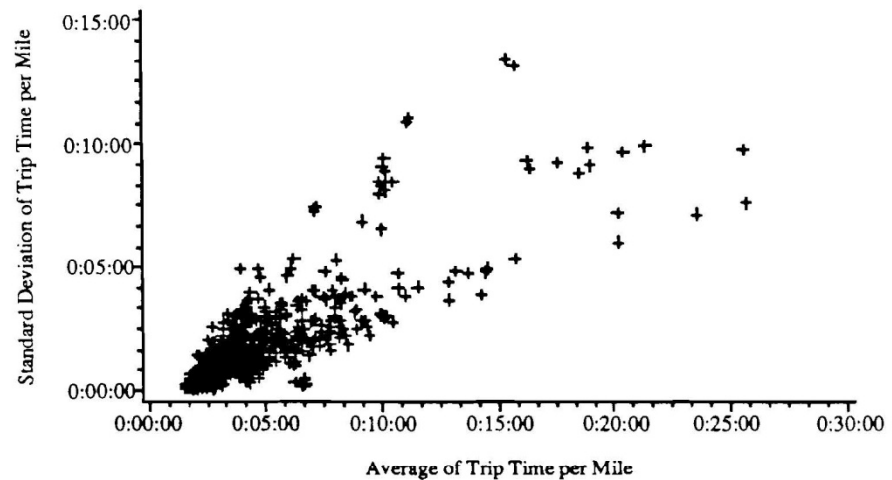
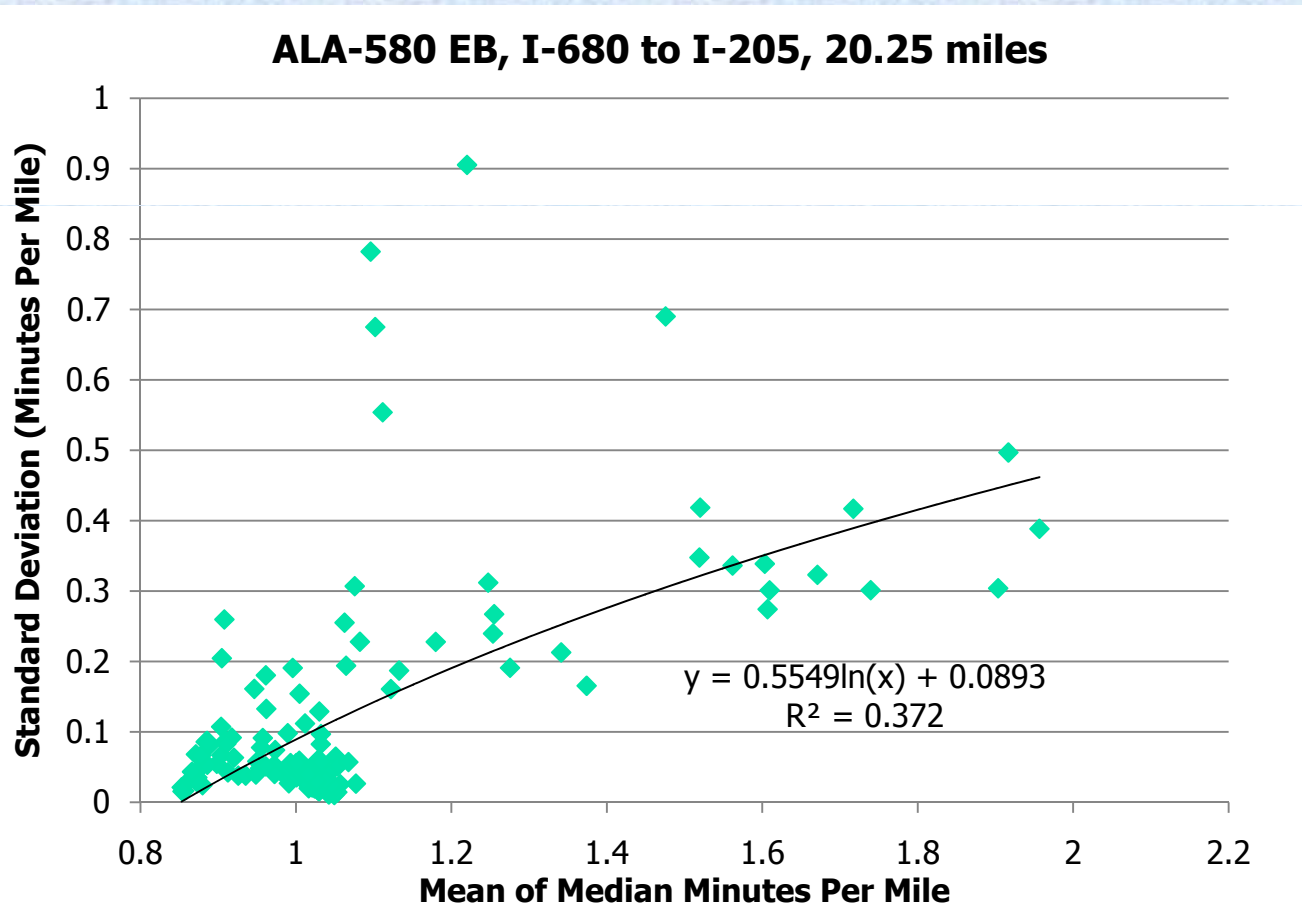
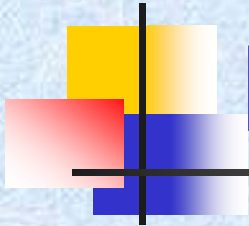


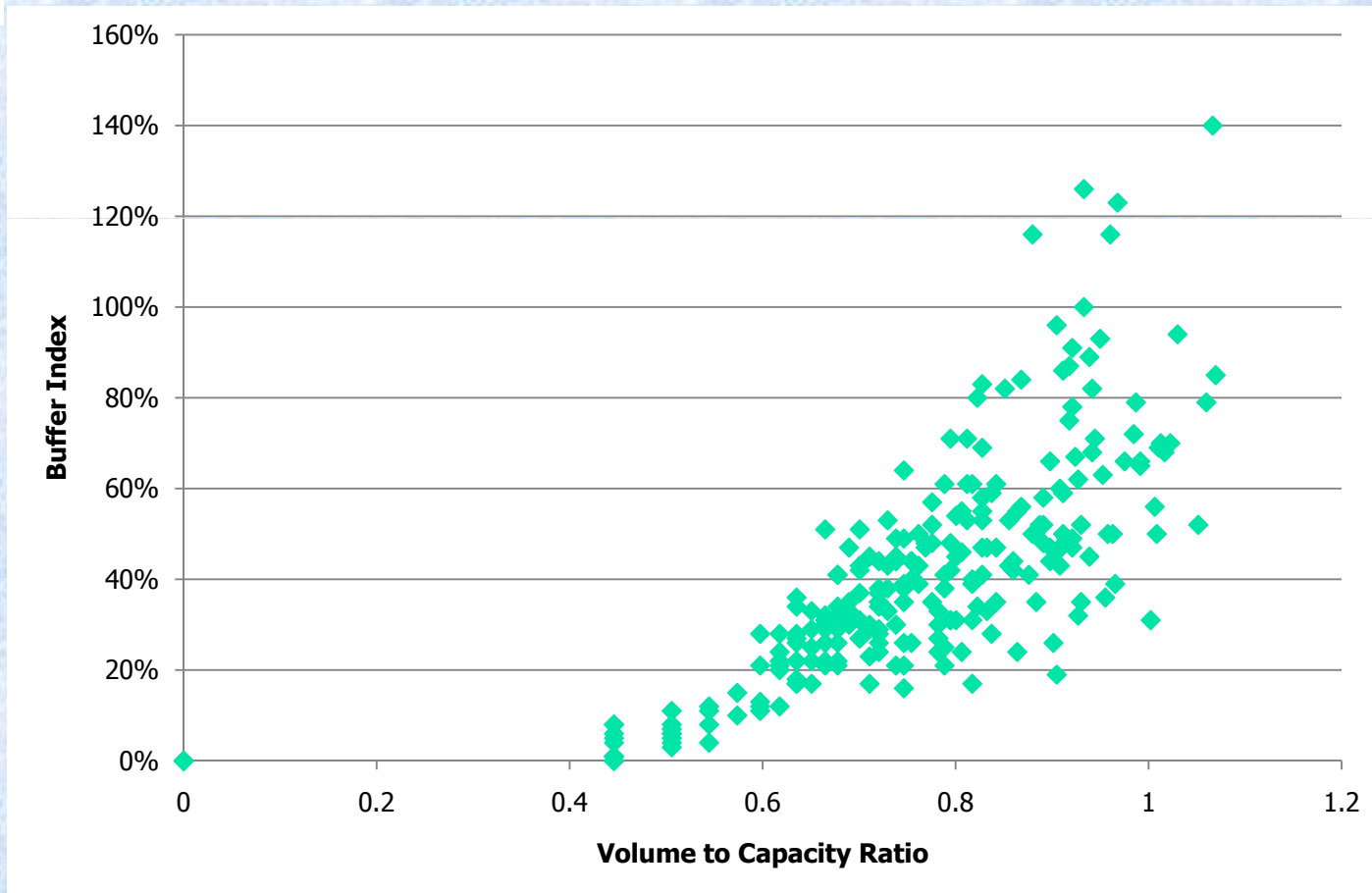
Fig. 53. Standard deviation of trip time per mile vs. average trip time per mile for arterial data. Each data point represents the average and standard deviation of the data collected on one link during one 5-minute observation period.

# Mean is Good Predictor of Variance – SHRP 2 L03





# Lemp & Kockelman, 2009



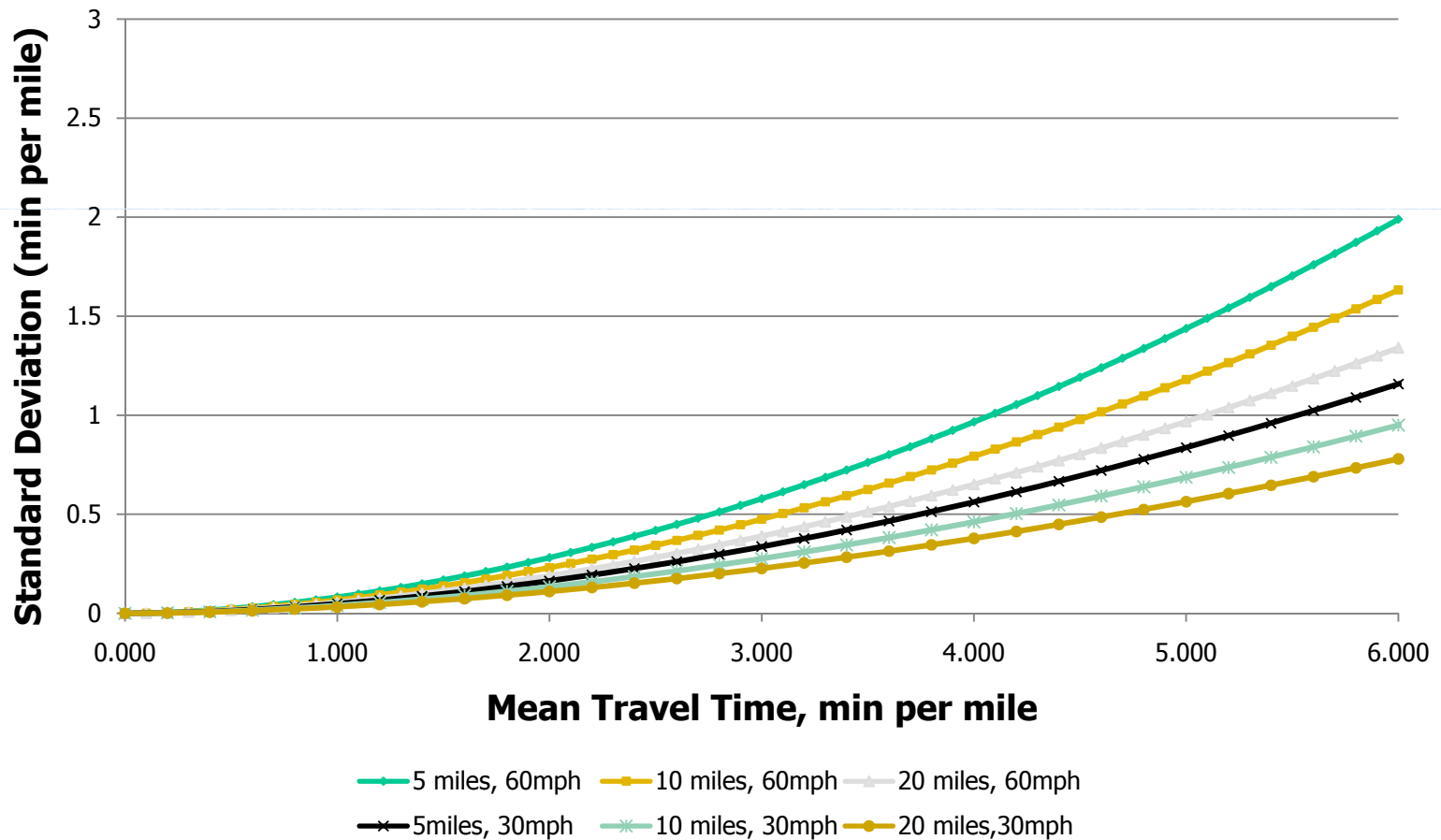
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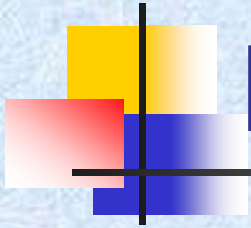


# Leeds, UK, Model (Arup, 2003)

- **$CV = 0.148 \times CI^{0.781} \times d^{-0.285}$** 
  - CV (Coefficient of Variation) =  $STD/MeanTT$
  - CI (Congestion Index) =  $MeanTT/FreefTT$
- Equivalent transformation by substitution:
  - $D = d/1.6$  (in miles)
  - $CI = MeanTT \times FreefSp/D$  (time in min, speed in min/mile)
  - $STD/MeanTT = 0.148 \times (MeanTT \times FreefSp/D)^{0.781} \times (D/1.6)^{-0.285}$
- Final expression (comparable with our tabulations):
  - Multiply both sides by  $(MeanTT/D)$
  - **$STD/D = 0.148 \times (Meantt/D)^{1.781} \times (FreefSp)^{0.781} \times (D/1.6)^{-0.285}$**

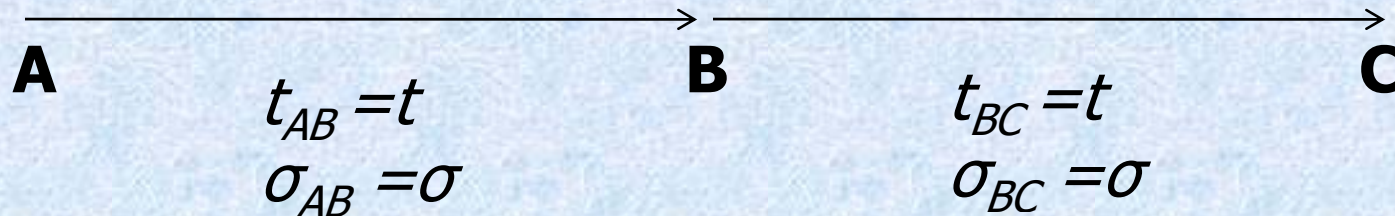
# Based on Leeds Equation

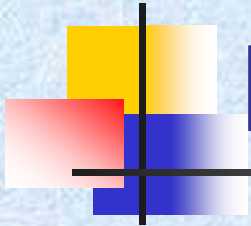




# Link vs. Route (OD) Reliability

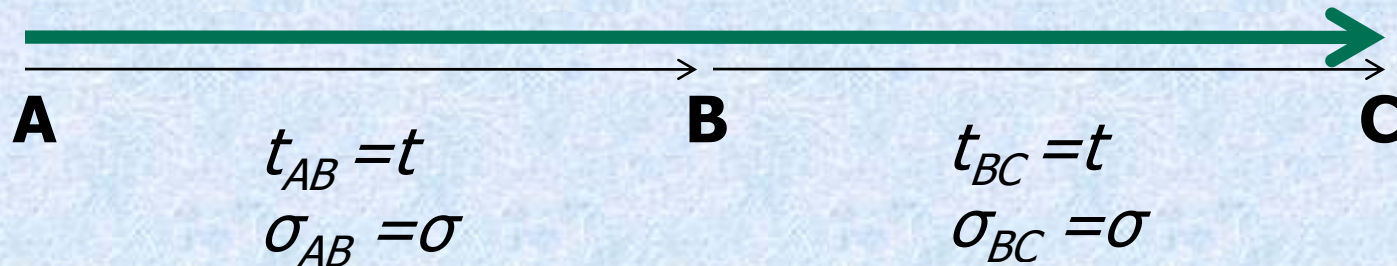
$$t_{ABC} = 2 \times t$$
$$\sigma_{ABC} = ?$$

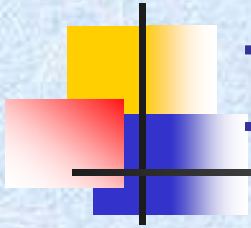




# Perfect Correlation

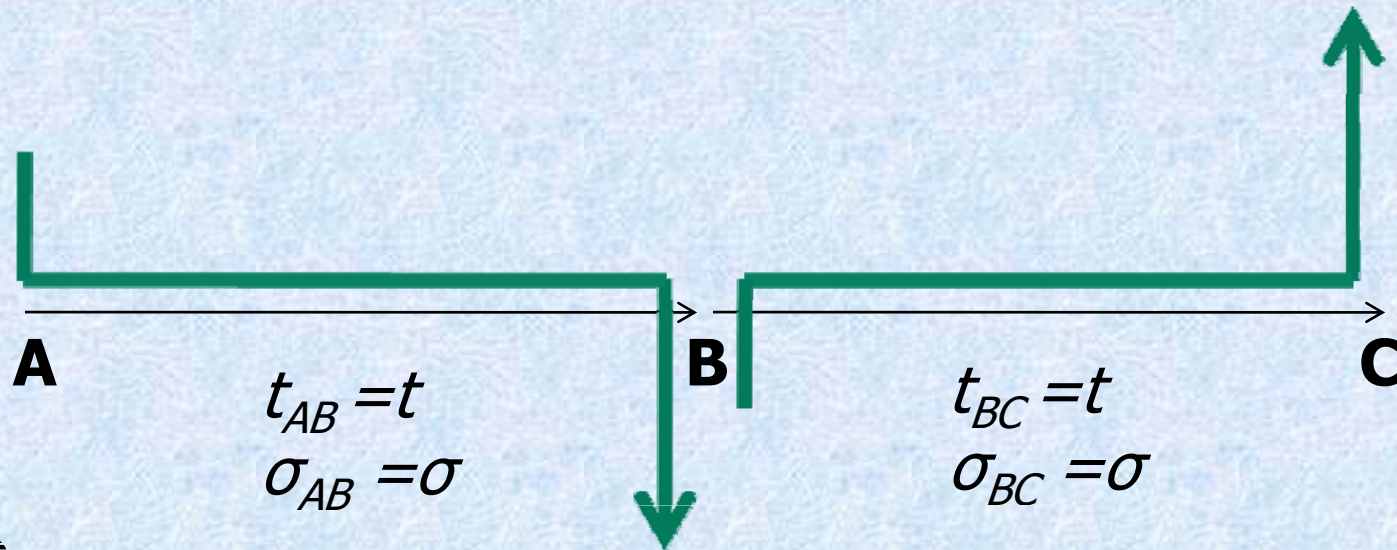
$$t_{ABC} = 2 \times t$$
$$\sigma_{ABC} = 2 \times \sigma$$





# Independent Link Flows

$$t_{ABC} = 2 \times t$$
$$\sigma_{ABC} = \sqrt{2} \times \sigma$$

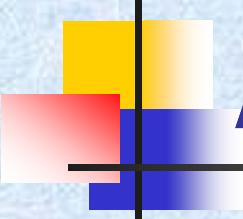




# Example of Generalization

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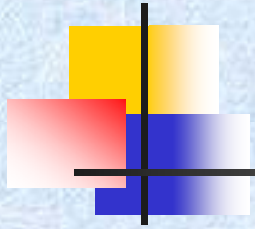
- For elemental unit (mile):
  - $\sigma = k \times t$
  - $k$  = coefficient of variation
- For entire OD route:
  - $\sigma = k \times t \times (d)^{-\mu}$
  - $d$  = distance
  - (independence)  $-0.5 \leq -\mu \leq 0$  (perfect correlation)



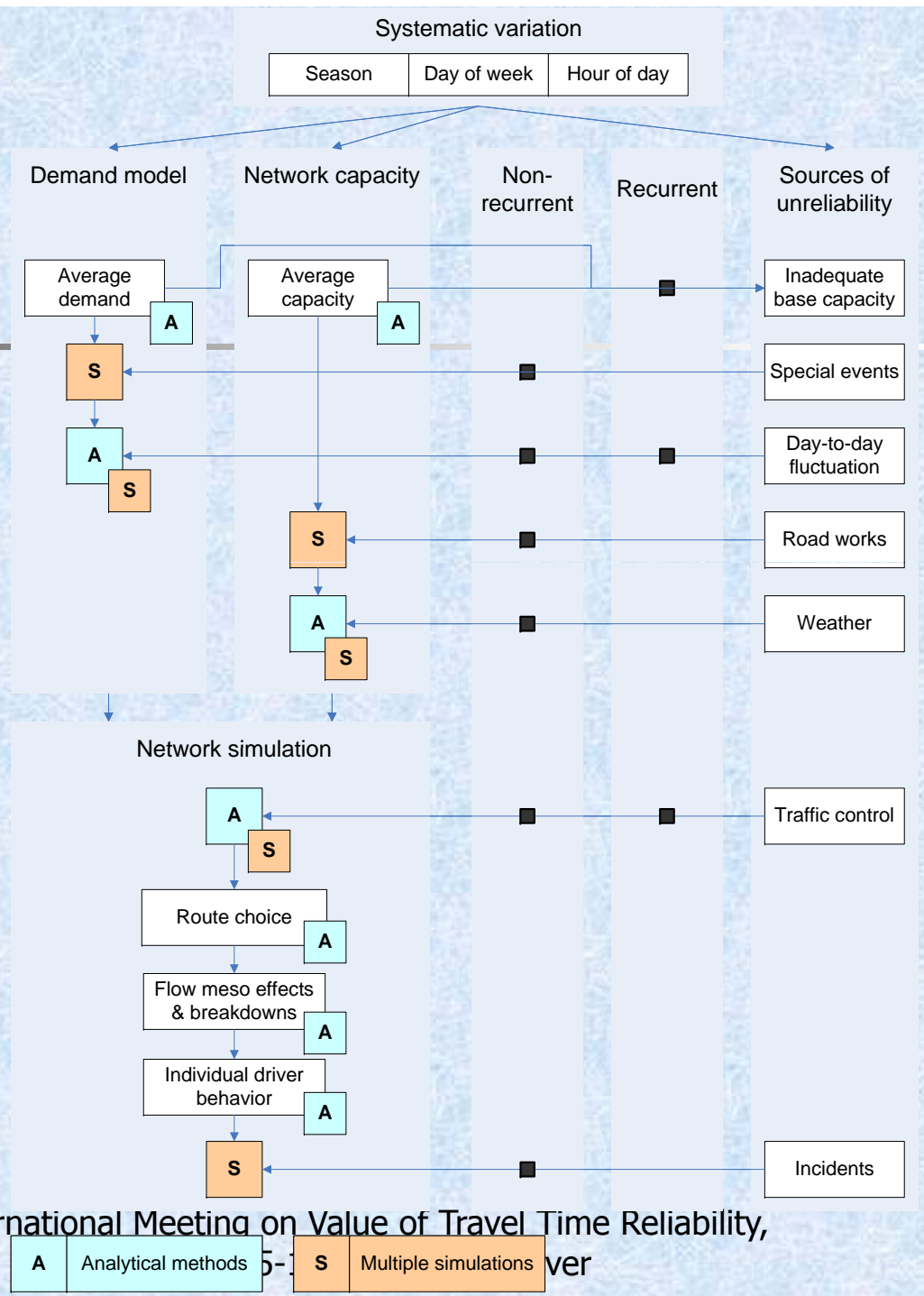
# Self-Calibration of $\mu$ in Link-Based Assignment

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- For each OD pair based on the previous iterations:
  - $(d_{OD})^{-\mu(OD)} = \sigma_{OD} / (\sum_a \sigma_a) = \eta_{OD}$
- Assume link generalized cost function:
  - $c_a = t_a(v_a) + \rho \times \sigma_a [t_a(v_a)]$
- Scale reliability ratio for next iteration:
  - $\rho_{OD} = \rho \times \eta_{OD}$

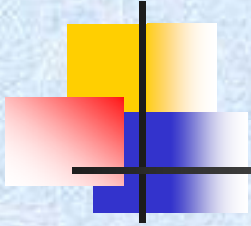


# Model System Vision

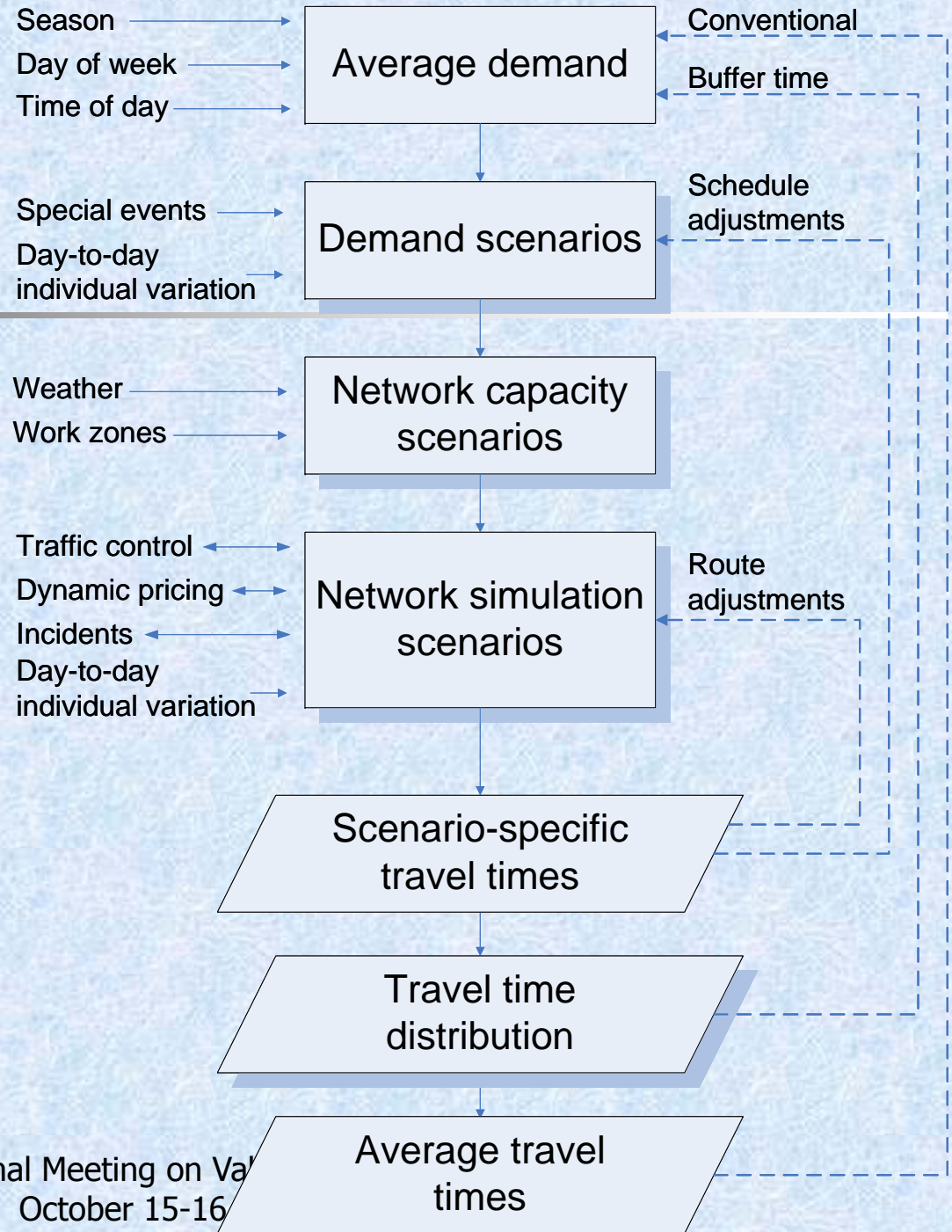


International Meeting on Value of Travel Time Reliability,





# Feedback with Scenarios





# Conclusions

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- Significant progress:
  - Reliability quantification and impact on travel demand
  - Physics of traffic flow and travel time distribution at elemental link level
- Roll off the sleeves:
  - Construction of reliability measures at OD-route level
  - Incorporation of reliability in route choice in (efficient) traffic assignment
  - Integration of demand and supply sides incorporating reliability
  - Exploration of analytical and explicit (multiple simulations) methods w.r.t each reliability source