PONTIFICIA
UNIVERSIDAD
CATÓLICA
DE CHILE

Departamento de Ingeniería de
Transporte y Logística

CENTRE OF
EXCELLENCE

THE IMPACT OF ASSUMING ALTRUISTIC BEHAVIOR IN THE LIMITED-STOP BUS SERVICE DESIGN PROBLEM

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OUTLINE

- Limited-stop services
- Designing Limited-stop services
- Naïve approach to passenger assignment
- Case study – magnitude of the error
- Conclusion

LIMITED-STOP BUS SERVICES

Travel times	:)
Waiting times	:(
Transfers	:(
Operator costs	:)

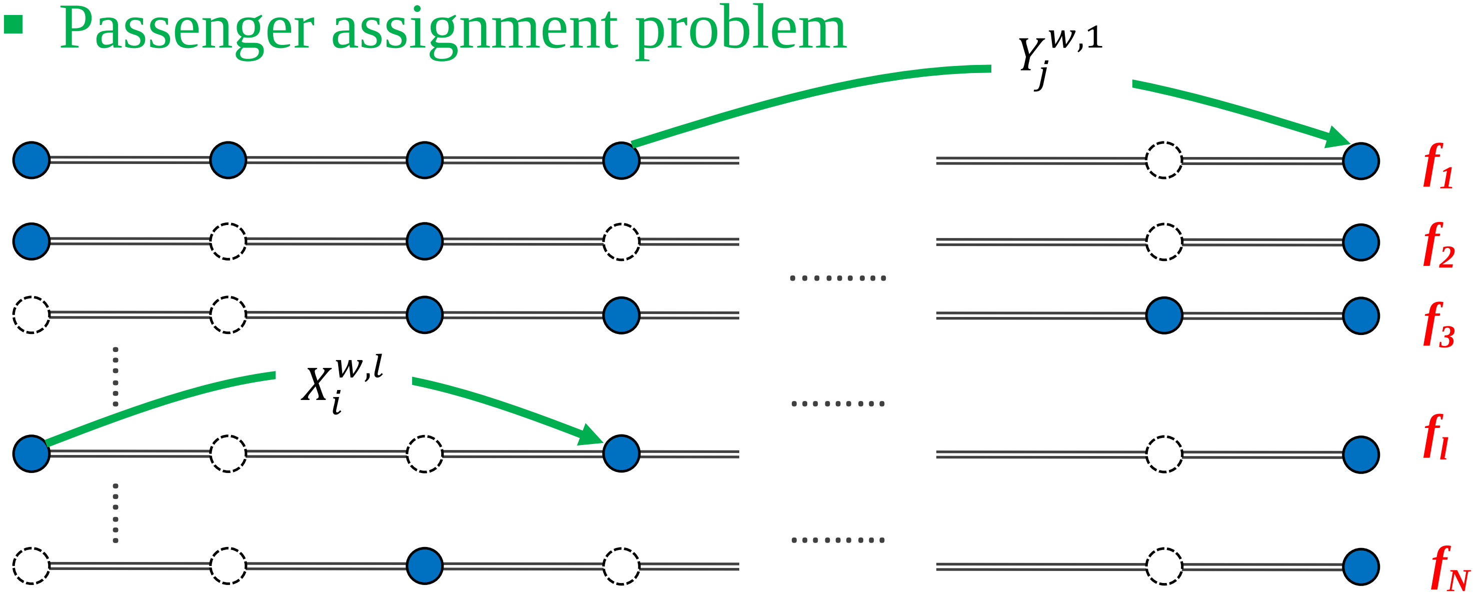
LIMITED-STOP BUS SERVICES

- TransMilenio Bogotá

- 45,000 pax/h
- 25 km/h

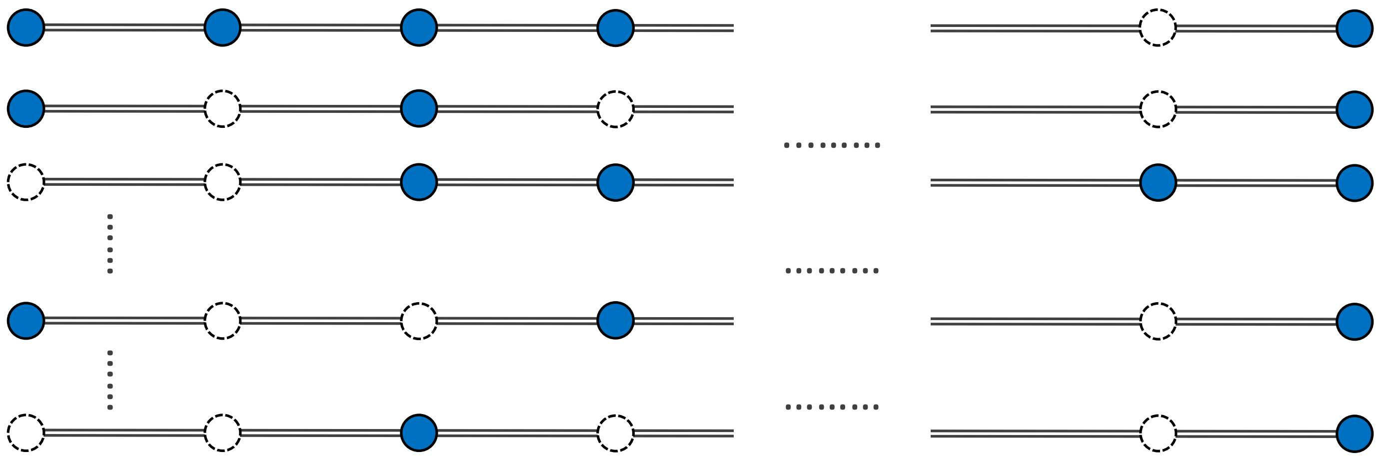
DESIGNING LIMITED-STOP BUS SERVICES

- Service generation problem
- Service design problem
- Passenger assignment problem

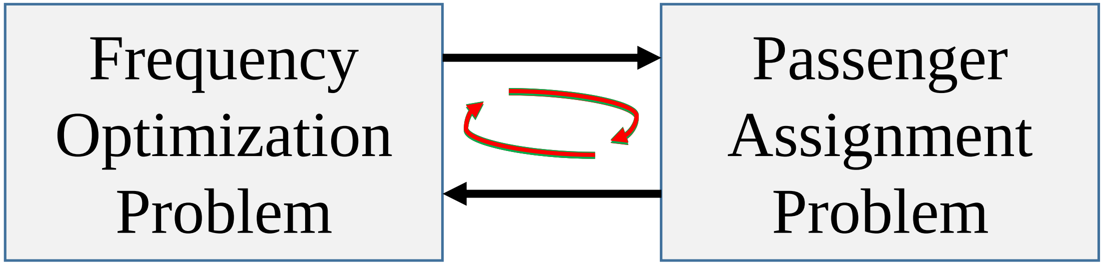


DESIGNING LIMITED-STOP BUS SERVICES

- Service generation problem



- **Service design & Passenger assignment problem**



DESIGNING LIMITED-STOP BUS SERVICES

- **Service design & Passenger assignment problem**

Frequency Optimization Problem ⇄ Passenger Assignment Problem

Minimize *Total Social Cost*

- Operating cost
- User cost

Individual passengers minimizes their own travel time

This argument is invalid when capacity constraints are active

EXAMPLE

- Meal Distribution in Airplane

- # Passengers – 100
- Meal preferences

Meat – 50
Veg. – 30
Meat / Veg. – 20

EXAMPLE

- Meal Distribution in Airplane

- # Passengers – 100
- Meal preferences

Meat – 50
Veg. – 30
Meat / Veg. – 20

1. Cost is very low / No capacity

Social Optimum
Meat – 70
Veg. – 50

2. Cost is considered / With capacity

Social Optimum
Meat – 50
Veg. – 50

User Optimum
Meat – 60
Veg. – 40

10 Passengers will not be Pleased

EXAMPLE

- Meal Distribution in Airplane

1. Cost is very low / No capacity

Social Optimum
Meat – 70
Veg. – 50

→

- User optimum
  - ✓ Selfish
  - ✓ Good forecast

2. Cost is considered / With capacity

~~Social Optimum~~
~~Meat – 50~~
~~Veg. – 50~~

→

- User optimum
  - ✓ Selfish
  - ✓ Good forecast

DESIGNING LIMITED-STOP BUS SERVICES

- **Service design & Passenger assignment problem**

Minimize *Total Social Cost*

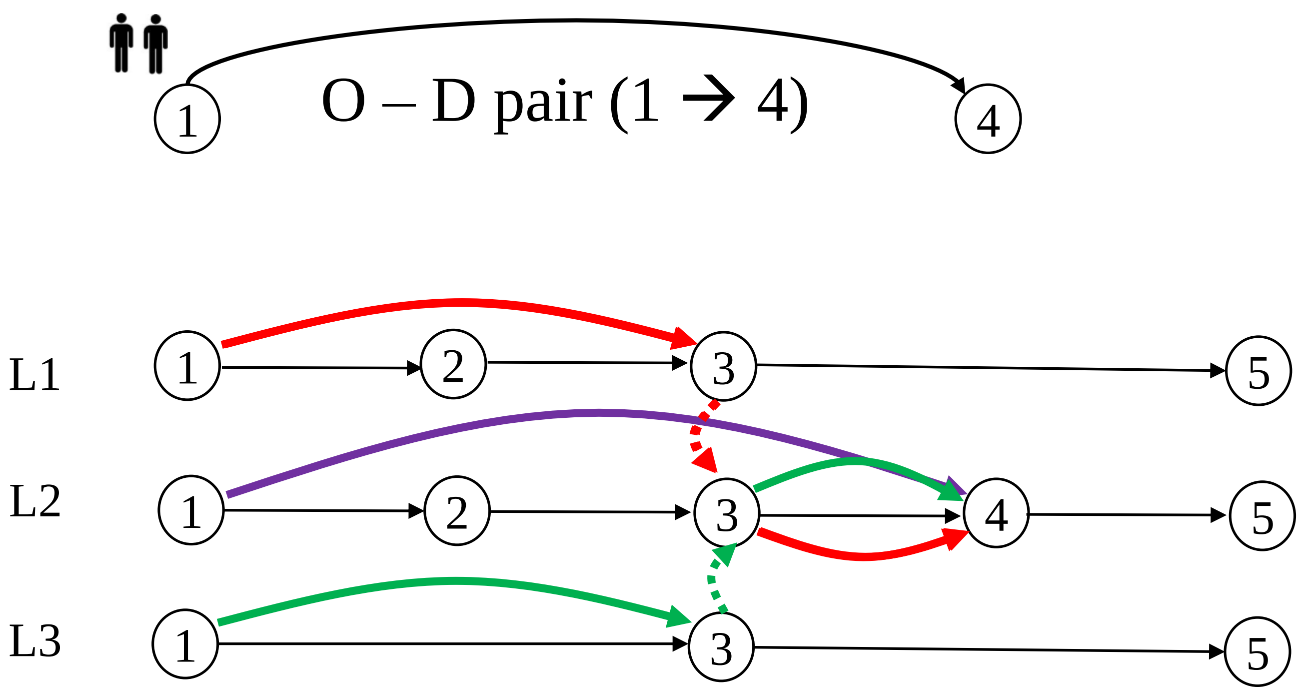
Operating cost

User cost

- Key challenges
  - Non-linear problem
  - Passenger assignment is not trivial

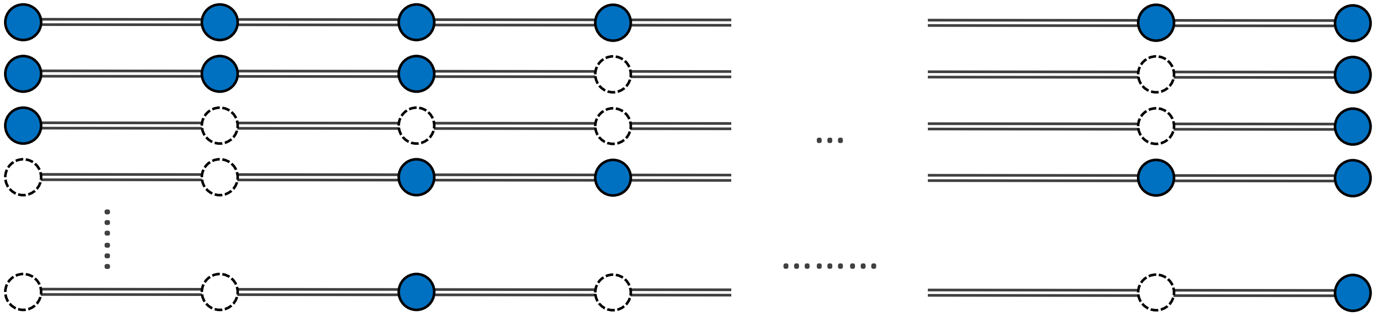
BEHAVIOR

- Itineraries



ASSUMPTIONS

- Passengers follow Itineraries
- Make forward transfers
- Predefined set of services



- Over a given corridor

BEHAVIOR V/S CAPACITY

- Objective: *Minimize total social cost*

Itineraries

Service design

Behavior (P.A.)

$$\underset{\{f_l,\ x_{ij}^{w,l}\}}{Minimize}\left[\sum_{l\in\mathcal{L}} C_l\cdot f_l\right.$$

Operating cost

$$+\ \theta_{wt}\left\{\sum\nolimits_{w\in\mathcal{W}}\sum\nolimits_{l\in\mathcal{L}}\sum\nolimits_{(i,j)\in\mathcal{S}_l}\left(\frac{k}{f_l}\right)\cdot x_{ij}^{w,l}\right\}$$

Waiting cost

$$+\ \theta_{tt}\left\{\sum\nolimits_{w\in\mathcal{W}}\sum\nolimits_{l\in\mathcal{L}}\sum\nolimits_{(i,j)\in\mathcal{S}_l} t_{ij}^{l}\cdot x_{ij}^{w,l}\right\}$$

In-vehicle travel cost

Transfer cost

User cost

Total social cost

s.t.: non-negativity and flow conservation.

EXAMPLE

- Meal Distribution in Airplane

1. Cost is very low / No capacity

Social Optimum

Meat – 70
Veg. – 50

- User optimum
  - ✓ Selfish
  - ✓ Good forecast

What if we want to model

Capacity?

BEHAVIOR V/S CAPACITY

- Objective: *Minimize total social cost*

Itineraries

Service design

Behavior (P.A.)

$$\underset{\{\boxed{f_l,}\ \boxed{x_{ij}^{w,l}}\}}{Minimize}\left[\sum_{l\in\mathcal{L}} C_l\cdot f_l\right.$$

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In-vehicle travel cost

Transfer cost

User cost

Total social cost

- Capacity constraints

$$\sum_{(i,j)\in\mathcal{S}_l}\sum_{w\in W} x_{ij}^{w,l}\cdot\beta_a^{ij}\ \leq\ f_l\cdot b_l\,,\qquad l\in\mathcal{L}, a\in A$$

s.t.:
non-negativity and flow conservation.

EXAMPLE

- Meal Distribution in Airplane

2. Cost is considered / With capacity

Social Optimum

~~Meat – 50~~

~~Veg. – 50~~

- User optimum
  - ✓ Selfish
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GAPS

- Our previous works have addressed this
  - Leiva et al. (2010)
  - Larrain et al. (2013)
  - Soto et al. (2017)
- Error induced by this simplification has not been studied
- Researchers are using this

Dimensioning the Effect of Direct Approach

- Solve the Naïve Approach — With Capacity constraint
  - Service Design ($\overline{f_l^{*}}$)
  - Passenger Assignment ($\overline{x_s^{w,l}}$)
    - Altruistic
    - May not be consistent with reality
- Realistic Passenger Assignment — User Equilibrium

How bad is this solution?

- Unconstrained passenger assignment ($\overline{\overline{x_s^{w,l}}}$)
  - Given Service Design ($\overline{f_l^{*}}$)
  - Passenger Assignment ($\overline{\overline{x_s^{w,l}}}$)

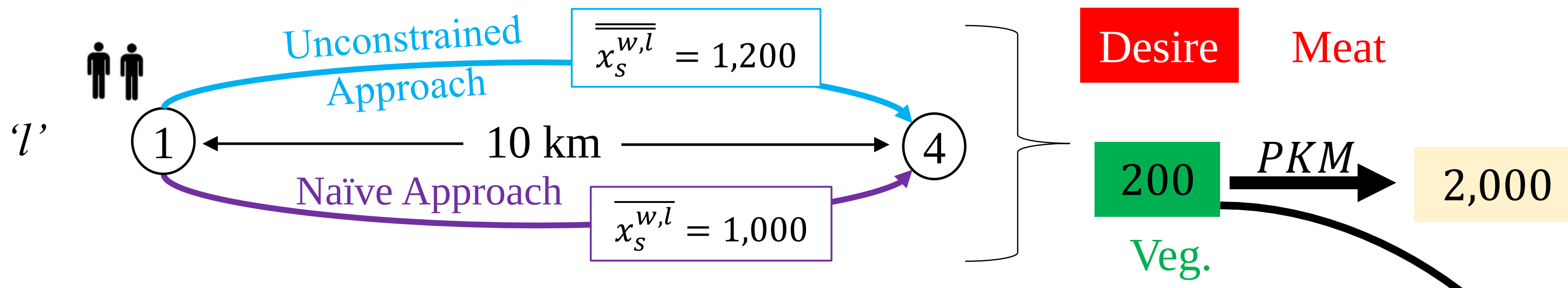
Without
Capacity constraint

Compare

Altruistic PA ($\overline{x_s^{w,l}}$) V/S Unconstrained PA ($\overline{\overline{x_s^{w,l}}}$)

Performance Indicators

1) Level of passenger-kilometer (PKM) diversion



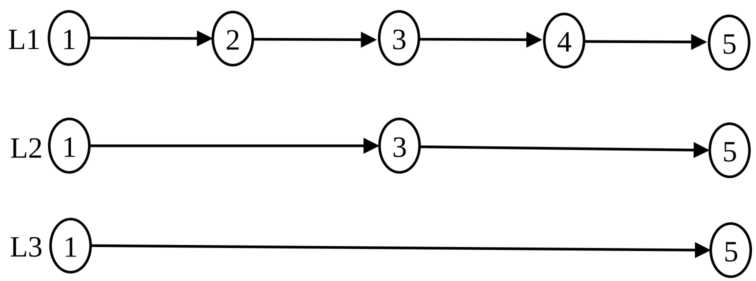
$$\%\Delta pkmD = 100\left(\frac{\sum_{l\in L}\sum_{w\in W}\sum_{s\in \mathcal{S}}\left(\max\limits_{l\in L,\, w\in W,\, s\in \mathcal{S}}\left\{\overline{\overline{x}}_s^{w,l} - \overline{x}_s^{w,l}, 0\right\}\cdot d_s^l\right)}{\sum_{l\in L}\sum_{w\in W}\sum_{s\in \mathcal{S}}\left(\overline{\overline{x}}_s^{w,l}\cdot d_s^l\right)}\right)$$

2) Level of infeasibility in the service design

$$\%\Delta f_l = 100\left(\frac{\max\left\{\frac{\max\limits_{a\in A}\left\{\sum_{w\in W}\sum_{s\in \mathcal{S}}\overline{\overline{x}}_s^{w,l}\cdot \beta_a^s\right\}}{b_l} - \overline{f_l}^{\,*},\ 0\right\}}{\overline{f_l}^{\,*}}\right), \qquad \forall l \in \mathcal{L}$$

Case Study

- A five stop bus corridor with three services.
- Passengers follow itineraries to reach their destination.
- Only allow forward transfers.
- Neglect congestion.



A 5-stop bus corridor with three services

Travel demand matrix (pax/h)

O-D	1	2	3	4	5
1	-	10,000	8,000	1,000	5,000
2	-	-	10,000	0	1,000
3	-	-	-	8,000	10,000
4	-	-	-	-	5,000
5	-	-	-	-	-

Experiments

Sets of experiments	Range	Interval	#Scenarios
Bus capacity (b)	30 - 270	10	25
Value of waiting time (θ_{wt})	0 - 1200	50	25
Value of in-vehicle travel time (θ_{tt})	0 - 1500	50	31
Value of transfer penalty (θ_{tr})	0 - 200	25	9
			87

- Base scenario
    - Bus capacity (b) = 50 (pax/bus)
    - Value of waiting time (θ_{wt}) = 100 (CLP/min)
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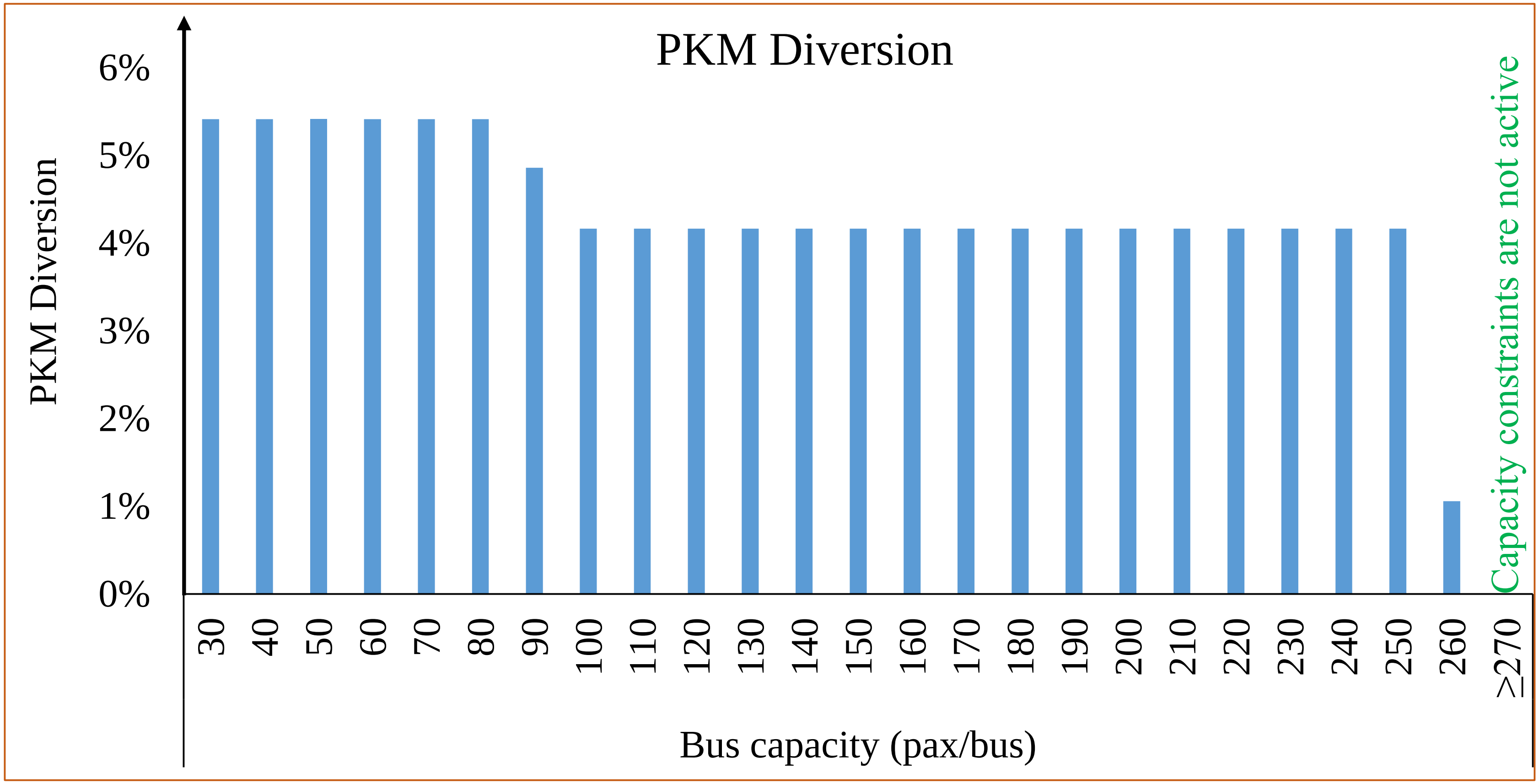
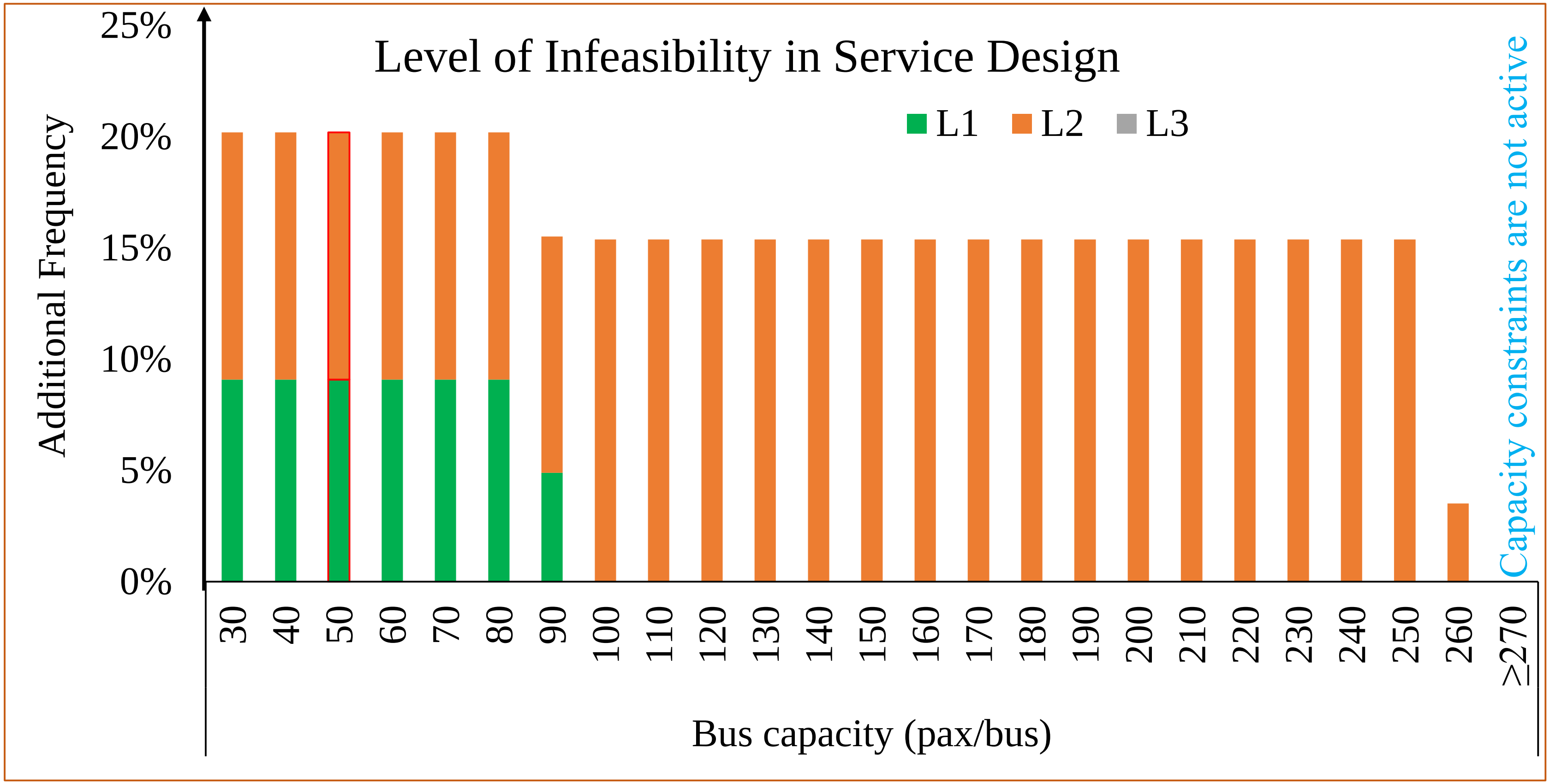
Impact with Bus Capacity

Passenger-Kilometer (PKM) Diversion



Impact with Bus Capacity

Infeasibility in Service Design



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Impact with Value of Waiting Time

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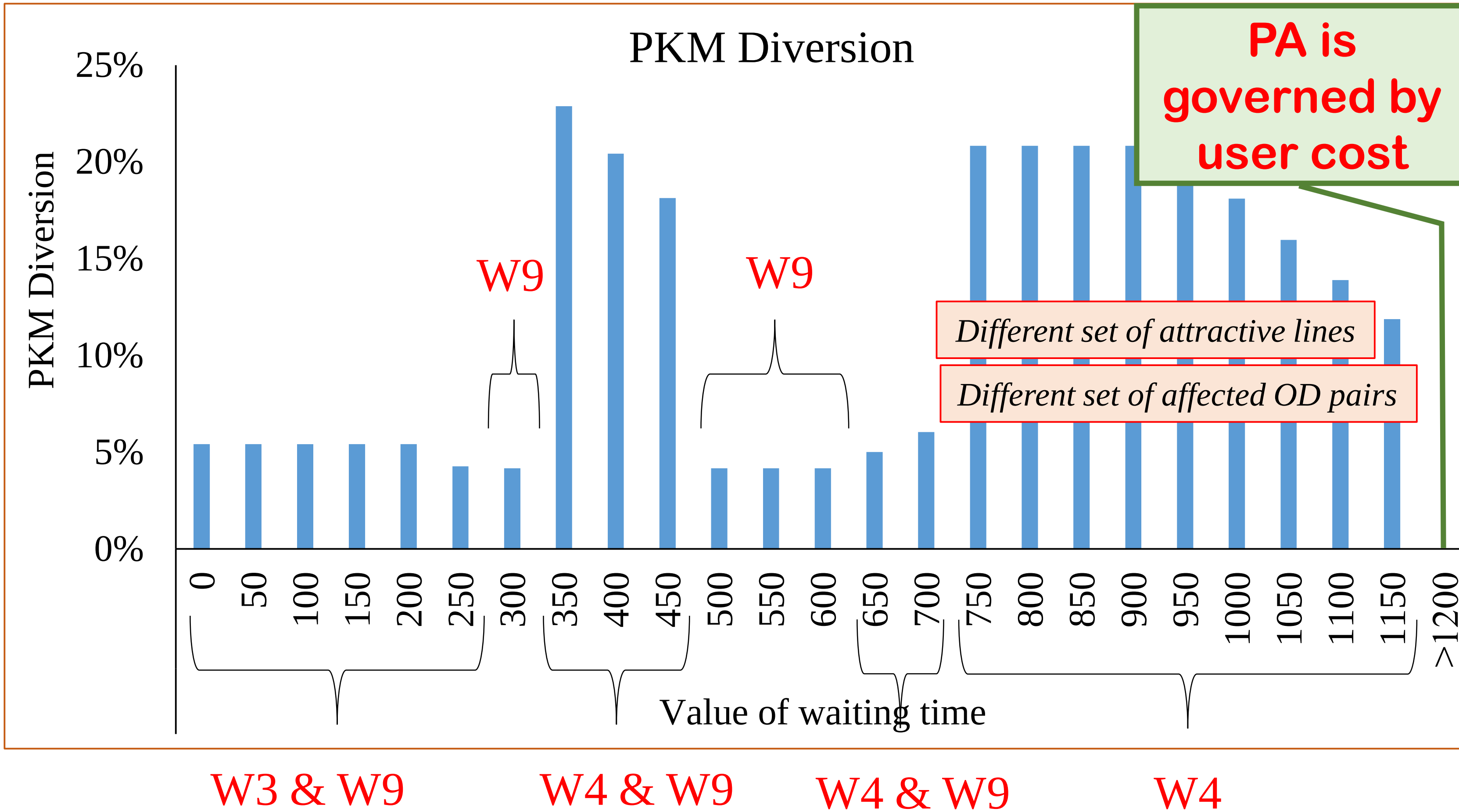
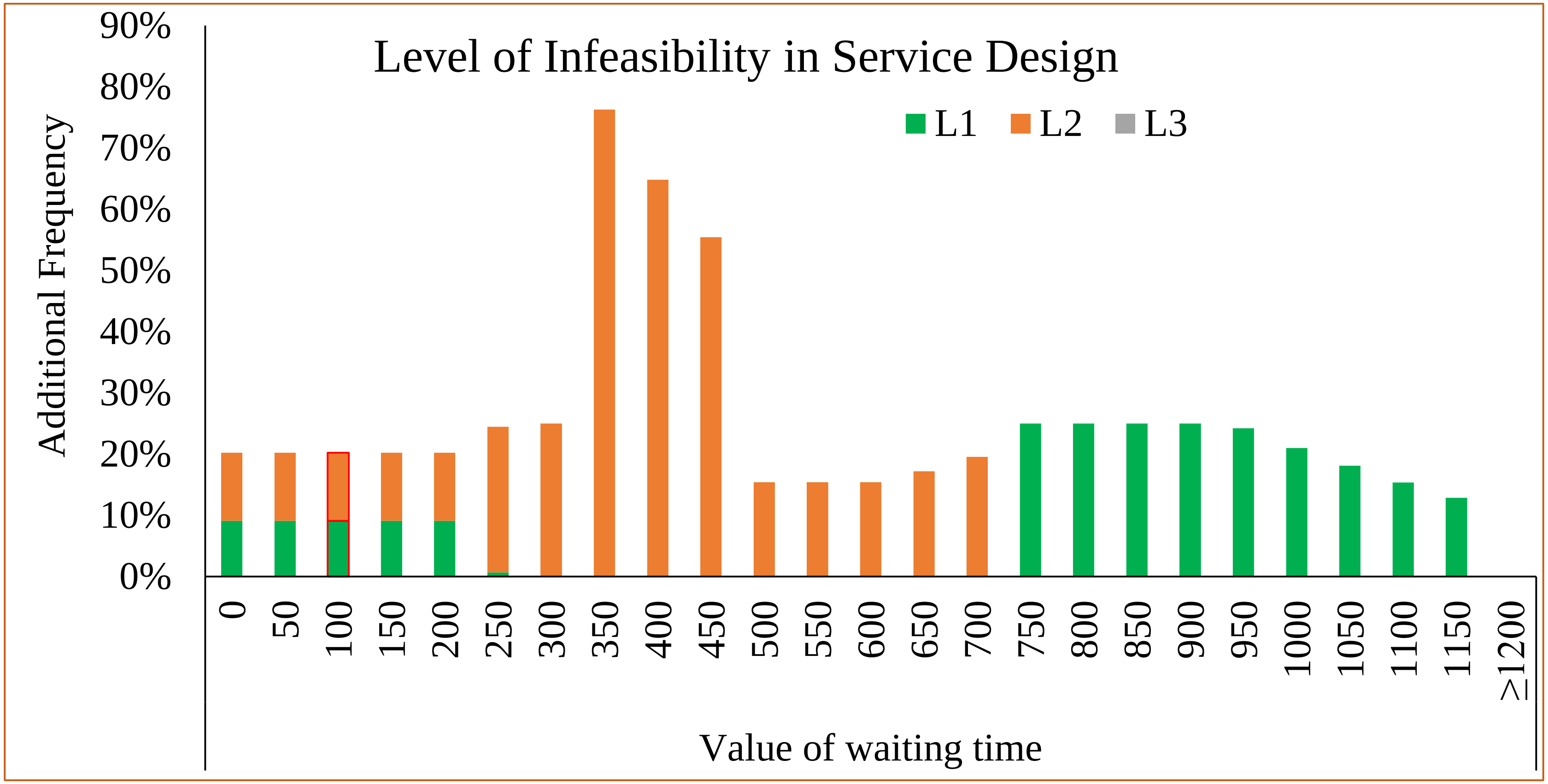


Impact with Value of Waiting Time

Infeasibility in Service Design



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CONCLUSIONS

- Altruistic passenger assignment is inconsistent with the reality.
- Naïve approach underestimates the required frequencies.
- Its impact might be pronounced more in congested networks.
- Future scope: **User Equilibrium** passenger assignment.

Thank you

Questions ?

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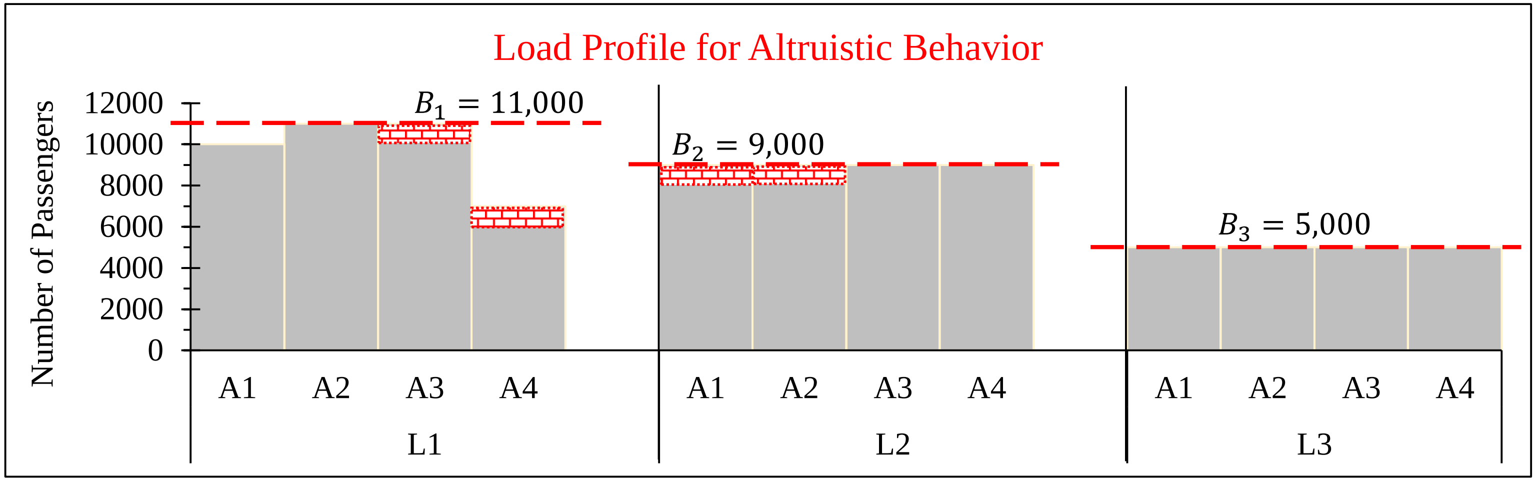
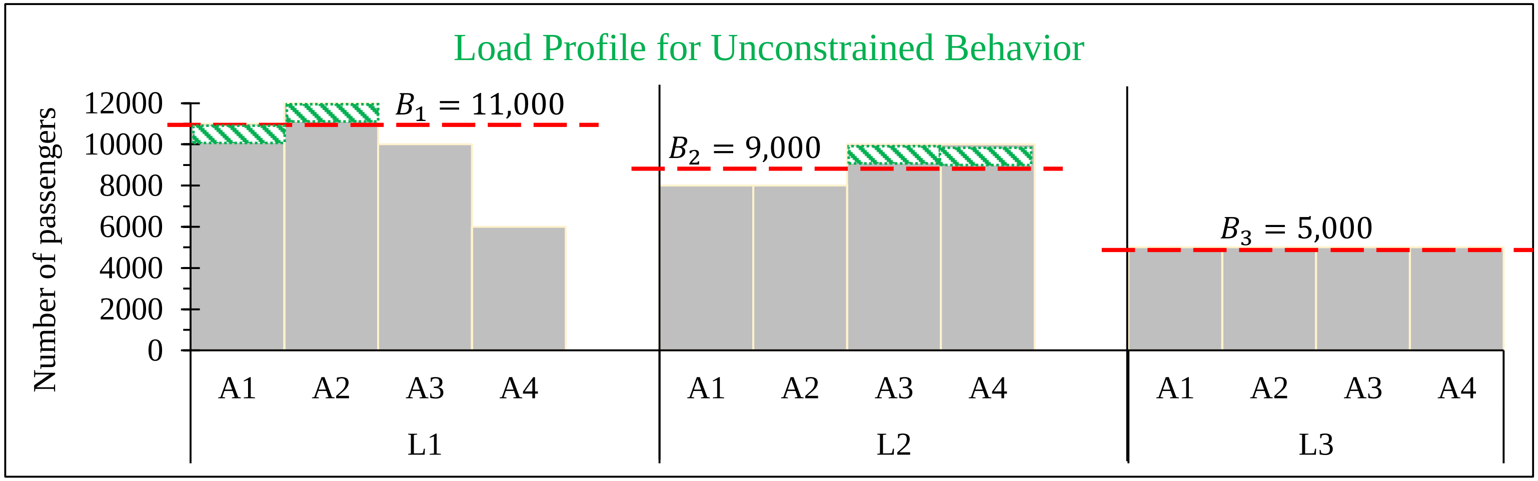
Results for Base Scenario

Scenario				PKM Diversion	Infeasibility in Service Design		
b	θ_{wt}	θ_{tt}	θ_{tr}		L1	L2	L3
50	**100**	**100**	**100**	5.4 %	9.1 %	11.1 %	0.0 %





CONCLUSIONS

- Altruistic passenger assignment is inconsistent with the reality.
- Naïve approach underestimates the required frequencies.
- Its impact might be pronounced more in congested networks.

- Similar experiments for - **Routes** instead of itineraries.
- Not providing enough capacity by just a little bit may affect much more people than if we fail by a large amount.

- Future scope: **User Equilibrium** passenger assignment.