Real-time Control Strategies for Public-Transport Transfer Synchronization

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What We Want?

- To shift a significant amount of car users to public transport (PT) in a sustainable manner.
- To improve serviceability by offering routes with "seamless" transfers; this is an important element for retaining existing users and attracting new passengers
- To aid agencies in providing credible service while attempting to reduce operating costs.

Motivations

- To develop an integrated, multi-modal transport system in order to provide travellers with a viable alternative to private cars.

How To Make Public Transport More “Efficient”, Thus To Attract More Passengers?

Why? What we can do?

Background

Planning Level

- Maximal Synchronized Transfers (MST)

Operation Level

- Synchronized Transfers do not always appear

Resulting in:

- Deterioration in system reliability, missed transfers, and passenger frustration

Research Needs

Possible Causes:

- Some uncertain and unexpected factors such as traffic disturbances and disruptions, inaccurate PT driver behaviour and actions, and random passenger demands;

- Improper or lack of certain control actions.

Improper or lack of a prudent real-time transit control system is of major concern of PT operators.

What is the Goal?

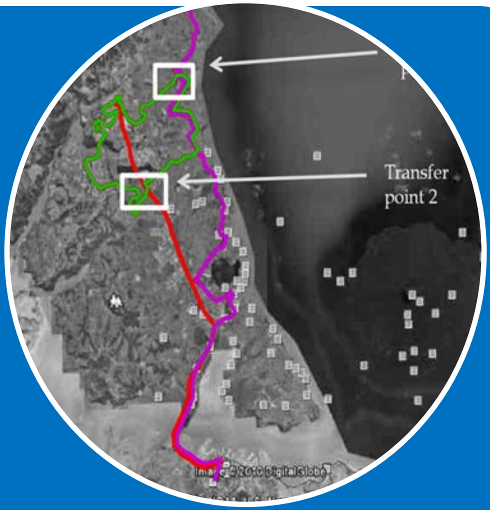
To increase PT service reliability;

- By minimizing passengers' travel time and reducing the uncertainty of meetings between PT vehicles.

Reducing the uncertainty of missed transfers by the use of control tactics in real-time operation

- **"How to create modelling for optimally selecting of operational PT tactics (control actions) for deployment in real-time operations?"**

What is the Method?

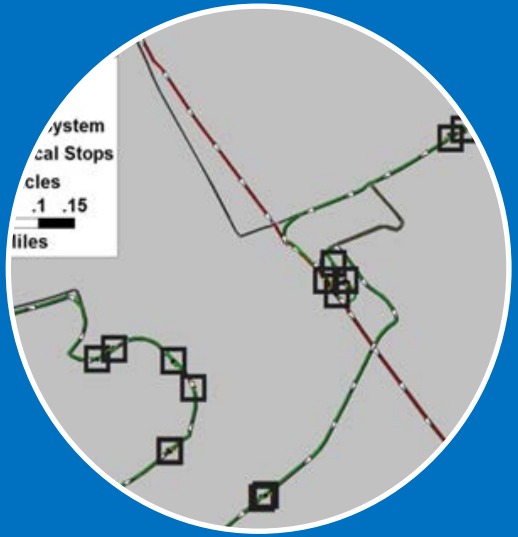


Simulation:

Data and Route Characteristics

Optimization:

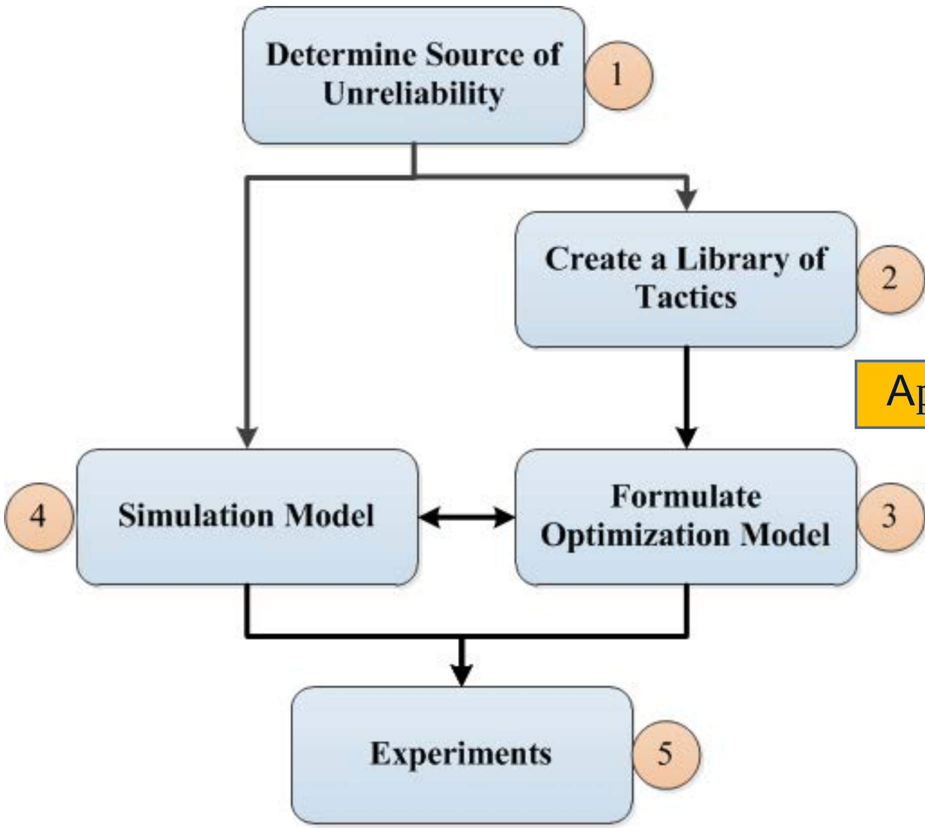
Model Description



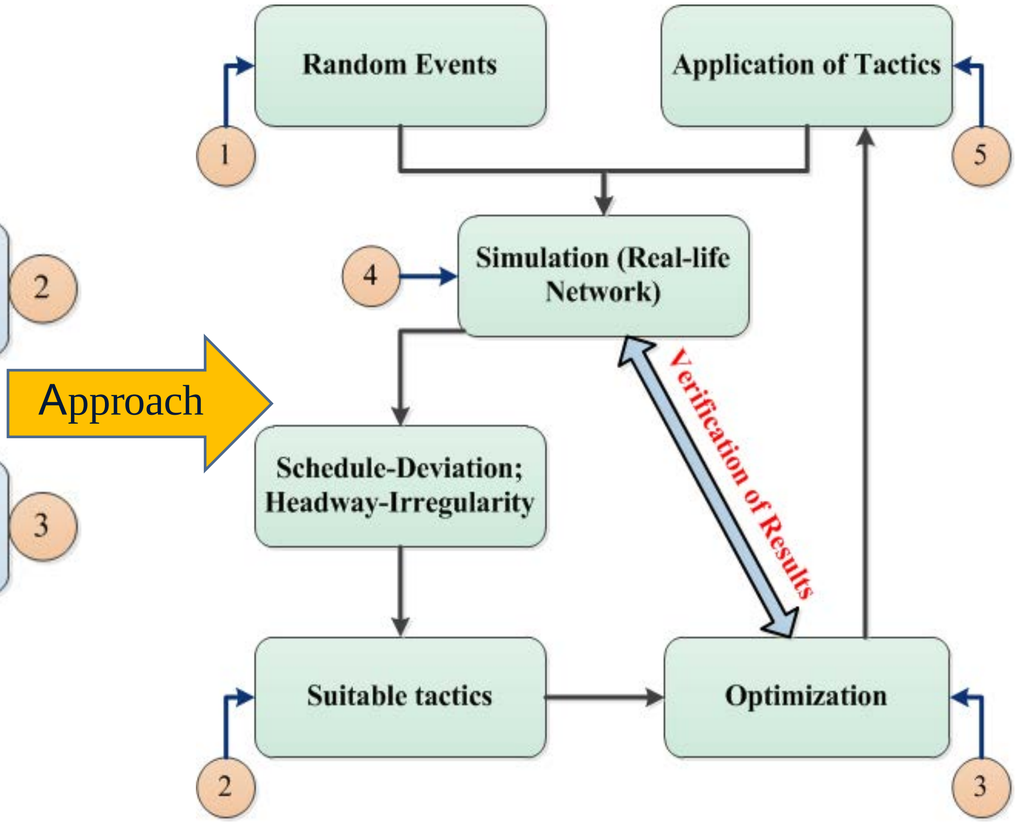
Validation:

Using Simulation

What is the Method?



(Study Process)

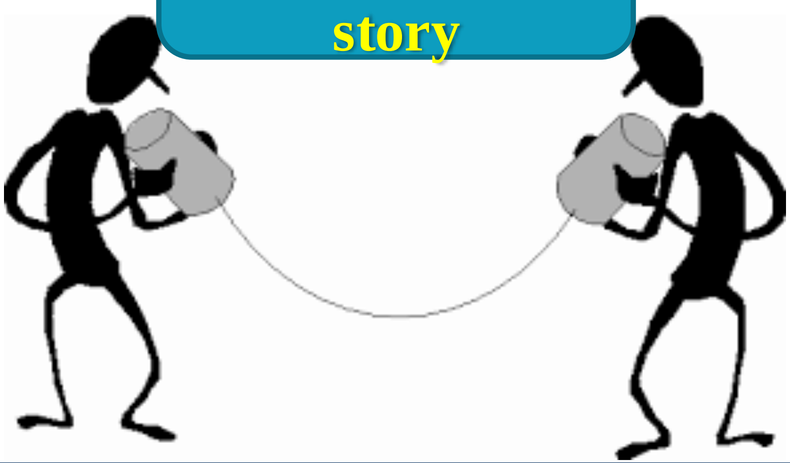


(Solution Approach)

Model Development

- Library of Tactics (LT)
- Direct Transfer (DT)
- Optimization Framework
- Formulation of Control Strategies
- Simulation Framework

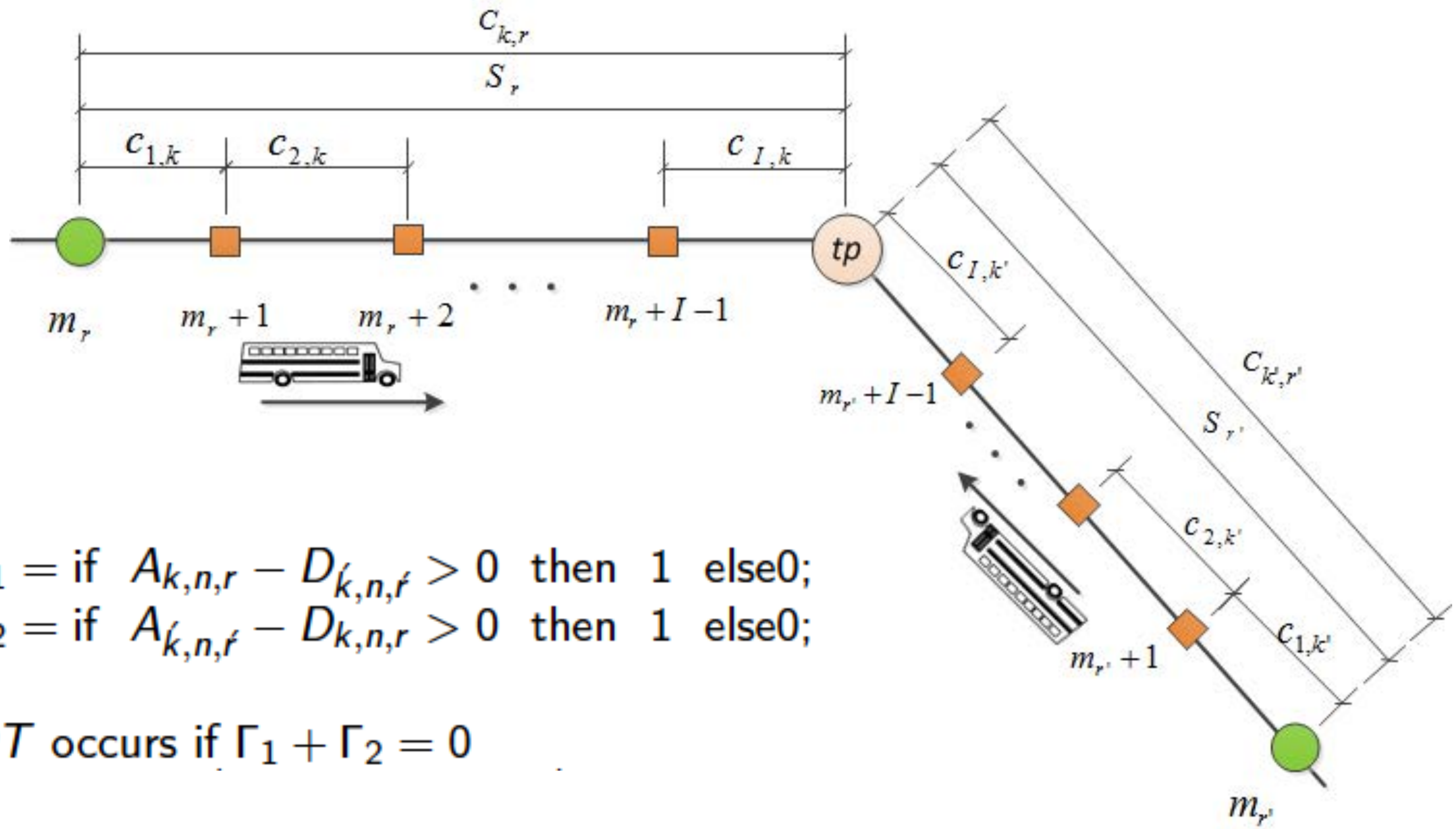
Coordination – this is the whole story



- Holding vehicle
- Skip-stop Operation
- Short-turn Operation
- Short-cut Operation
- Changes in Speed
- Boarding-limit

Model Development-DT

- Real-time Synchronization



$$\Gamma_1 = \text{if } \; A_{k,n,r} - D_{\acute{k},n,\acute{r}} > 0 \; \text{ then } \; 1 \; \text{ else} 0;$$
$$\Gamma_2 = \text{if } \; A_{\acute{k},n,\acute{r}} - D_{k,n,r} > 0 \; \text{ then } \; 1 \; \text{ else} 0;$$

DT occurs if $\Gamma_1 + \Gamma_2 = 0$

Model Development-Formulation

- Optimization-MIP, CP;

OF= $$\min \sum_{r \in R} \sum_{n \in N} \Delta TPTT \{ (LT)_r^n + (T)_r^n \}$$

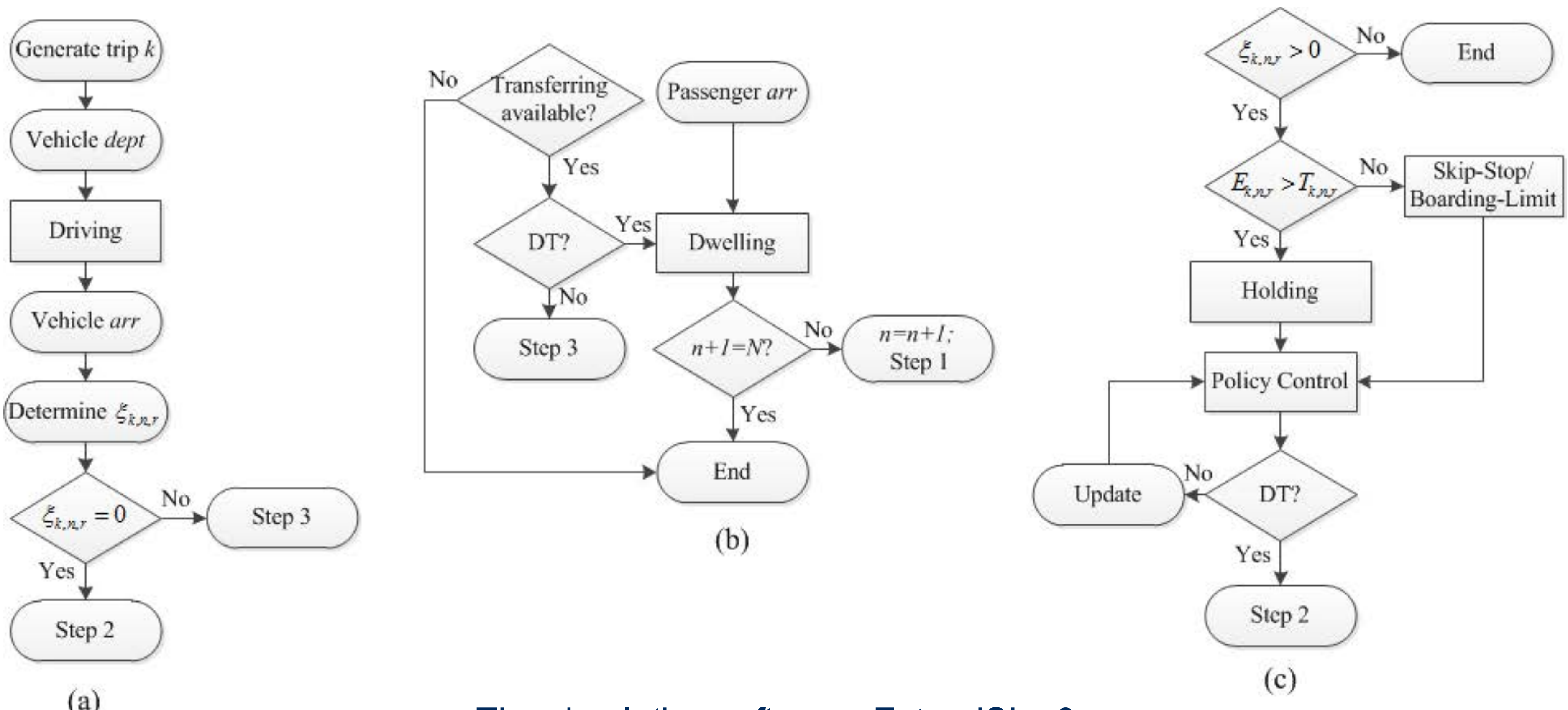
TPTT= Total Passenger Travel Time

IBM, ILOG

```
 * OPL 12.5 Model
 * Author: Mahmood
 * Creation Date: 4/03/2014 at 3:05:22 PM
 *********************************************/
using CP;
//Data
int f=...;
int M=...;
int maxholdtime=...;
int nbroutes=...;
int nbphysicalstops=...;
int nbtransfers=...;
int nbtransfers2=...;
range routes=1..nbroutes;
range stops=1..nbphysicalstops;
range transfers=1..nbtransfers;
range holdoptions=0..maxholdtime;
int TP[routes][transfers]=...;
int TF[routes][routes]=...;
int T[routes]=...;
int k[routes]=...;
int g[routes]=...;
int lasttransfer[routes]=...;
int c[routes][stops]=...;
int h[routes]=...;
int m[routes]=...;
float l[routes][stops]=...;
float e[routes][stops]=...;
int d[routes][stops]=...;
range order=1..max(i in routes) m[i]+1;
range order2=1..max(i in routes) m[i];
//range order3= max(i in routes)m[i]+1..max(i in routes) N[i];
int Q[routes][order]=...;
int V[routes][stops]=...;
int t[x in routes][u in routes][n in stops]=0;
{int} s1[x in routes][tp in transfers];//set to get transfer value
{int} s2[x in routes][tp in transfers];
execute {
//add another t for next transfering
t[1][3][2]=10;
t[3][1][2]=9;
t[2][3][24]=6;// 34 in 3 routes
t[3][2][24]=8;
//t[1][3][19]=10;
//t[3][1][19]=13;
//t[2][3][133]=14;
//t[3][2][133]=15;
t[4][6][142]=10;
t[6][4][142]=13;
```

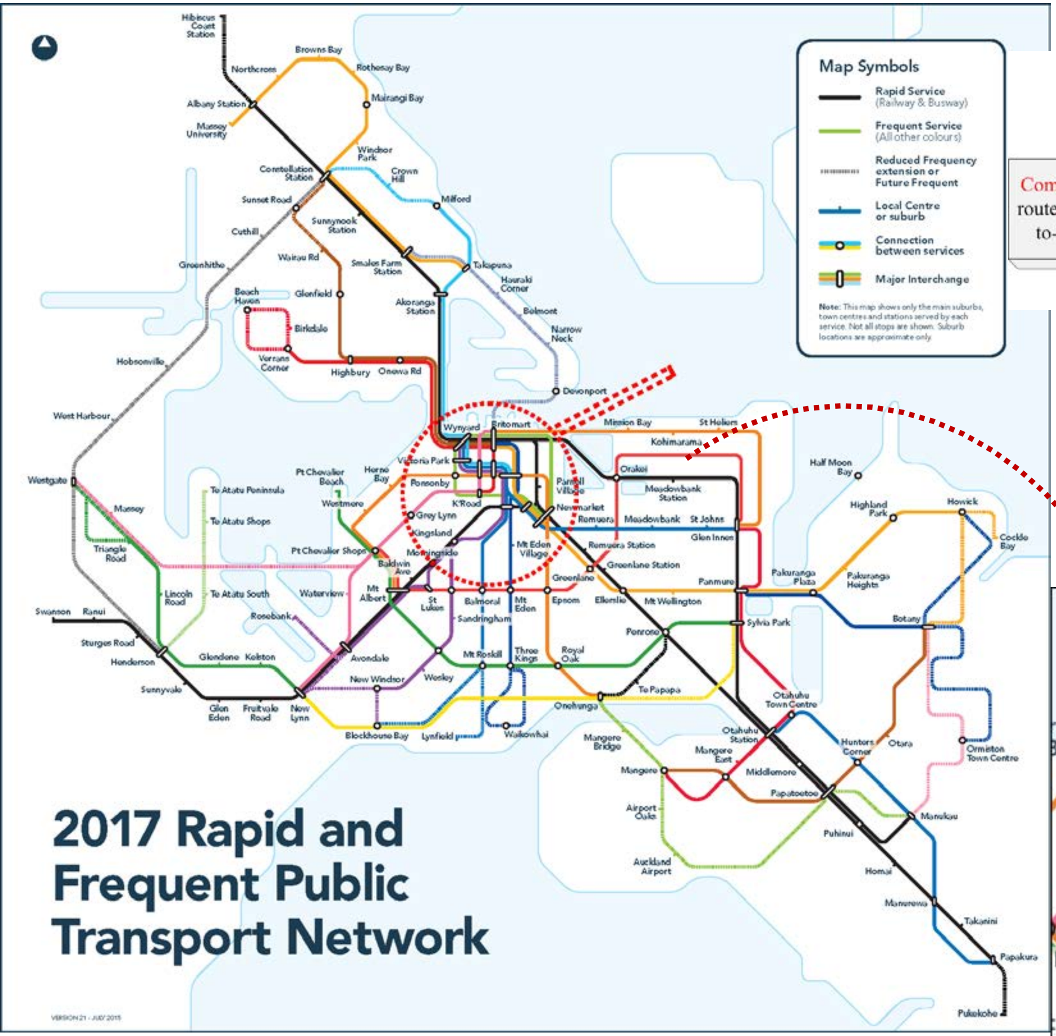
Model Development-Simulation

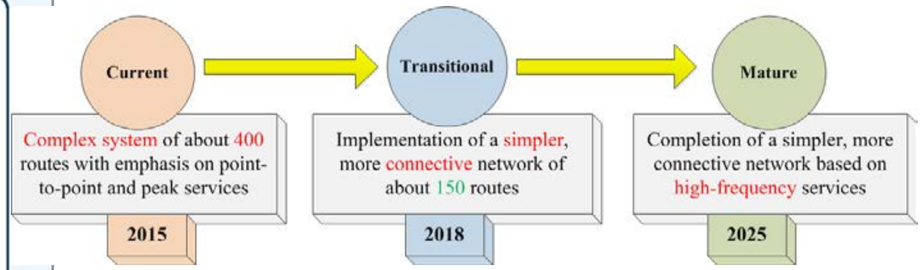
- Event-Activity Process Modeling



The simulation software, ExtendSim 8

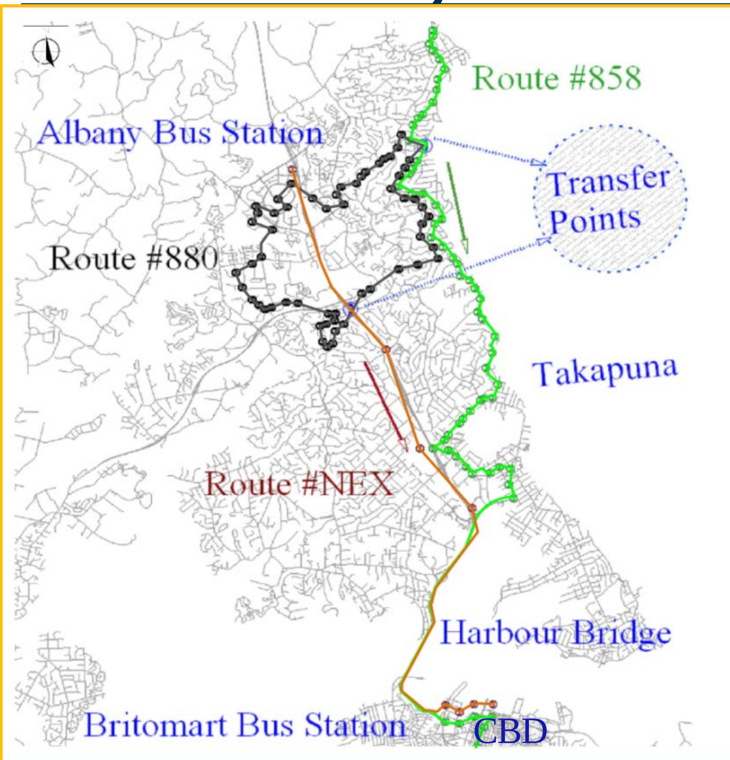
Case Study-Auckland, New Zealand



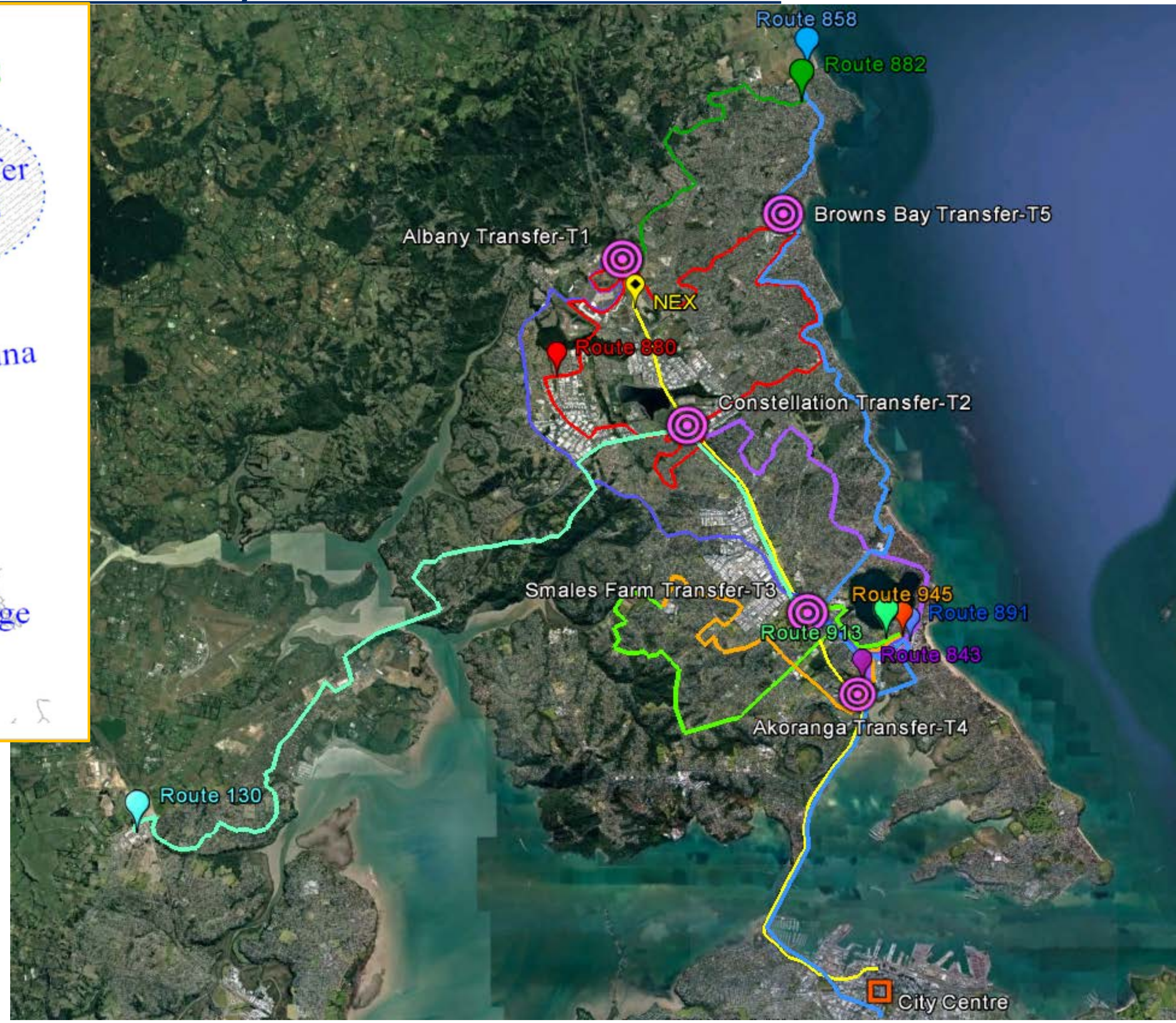


- AVL data
- GPS data
- AT-HOP cards
- AFP data
- APC data

Case Study-Auckland, New Zealand



a)



b)

Scenarios & Policies

Scenarios

- Different schedule deviations (e.g., ±5 min schedule deviation or ±10 schedule deviation,…)
- Different frequencies (e.g., High, Medium, Low)

Policies

- Combination of different tactics (e.g., Holding and Skip-stops, or Holding and Boarding-limit)

Analysis

- Performance Evaluation

Passenger Perspective

- Total Passenger Travel Time
- Total Passenger Waiting Time
- Number of Successful Transfers
- Number of Missed Transfers

Vehicle Perspective

- Average Vehicle Travel Time
- Average Cycle Time
- Average Schedule Deviation
- Average Standard Deviation of Headways
- Vehicle Bunching Percentage

Results

- Summary1-Example

Scenario	Policy	Control strength	Total waiting time(s)	Avg. cycle time (s)	CV(h)	DT(%) Simulation	DT(%) Improvement
1	None	-	9156.87	7565	0.63	26.58	-
	H-BL	$\alpha = 0.75$ $\beta = 0.75$	3251.94	6859	0.25	55.6	115.50
	H-SS	$\alpha = 0.75$ $\beta = 1$	3543.53	6881	0.27	58.2	125.58
2	None	-	11368.62	7740	0.68	24.18	-
	H-BL	$\alpha = 0.75$ $\beta = 0.5$	4698.65	7092.4	0.28	57.9	140.25
	H-SS	$\alpha = 0.75$ $\beta = 1$	4358.36	6923	0.24	59.3	146.06

Note: H= holding; BL= boarding-limit; SS= skip-stops; CV= coefficient of variation; DT= direct transfer.

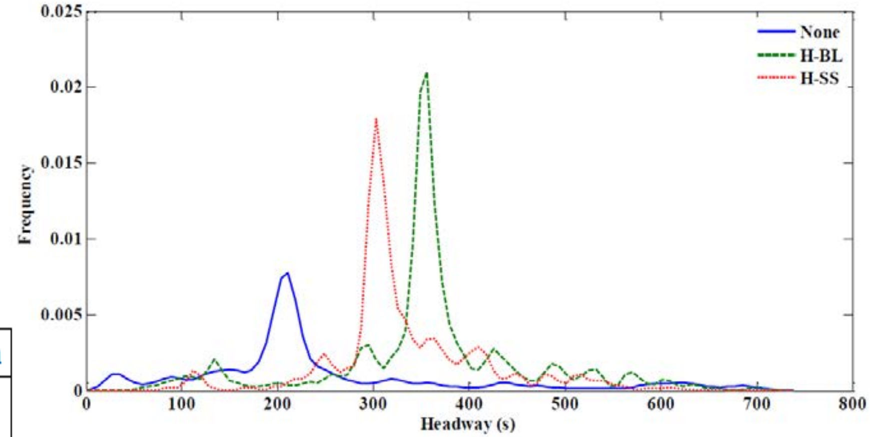
1=High frequency; 2=Medium frequency

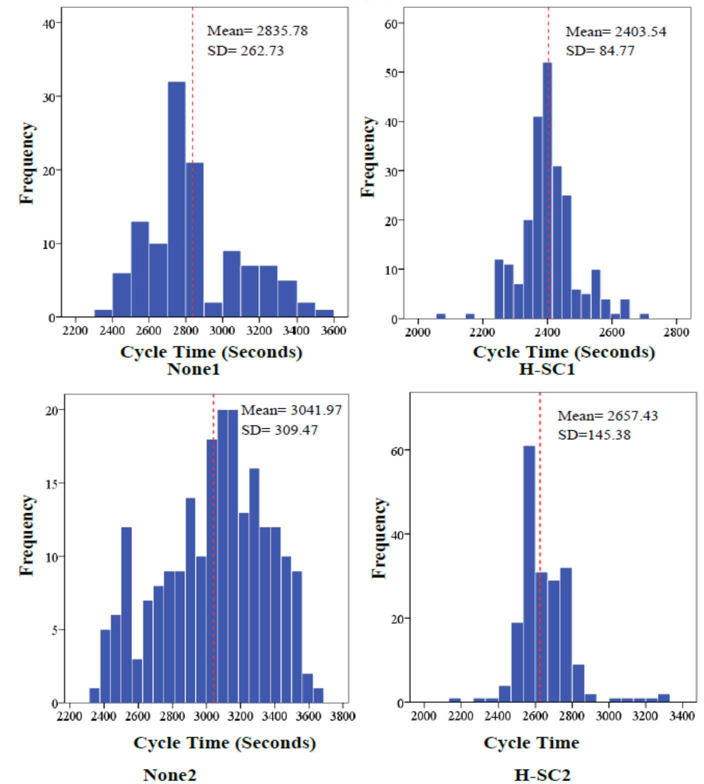
Results

- Summary2-Example

(a) Optimal 'Holding & Skip-Segment' scenario

Bus Location	Route 858		Route 880		Transfers		Modification
Time Deviation from Schedule (sec)	Skipped Segment	Holding at Transfer 1	Skipped Segment	Holding at Transfer-point 1	Improved Direct Transfers; from route→to route (Z)	DT	ΔTPTT
-128	101...107			61 sec	858→880	YES	-6591.907
-92	102...107			35 sec	858→880	YES	-6457.055
-69	103...107			19 sec	858→880	YES	-5857.552
-47	103...107				858→880	YES	-6473.152
-23	104...107				858→880	YES	-5276.088
0					-	YES	0
27					-	YES	0
60			89...92		880→858	YES	-3425.776
100		18 sec	89...92		880→858	YES	-1748.266
140					-	NO	0
177					-	NO	0

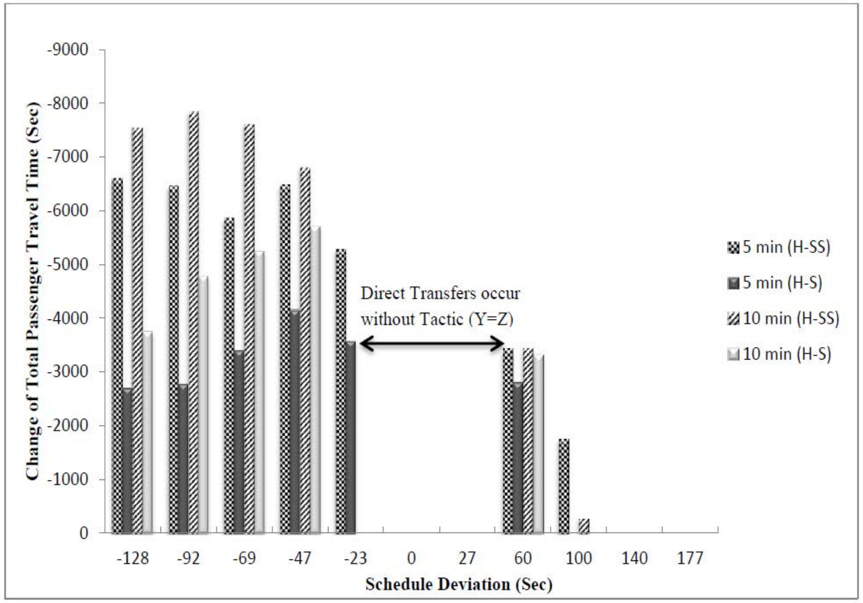




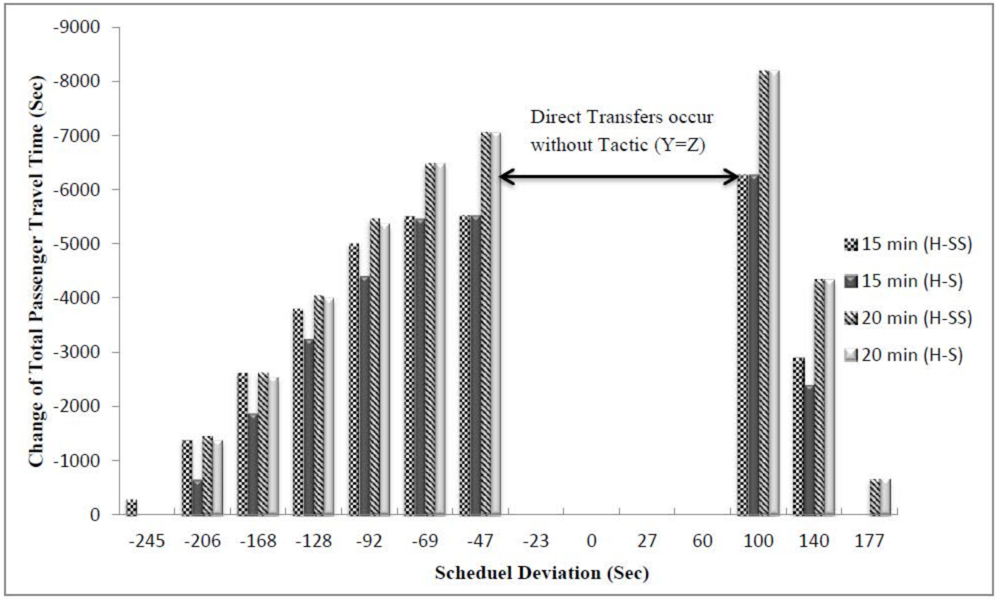
Results

- Summary 3-Example

➢ The results of short headways headways, in Part (a), are completely different from the results of the long, in Part (b) in terms of the shape of the trend before and after the No-Tactics zone



Parts (a)



Parts (b)

Some Main Findings

- If possible, a combination of tactics should be applied.
  - The utilization of a combination of selected online operational tactics improves the actual occurrence of planned coordinated transfers, reduces transfer waiting times and increases the reliability and regularity of the PT service.
- When the schedule deviation tends to zero, the maximum saving of TPTT occurs without the use of any tactics; this max travel time saving coincides with max numbers of direct transfers.

Some Main Findings

- Generally, the analysis shows significant better results for short headway cases.
- The combination of some tactics yield the better result in high frequency service like holding and boarding-limit policy.
- A considerable improvement in direct transfers is attained in holding and skip-stop control policy.

Related Papers

1. Nesheli, M.M., Ceder, A. (2014). Optimal Combinations of selected tactics for public-transport transfer synchronization. ***Transportation Research Part C****: Emerging Technologies*, 48, 491-504
2. Nesheli, M.M., Ceder, A. (2015). A Robust, Tactic-Based, Real-Time Framework for Public-Transport Transfer Synchronization*.* ***Transportation Research Part C****: Emerging Technologies*, 60, 105-123
3. Nesheli, M.M., Ceder, A. (2015). Improved Reliability of Public Transportation Using Real-Time Transfer Synchronization. ***Transportation Research Part C****: Emerging Technologies ,* 60, 525-539
4. Nesheli, M.M., Ceder, A., Gonzalez, V. (2016). Real-time Public-Transport Operational Tactics Using Synchronized Transfers to Eliminate Vehicle Bunching. ***IEEE Transactions on Intelligent Transportation Systems,*** 17, 3220-322.
5. Nesheli, M.M., A.Ceder. (2017). Real-Time Public Transport Operations: Library of Control Strategies. ***Transportation Research Record*** (In press).

End of the Presentation

Thank you for your attention!

It certainly opens the window for a future research