Real Time Public-Transport Operational Tactics Using Synchronized Transfers to Eliminate Vehicle Bunching

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Outline:

1. Introduction
2. Objectives
3. Methodology
4. Results
5. Conclusion

How to make public-transport service more efficient and comfort, thus to attract more passengers ?

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Efficient Public-Transport (PT) Service

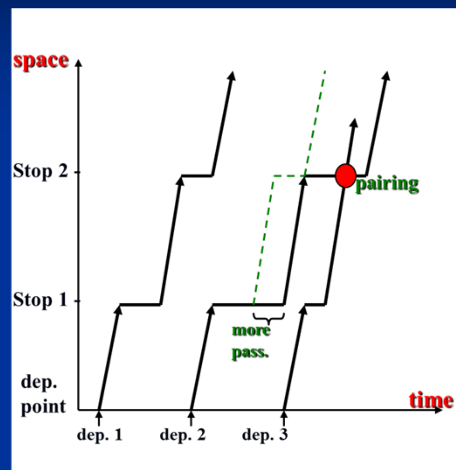
Advanced and attractive Public Transport (PT) service that operate reliably, and relatively rapidly, part of the passenger door-to-door chain with smooth and synchronized transfers, Ceder (2007)

Jacksonville, Florida, USA

Motivation

Observed Problems:

- **Unforeseen variations of arrival times, difficulty in maintaining PT vehicles' headway.**
- **These variations will create the undesirable vehicle (especially bus) bunching phenomenon.**
- **Uncertainty results in missed transfers, increase of passenger waiting and travel times, and of passenger frustration.**



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**

Lack of a prudent real-time transit control system is of major concern of public-transport (PT) operators

Objective of Study

Use the availability of real-time information to quickly correct headway irregularity and allows for increasing the chances of simultaneous transfers

How to increase the attractiveness of the PT system?

5

Assumptions

- **The vehicles are operated in a FIFO manner, with an evenly scheduled headway per route.**
- **Route information, including, travel times between stops, estimation of passenger arrival rates at each stop and average number of transferring passengers, are presumed known and fixed over the period concerned.**
- **Passengers on-board a vehicle will be informed of any action at the time of the decision so that they can choose to alight before or after the action.**
- **The PT drivers comply with the speed-change and holding instructions provided by their operator.**

6

Methodology-1

- ❑ Headway-based model
- ❑ Direct transfer (DT)
- ❑ Library of tactics

The system underlying the model consists of main and feeder routes. The transfers occur at separate transfer points for each route. The service area includes $n=1,2,\ldots N$ stops and $r=r, r`,\ldots R$ routes. A route is made up of a collection of "trips"; each trip k represents a single vehicle run, based on a certain departure time, along the series of stops on the route.

7

Methodology-2

- ❑ Headway-based model

Dynamic headway-based model according to real-time vehicles motion information instead of schedule-based counterpart

$$h_{k,n,r} = \frac{S_{k,r}}{|v_{k,n,r} - v_{k-1,n,r}|_t}$$

$$E_{k,n,r} = \max[(\min H_{k,r} - h_{k,n,r}), 0]$$

$$T_{k,n,r} = \max[(h_{k,n,r} - \max H_{k,r}), 0]$$

$$\xi_{k,n,r} = \alpha E_{k,n,r} + \beta T_{k,n,r}$$ ← Headway deviations

$$W^{stop}_{k,n,r} = (1+\gamma_{n,r})\left[\frac{H_{k,r}}{2}\left(1+\frac{\sigma^2(h_{k,n,r})}{H^2_{k,r}}\right)\right]$$ ← Passenger waiting time at stop

8

Methodology-3

❑ Direct transfer (DT)

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

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

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

$$W_{k,n,r}^{missed} = \left(1 + \frac{p_{k,n,rr'}}{\sum_{n=1}^{N} \lambda_{n,r'} . h_{k',n,r'}}\right) h_{k',n,r'}$$

Passenger waiting time at transfer stop

A= vehicle arrival time;
D= vehicle departure time;
λ= passenger arrival rate;
p= transferring passengers.

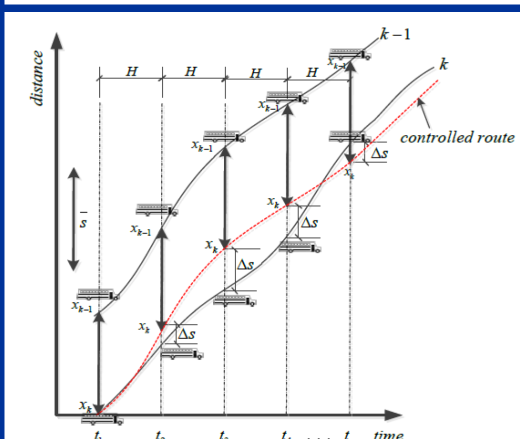
Methodology-4

Real-time control actions (Tactics)

❑ Library of tactics

➢ Speed-change control model

$$v_{k,n,r}^{c} = \sqrt{\pm 4\left|\frac{\Delta s_{k,r} - v_{k,n,r}\xi_{k,n,r}}{\xi_{k,n,r}^{2}}\right| \Delta s_{k,r} + v_{k,n,r}^{2}}$$



Time-space diagram of PT operations

$v^c_{k,n,r}$=new speed under control;
$v_{k,n,r}$= current vehicle speed;
$\Delta S_{k,r}$= spacing between vehicle and desired space.

Methodology-5

Real-time control actions (Tactics)

- **Library of tactics**
  - Holding control model

$$HO_{k,n,r} = \min(\alpha E_{k,n,r}, HO_{k,n,r}^{\max})$$

$$D_{k,n,r} = D_{k,n-1,r} + c_{k,n,r} + d_{k,n,r} + HO_{k,n,r}$$

$$W_{k,n,r}^{in-vehicle} = \left(1 + \frac{B_{k,n,r}}{\sum_{n=1}^{N} B_{k,n,r}}\right) HO_{k,n,r}$$

HO =holding time;
C= running time between stops;
d= dwell time of the vehicle.

In-vehicle waiting time for passengers aboard

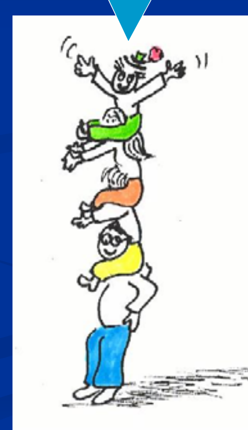
11

Methodology-6

Total waiting time

$$\min \sum_{k} \sum_{n} \sum_{r} (W_{k,n,r}^{stop} + W_{k,n,r}^{missed} + W_{k,n,r}^{in-vehicle})$$

To define precisely is the whole story



12

Simulation

Event-activity system modelling

Events

- departure of a vehicle from a stop (departure event)
- at time *t*, arrival of a vehicle to position *x* which is a location between two stops (position event),
- arrival of a vehicle at a stop (arrival event)

Activity

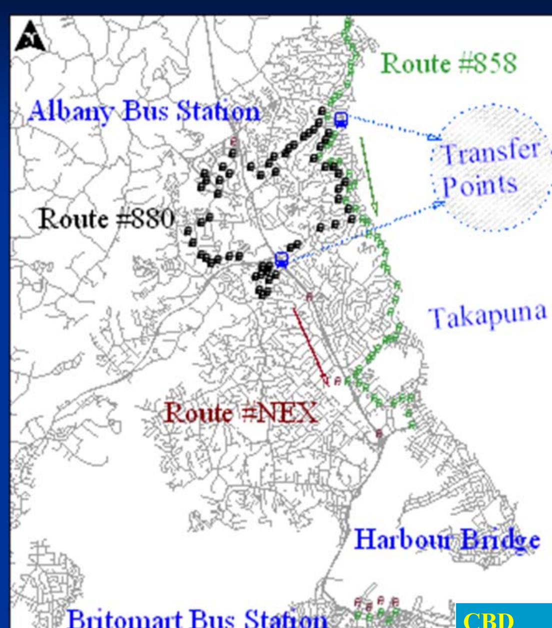
- travelling on the route between consecutive stops (driving activity)
- serving passengers at a stop (dwelling activity)

❖ Simulation software used ExtendSim 8

Case Study

Case Study:
Auckland, New Zealand

- ❑ AT- HOP cards (Auckland Integrated Fares System)
- ❑ AVL data



Case Study Scenarios

Route	Headway (min.)	Average number of passengers	
		Scenario1	Scenario2
1	5	257	514
2	7	1342	2648
3	5	958	1916

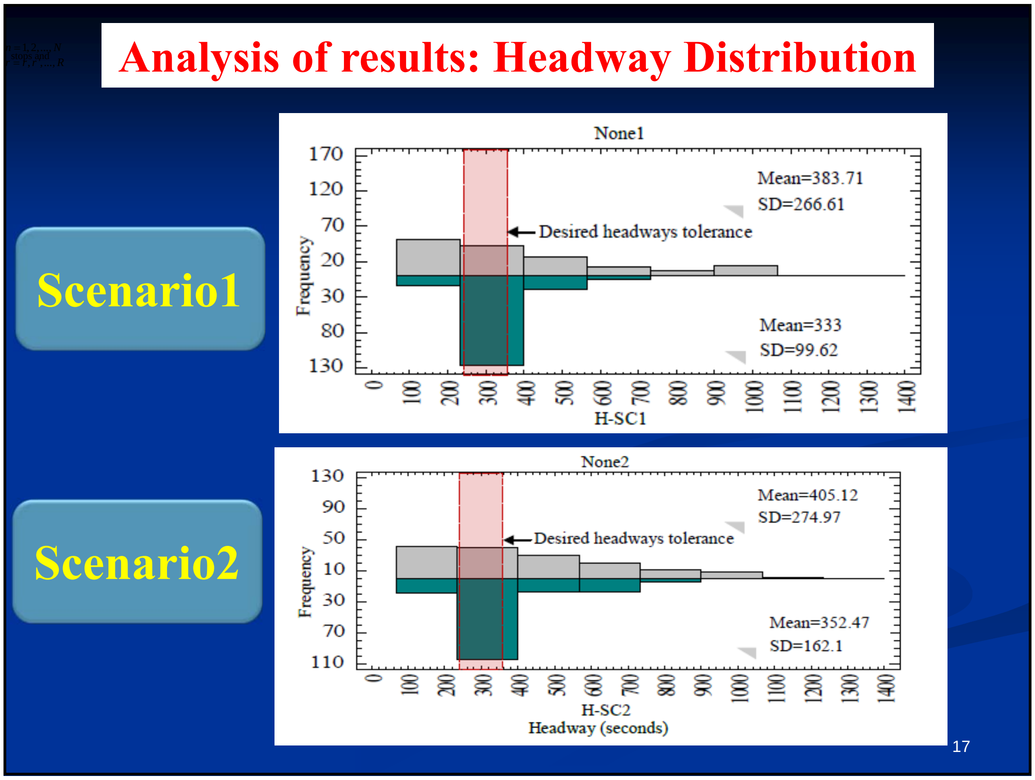
- ❖ **Scenario 2 is with high passenger demand**
- ❖ **The minimum and maximum headway variations, as the boundary for triggering an intervention, were set to ±20%.**

Analysis of results: Performance Measures

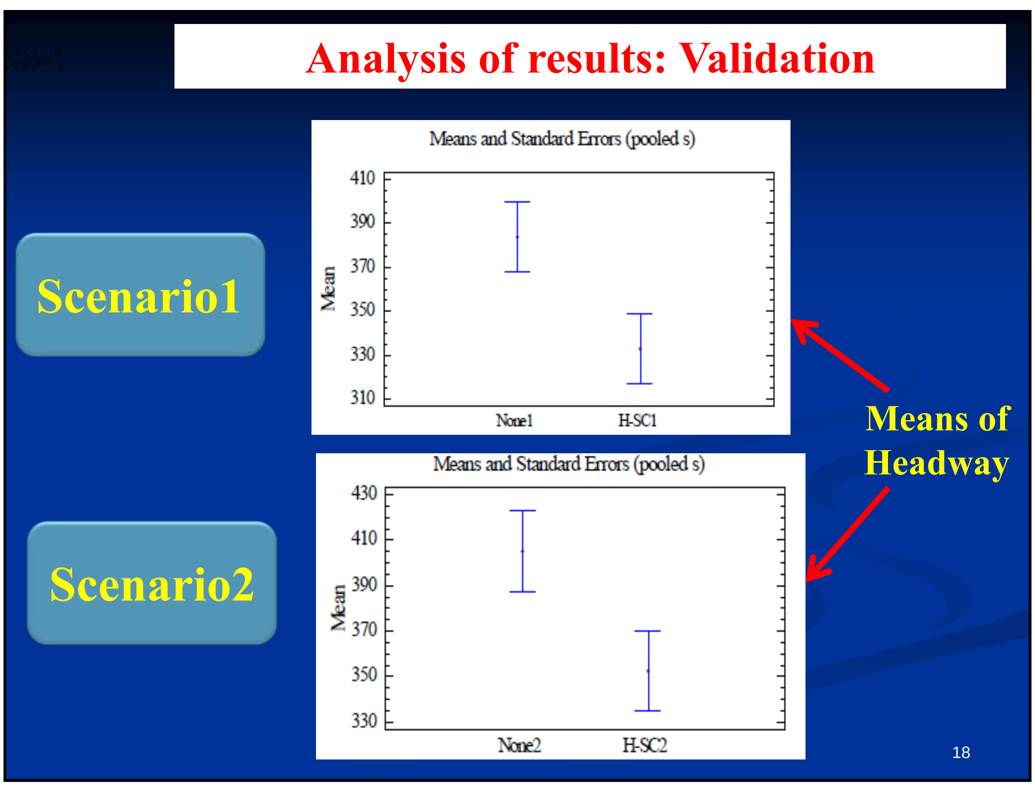
	Scenario 1				Scenario 2			
	None	H-SC			None	H-SC		
		$\alpha = 0.5$	$\alpha = 0.75$	$\alpha = 1$		$\alpha = 0.5$	$\alpha = 0.75$	$\alpha = 1$
W^{stop}	7828.32	3669.45	2698.74	2417.39	11342.16	5918.34	4784.12	5143.67
SD	712.33	174.09	76.2	42.8	1345.29	311.48	85.23	112.78
Improvement%		53.13	65.53	69.12		47.82	57.82	54.65
$W^{in-vehicle}$	182.4	645.3	821.84	1105.26	298.32	942.34	1362.3	1613.87
SD	34.2	69.52	95.3	122.33	86.2	101.25	93.21	162.05
Improvement%		-253.78	-350.57	-505.95		-215.88	-356.66	-440.99
W^{missed}	1345.74	504.823	341.85	114.33	2224.3	631.12	445.8	383.5
SD	945.12	156.11	90.24	19.32	873.26	91.85	61.25	26.12
Improvement%		62.49	74.60	91.50		71.63	79.96	82.76
Total	9356.46	4819.57	3862.42	3636.97	13864.78	7491.79	6592.22	7141.04
SD	1183.99	243.95	151.76	131.03	1606.18	340.158	140.37	199.15
Improvement%		48.49	58.72	61.13		45.97	52.45	48.50
Bunching (%)	26.3	9.25	3.93	3.07	35.6	14.2	8.3	6.8
Improvement%		64.83	85.06	88.33		60.11	76.69	80.90

Note: H-SC = holding and speed-change.

- ❖ **The control strength for earliness was set to half control, semi-full control and full control. The constant value for tardiness is set to full control**



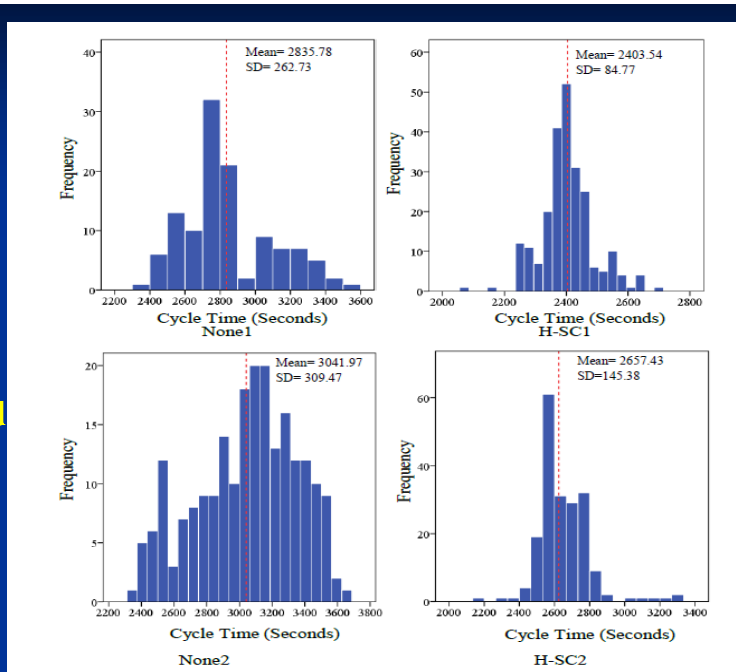
Analysis of results: Headway Distribution
Scenario1
None1
Mean=383.71
SD=266.61
Desired headways tolerance
Mean=333
SD=99.62
Frequency
H-SC1
Scenario2
None2
Mean=405.12
SD=274.97
Desired headways tolerance
Mean=352.47
SD=162.1
H-SC2
Headway (seconds)
17



Analysis of results: Validation
Scenario1
Means and Standard Errors (pooled s)
Mean
None1
H-SC1
Scenario2
Means and Standard Errors (pooled s)
Mean
None2
H-SC2
Means of Headway
18

Analysis of results: Cycle-time distribution

Case Study: Auckland, New Zealand



19

Conclusions

- The **tactic-based control strategy** always results with a significant lower standard deviation of the scheduled headways than the no-control strategy
- Applying **semi-control strength** in Scenario 2 results with a significant lower passenger waiting time than in the no-control strategy. For Scenario 1 the **semi-control and full-control** strengths yield close results
- Vehicle bunching situations are reduced significantly by the use of the **tactic-based control strategy**

How to avoid rain of problems in making online transfers

20

Conclusions-cont.

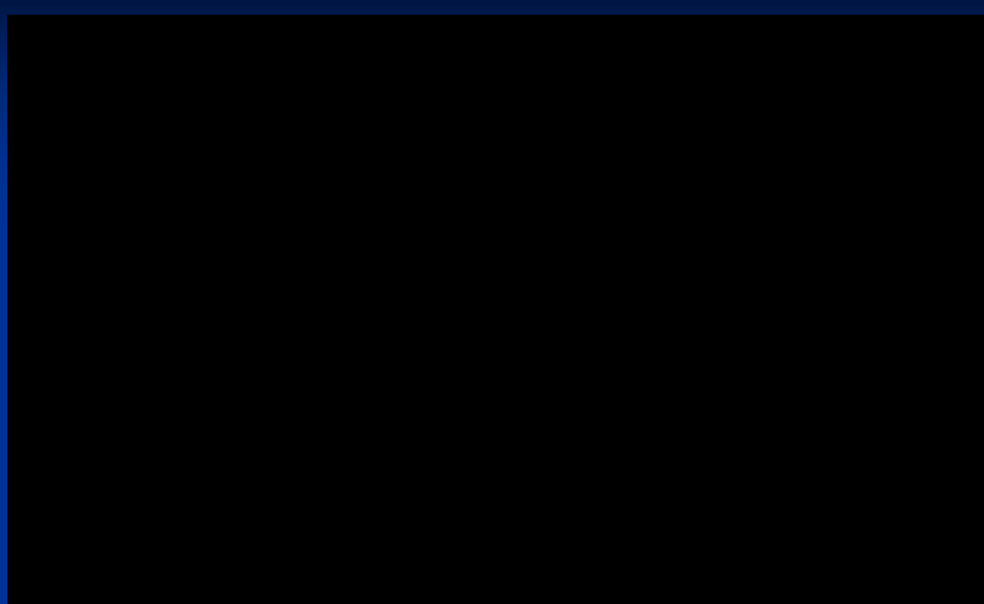
- The results show a better outcome of reducing headway variations for Scenario 1 (base-demand) than Scenario 2 (high-demand)

- The control tactics using Scenario 1 exhibit smaller average cycle time and lower variability of the reliability measures than when using Scenario 2

It certainly opens the window for a future research

21

Example of Smartphone Application (the Future)



22

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End of the Presentation

Thank you !

23