Communication-based Cooperative Control Strategy for Public-Transport Transfer Synchronization

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THE UNIVERSITY OF AUCKLAND NEW ZEALAND
Te Whare Wānanga o Tāmaki Makaurau

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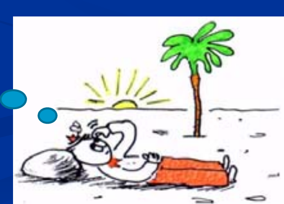
Communication-based Cooperative Control Strategy for Public-Transport Transfer Synchronization

Outline

1. Motivation
2. Objectives
3. Methodology
4. Performance Evaluation
5. Examples
6. Conclusions

What is a perfect Public-Transport connection? How this can be materialized?



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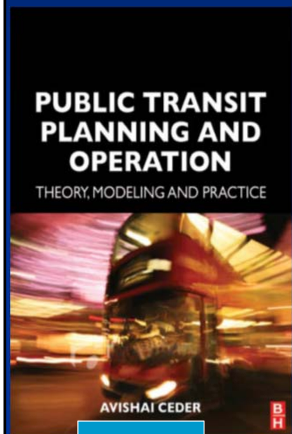
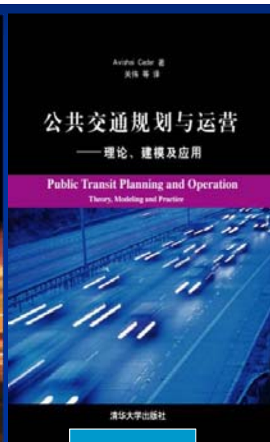
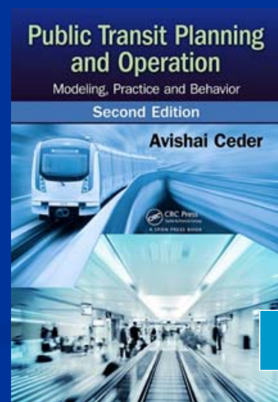
Initial work and motivation in the book by
(1) Elsevier (UK, Oxford), 2007
(2) Tsinghua Publishing House (Chinese), June 2010
(3) Taylor and Francis (UK, London), 2nd Edition, July 2015



2007



2010



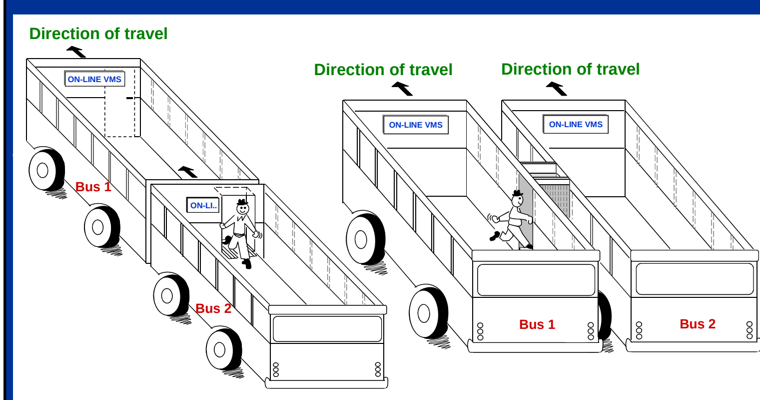
2015

How to get rid of problems related to public transport operations planning ?

Background-1

From Ceder (2007) re ideal transit

"Advanced and attractive transit service that operate reliably, and relatively rapidly, part of the passenger door-to-door chain with smooth and synchronized transfers"



Longitudinal Transfer

Lateral Transfer

Direct (no wait) transfers is the key !

Background-2

- The Auckland Regional Public-Transport (PT) Plan identified that significant changes are needed if we are to provide a simpler, connected network which can deliver better levels of service to Aucklanders and better connections to the places they want to go.
- The Public Health Advisory Council lists good connectivity as a major point in improving accessibility to PT.
- The recently released Public Transport Interchange Design Guidelines by Auckland Transport provides guidance on the design of PT transfers in order to enable PT users to move easily between PT services.

Jacksonville, Florida

Germany

Motivation

Why Transfer Synchronization is Important?

- Synchronized transfers in PT networks are used to reduce the inter-route or inter-modal passenger transfer waiting time and provide a well-connected service.
- Because of some stochastic and uncertain factors, such as traffic disturbances and disruptions, random passenger arrivals and inaccurate PT driver actions, synchronized transfers are not always materialized.
- Missed direct-transfers will not only frustrate present passengers, but also discourage potential passengers from using PT service.

Objectives

- To alleviate the uncertainty of simultaneous arrival of vehicles using some selected online operational tactics, such as holding, skip-stop, speed change
- To develop a general network with dynamic moving elements, random variables and definitions of vehicle meetings to represent the PT transfer synchronization problem
- To design a optimization procedure for real-time operational tactics deployment
- To provide a decision support system to increase the actual occurrence of planned direct-transfers

What are the goals ?

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Methodology

Communication-based Cooperative Control (CCC) Strategy

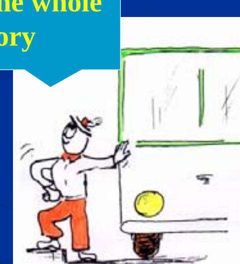
I. Library of Tactics

II. Optimization Framework

III. Formulation of Control Strategies

IV. Monte-Carlo Method for Network Simulation

Coordination – this is the whole story



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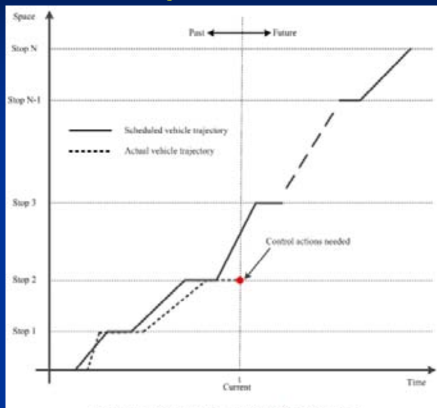
Methodology-1

I. Library of Tactics

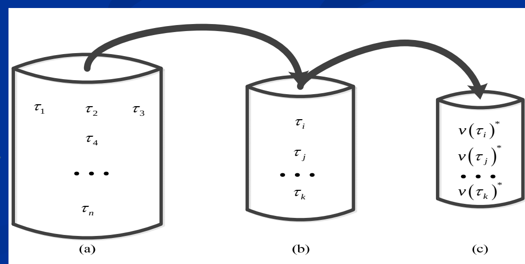


Time-space diagram for dynamic PT operations

Tactics

- ✓ Holding vehicle
- ✓ Skip-stop operation
- ✓ Changes in speed
- ✓ Short-turn operation
- ✓ Short-cut operation
- ✓ Leapfrogging operation
- ✓ …

Real-Time Tactics Deployment



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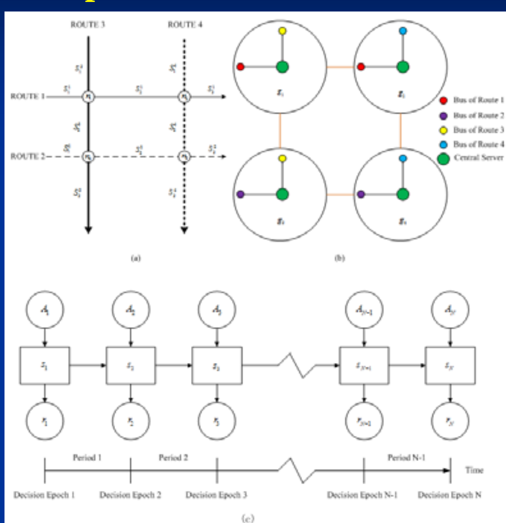
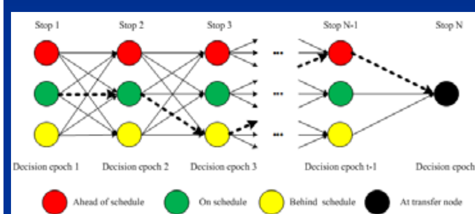
Methodology-2

II. Optimization Framework





The Dynamic Vehicle State Propagation Process

Decentralised Communication-based Cooperative Control Framework

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Methodology-3

III. Formulation of Control Strategies

1. **Without Control (WC) Strategy: used for comparison purpose**
2. **Conventional Schedule-based Control (CSC) Strategy**

if

$CDT_{i,u} < SDT_{i,u}$

then

$ADT_{i,u} = SDT_{i,u}$

else

$ADT_{i,u} = CDT_{i,u}$

$$AAT_{i,u} = SAT_{i,u} + \theta \cdot |CAT_{i,u} - SAT_{i,u}|$$

Control Logic

3. **Communication-based Non-Cooperative Control (CNC) Strategy**

Methodology-3

III. Formulation of Control Strategies

4. **Communication-based Cooperative Control (CCC) Strategy**

if

station u is not a transfer station; $NB_{i,u} = 0$ and $NA_{i,u} = 0$

then

$v_i(skip\text{-}station) = 1$

else

if

station u is not a transfer station and $\max\{NB_{i,u}, NA_{i,u}\} \neq 0$

then

compute the actual arrival time $AAT_{i,u}$ and the actual departure time $ADT_{i,u}$ as follow

$$AAT_{i,u} = SAT_{i,u} + \theta \cdot |CAT_{i,u} - SAT_{i,u}|$$

$$ADT_{i,u} = \max\{CDT_{i,u}, SDT_{i,u}\}$$

else (station u is a transfer station)

compute the actual arrival time $AAT_{i,u}$ and the actual departure time $ADT_{i,u}$ as follow

$$AAT_{i,u} = SAT_{i,u} + \theta \cdot |CAT_{i,u} - SAT_{i,u}|$$

$$ADT_{i,u} = \max\left\{CDT_{i,u}, SDT_{i,u}, AAT_{j,u} + \max_{j \in R_i}(\Delta_{j,i})\right\}$$

Main Control Rules

Methodology-4

IV. Monte-Carlo Method for Network Simulation

Step 1 (Initialization): Set the sample number $k = 1$.

Step 2 (Sampling): For a given PT route, the inter-station travel time r_m is assumed to be a random variable with a given mean and variance. For each vehicle trip, generate a vector of travel times based on the associated inter-station travel time distribution functions. For each station, sample the control strength θ within a given range.

Step 3 (Calculating parameters): Based on the passenger boarding/alighting rate and the sampled interstation travel times for each vehicle trip, calculating parameters used for constructing vehicle trajectory, which include vehicle arrival/departure time at each stop, headways, the number of boarding/alighting passengers, dwell time at each stop.

Step 4 (Deploying control strategies): The four proposed control strategies are applied to optimize the motion processes of vehicles. After the optimization, a set of new vehicle trajectories is obtained for each route.

Step 5 (Collecting performance indicators): Based on the modified new vehicle trajectories, the values of the performance indicators are collected.

Step 6 (Termination): If sample number $k < k_{\max}$, where $k_{\max}$ is the predetermined sample size, then increase sample number $k := k + 1$ and go to step 2; otherwise, stop.

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Performance Evaluation

Performance Indicators

1. Transfer Waiting Time
2. Number of Connected Transfers
3. Number of Missed Transfers
4. Average Vehicle Travel Time
5. Average Vehicle Travel Speed
6. Average Schedule Deviation
7. Average Standard Deviation of Headways
8. Vehicle Bunching Percentage

Fresh Food comes from excellent Preparation of indicators

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Control vs Math-Programming Approaches

General Comparison

The control approach is based on some predefined control logic (rules).

Example: in a conventional schedule-based control, vehicles are not allowed to depart before the scheduled departure time, if vehicles arrive late the rule is to depart immediately.

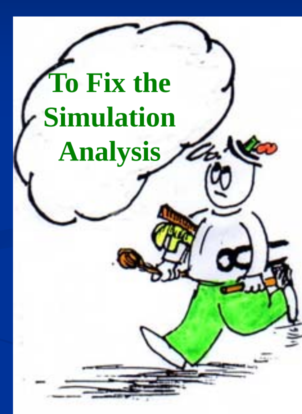
Advantages

- Compared with the math-programming approach, decisions of deploying tactics can be made in real-time.
- Traditional optimization is very time-consuming (often unacceptable) for large-scale real-life networks.
- Under the control approach, the problem is divided into a set of small groups, each is based and solved by simple control rules easily and quickly.
- The control approach works in parallel and distributive, thus can be applied in real-life problems.

Simulation Features used for the Control Approach

The proposed Monte Carlo method-based simulation procedure for simulating control strategies is coded in Matlab R2012b and implemented on a personal computer with 64 bit operating system, Inter Core i5-3570 CPU @3.40GHZ, and 8.00 GB RAM.

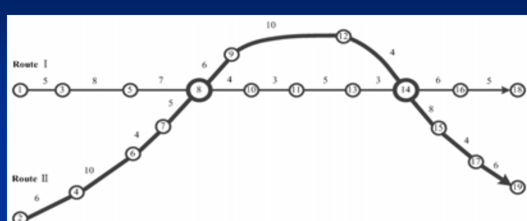
The simulation time depends on the problem size and data accumulated for statistical analysis.



Visual synchronization by Simulation

Example 1

Numerical Example



The Example PT Network

Departure time (min) Route Ⅰ	Route Ⅱ	Meeting time at stop 8 (min)	Meeting time at stop 14 (min)	Total no. of meetings
5	0	25		
13	8	33		4
21	16	41		
26			61	

Maximal Synchronized Timetable

Route												
Route Ⅰ	Stop	1	3	5	8	10	11	13	14	16	18	
	Boarding	1.250	0.625	0.375	1.250	0.250	0.625	1.000	0.750	0.125	0.000	
	Alighting	0.000	0.000	0.000	1.000	0.125	0.750	1.250	0.500	1.000	1.625	
Route Ⅱ	Stop	2	4	6	7	8	9	12	14	15	17	19
	Boarding	0.500	2.125	1.250	0.750	1.500	0.125	1.000	1.625	0.375	0.125	0.000
	Alighting	0.000	0.000	1.000	0.875	1.500	0.625	0.500	1.750	1.250	0.875	1.000

Average boarding and alighting rate at each stop (pass/min)

Example 1 : Analysis and Results (a)

Simulation results of different control strategies for route Ⅰ

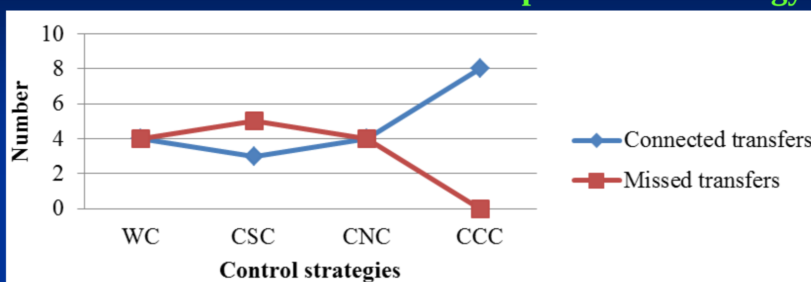
Performace measures	Control strategies			
	WC	CSC	CNC	CCC
Average transfer waiting time (s)	231	273	192	39
Number of connected transfers	2	2	2	4
Number of missed transfers	2	2	2	0
Average vehicle travel time (s)	2939	2939	2835	2855
Average vehicle travel speeed (km/h)	14.09	14.09	14.60	14.50
Average schedule deviation (s)	100	72	25	34
Average standard deviation of headways	112.02	94.99	41.14	40.49
Vehicle bunching percentage	12.28%	12.28%	0.00%	0.00%

Simulation results of different control strategies for route Ⅱ

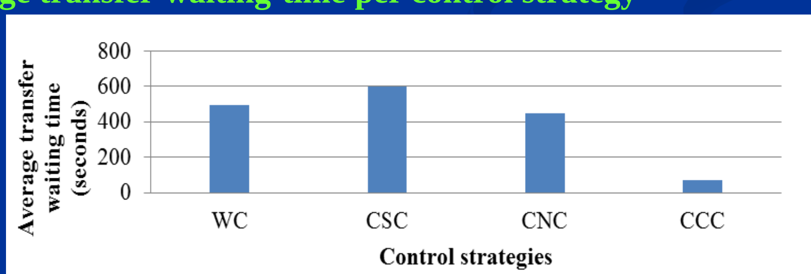
Performace measures	Control strategies			
	WC	CSC	CNC	CCC
Average transfer waiting time (s)	261	328	258	29
Number of connected transfers	2	1	2	4
Number of missed transfers	2	3	2	0
Average vehicle travel time (s)	3779	3922	3832	3841
Average vehicle travel speeed (km/h)	15.01	14.46	14.80	14.76
Average schedule deviation (s)	123	82	28	34
Average standard deviation of headways	133.34	88.66	46.83	41.73
Vehicle bunching percentage	9.52%	0.00%	0.00%	0.00%

Example 1 : Analysis and Results (b)

Number of connected and missed transfers per control strategy



Average transfer-waiting-time per control strategy



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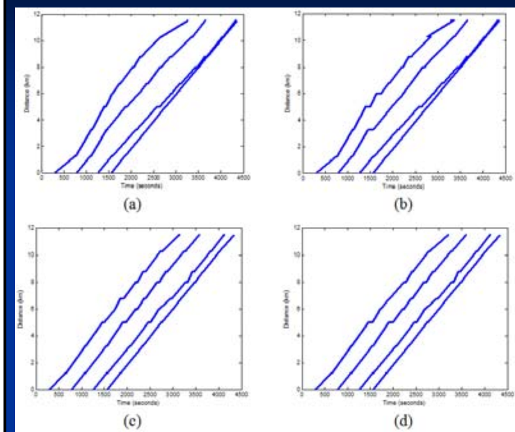
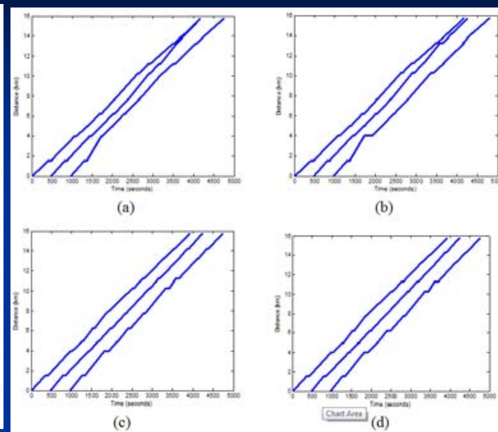
Example 1 : Analysis and Results (c)



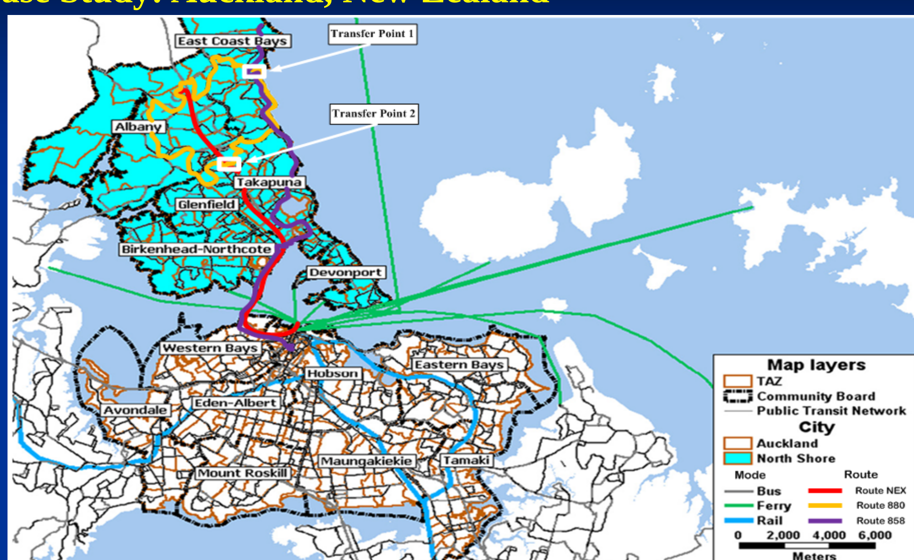


Route I's Vehicle trajectories under different control strategies: (a) WC; (b) CSC; (c) CNC; (d) CCC

Route II's Vehicle trajectories under different control strategies: (a) WC; (b) CSC; (c) CNC; (d) CCC

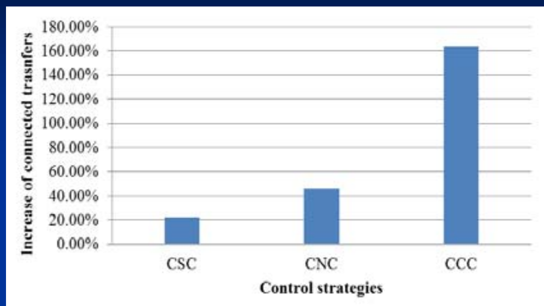
Example 2

Case Study: Auckland, New Zealand



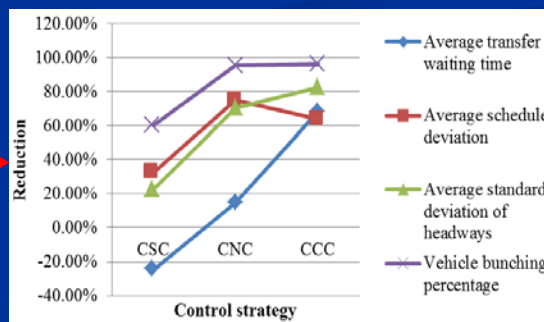
PT study routes of Auckland city and North Shore

Example 2: Case Study Results



Optimization results on connected transfers compared with no control (WC) strategy

More results of the simulation-based optimization compared with no control (WC) strategy



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Conclusions

The main findings of the study are:

- 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.
- The communication-based cooperative control strategy (CCC) attains the best performance-based results in comparison with the other three control strategies.
- The behaviour of drivers, related to schedule recovery, plays an important role in improving schedule adherence and the actual occurrence of planned coordinated transfers.

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The only way to eat and enjoy a Baguette Sandwich (to arrive on time) is lengthwise (make control actions consecutively), and not across (planning all the control actions concurrently), even if you're hungry (in a rush).

End of the Presentation

Thank you !

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