MONASH University

Information Technology

Cheap Solutions to the Transport Problem

Mark Wallace
June 2013

We could use the transport network we have, to make journeys quicker for everyone!

The AMSI Workshop on Mathematics of Transportation Networks

Rush Hour

Morning rush hour traffic

Early morning rush hour traffic

The term “rush hour” is out-of-date: morning traffic congestion in Melbourne lasts from 6:30 until 9:30am

The Age April 2012

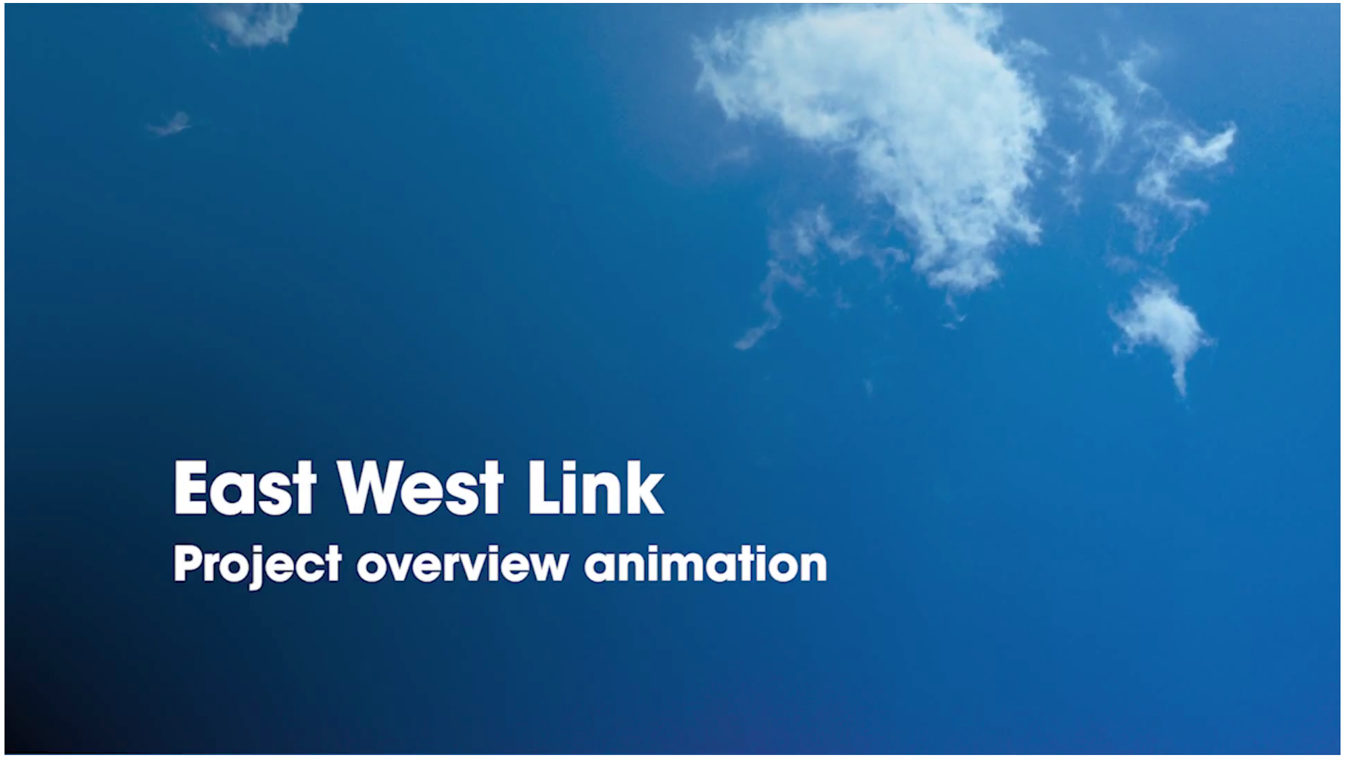
They say it's getting worse!

Road Name	Predicted Volume 2031
Western Ring R	150,700
Princes Hwy We	194,300
Geelong Road	80,200
Calder Freeway	128,100
West Gate Free	235,000
Monash Freewa	213,500

Estimates suggest that the cost of congestion to Victoria will rise from $3 billion to $6 billion by 2020.

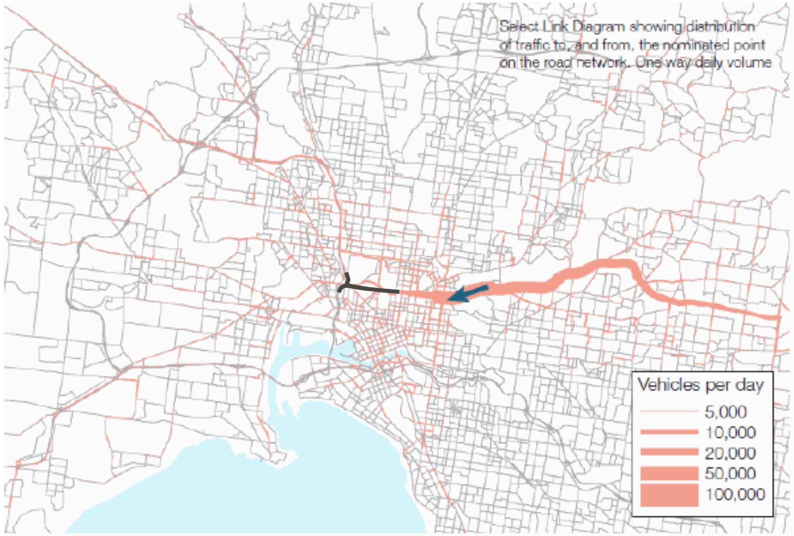
One Way to Relieve Congestion

The Planned Solution

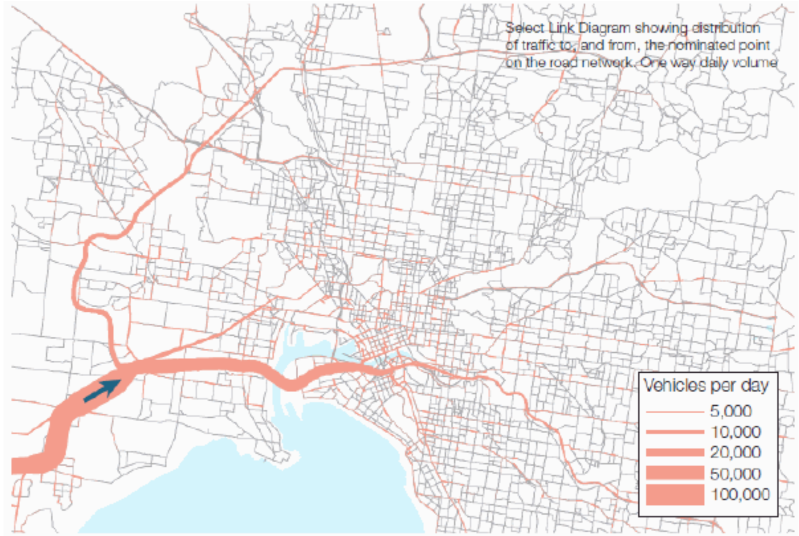


The Victorian Government has committed to funding the first stage of the 18 kilometre road, which has an estimated capital cost of between **$6 billion** and $8 billion.

…but which problem?



Traffic flowing in from the Eastern Freeway



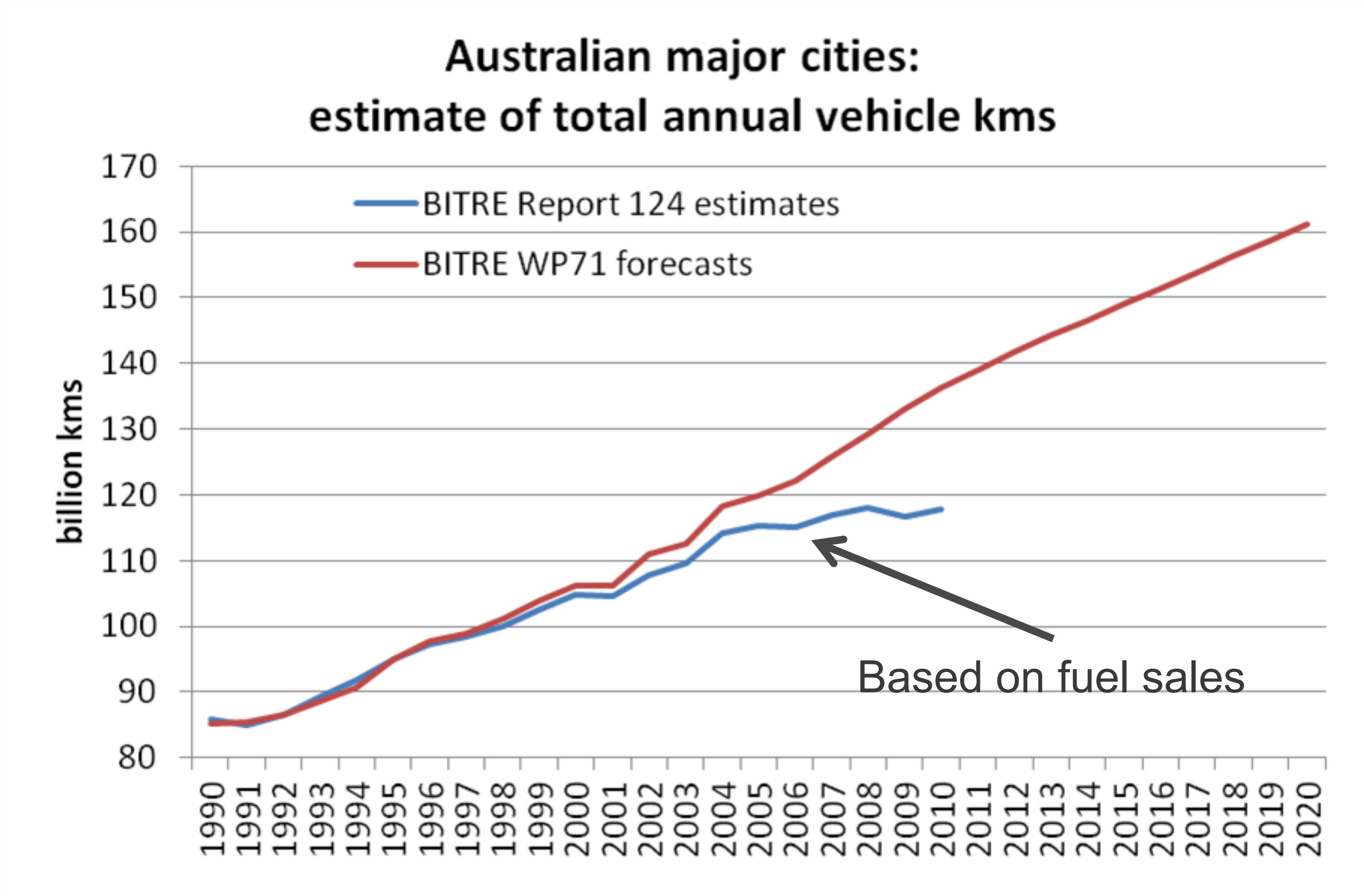
Traffic flowing in from the Princes Freeway

"There's more votes in moving voters' cars than moving trucks,"

A new road will not solve the congestion problem

Transport Demand based on BITRE Data

[Bureau of Infrastructure, Transport and Regional Economics (*BITRE*)]



Transport Demand based on BITRE Data

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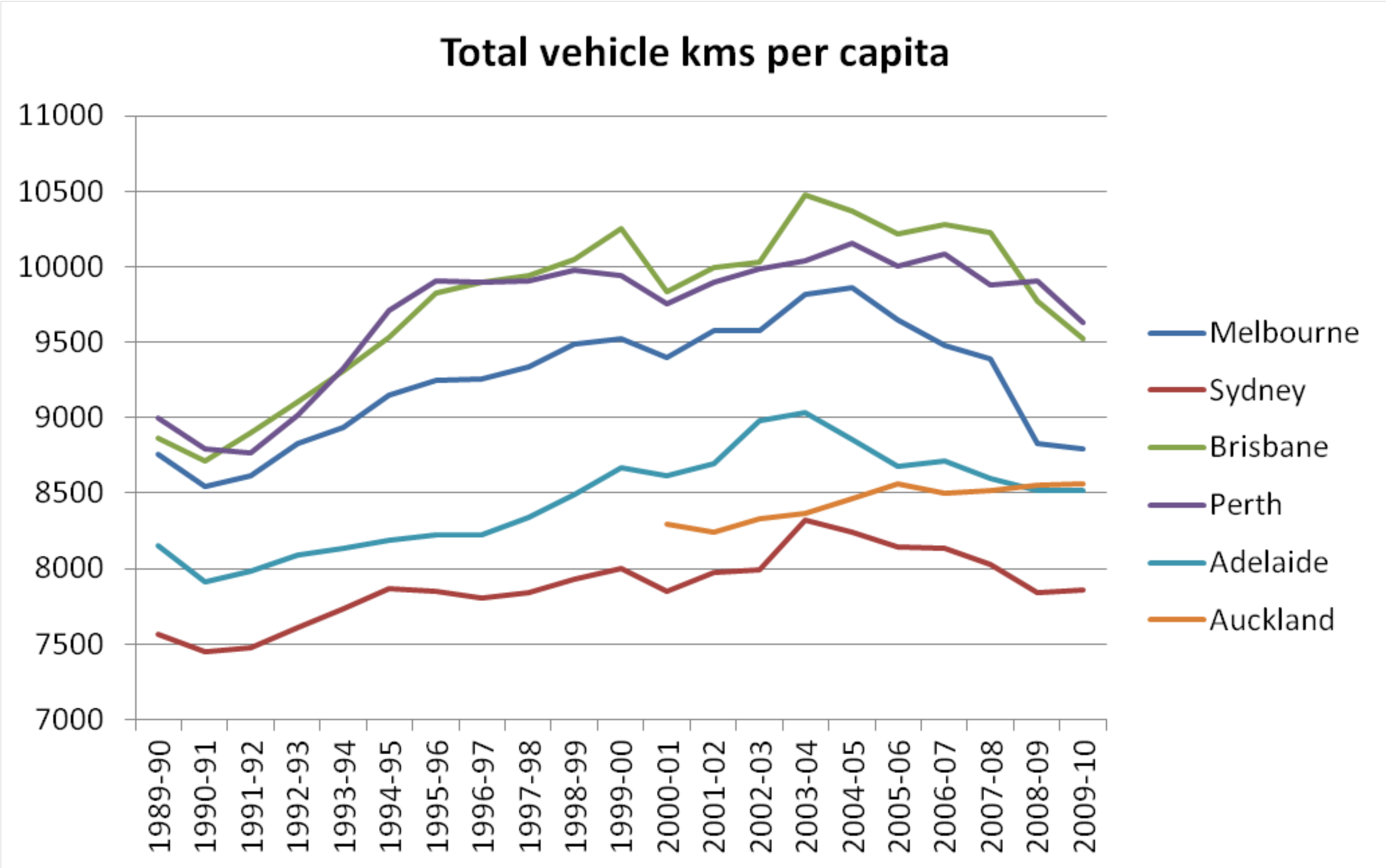
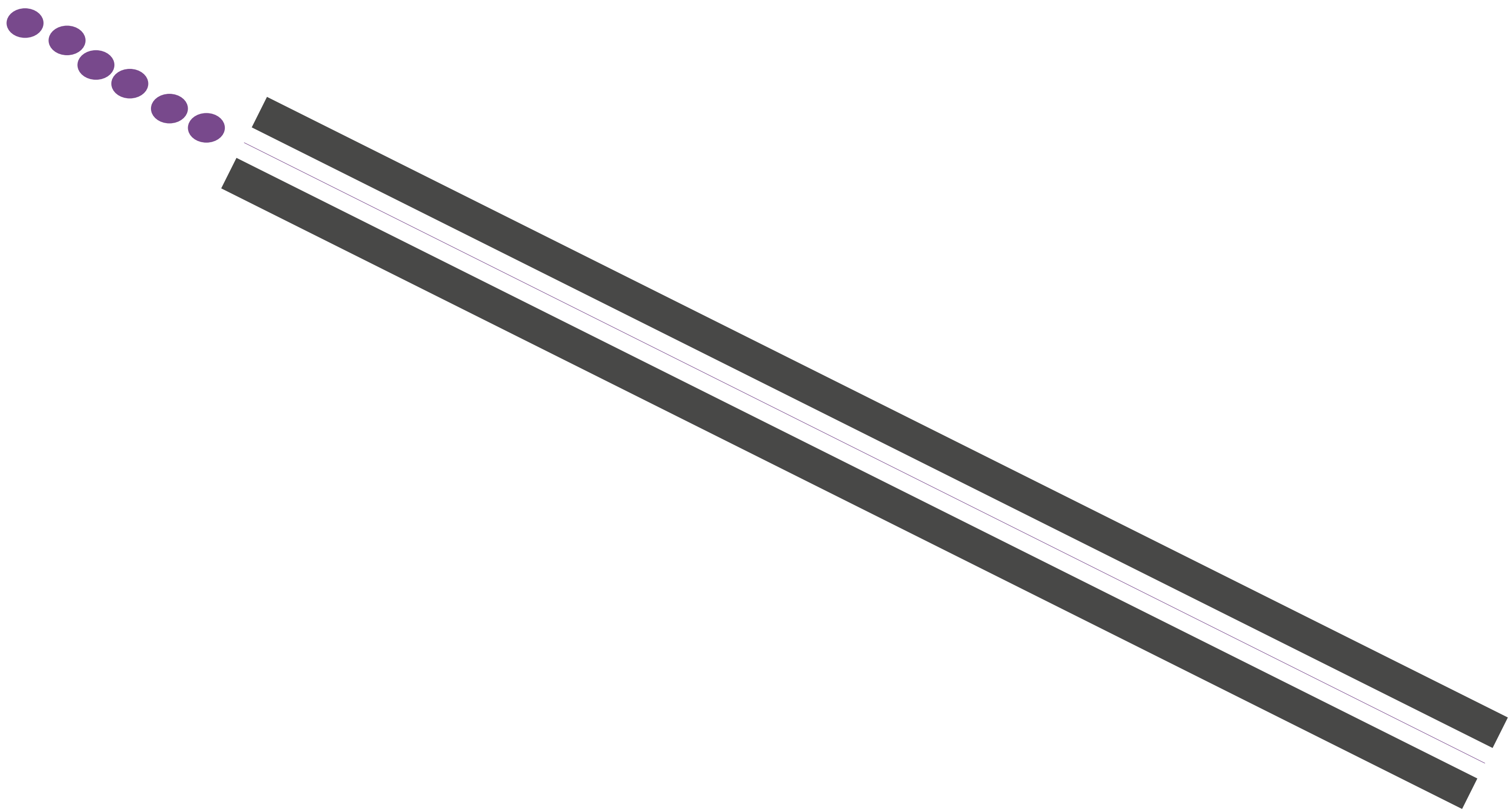


The impact of new roads

- A new road can increase traffic

The impact of new roads

- A new road can increase traffic



The impact of new roads

- A new road can increase traffic
- A new road can shift the congestion from one place to another

The impact of new roads

- A new road can increase traffic
- A new road can shift the congestion from one place to another
- It is even possible that *without any increase in traffic*

  a new road can make every single journey slower!

Different Types of Roads

Most roads take longer when there is more traffic

Example:

Cars per hour	60	600	1200
Travel time	10	15	30

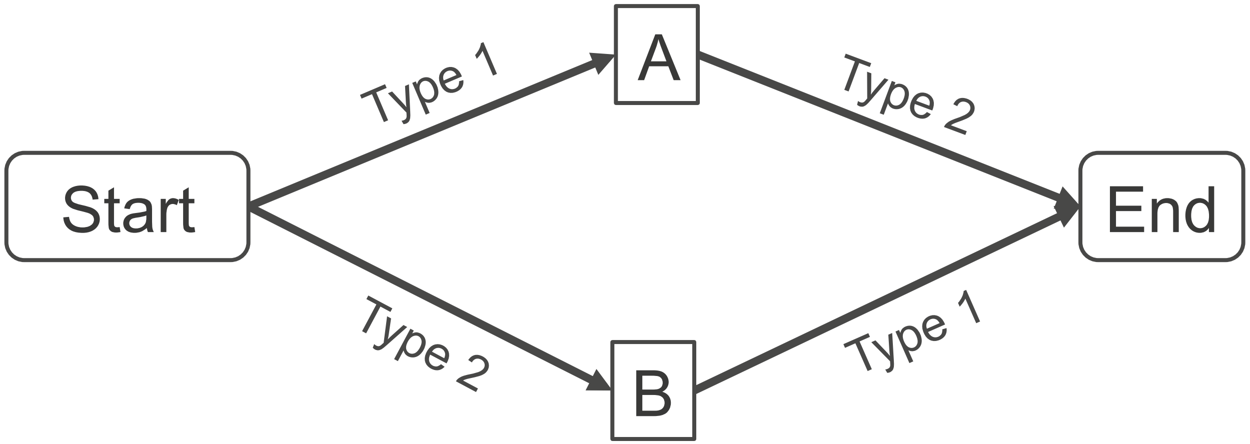
Some roads are wide (or narrow) enough that the amount of traffic doesn't make much difference

Example:

Cars per hour	60	600	1200
Travel time	10	10	10

Braess' Paradox - How adding a road can make every journey slower

Imagine this road network:



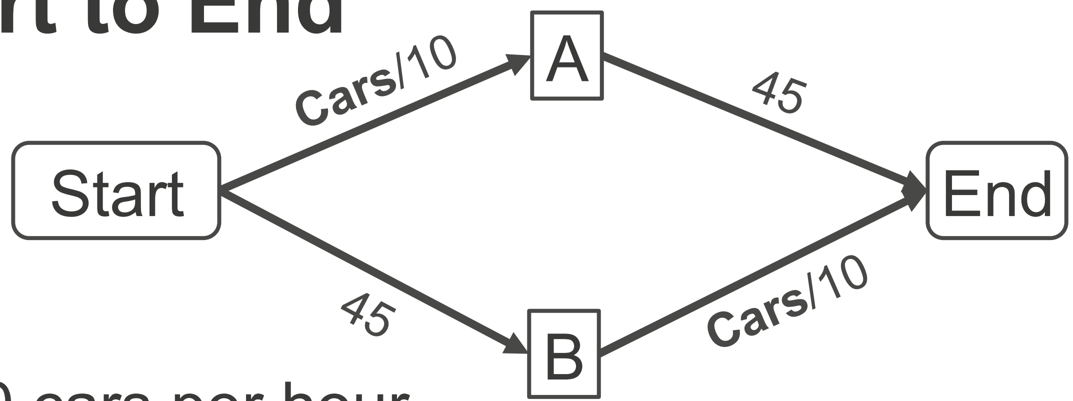
Type 1

Cars per hour	200	400	***Cars***
Travel time	20	40	***Cars*** /10

Type 2

Cars per hour	200	400	***Cars***
Travel time	45	45	45

How long does it take to get from Start to End



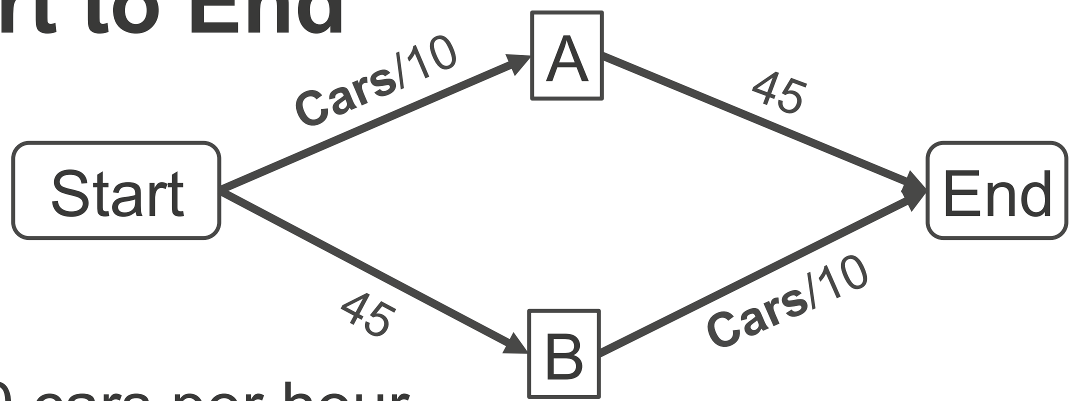
Assume there are 400 cars per hour.

The journey time depends on how many drivers choose Start → A → End and how many choose Start → B → End

Scenario 1	Cars
Start → A → End	400
Start → B → End	0

Scenario 1	Cars	Time
Start → A	400	40
A → End	(400)	45

How long does it take to get from Start to End



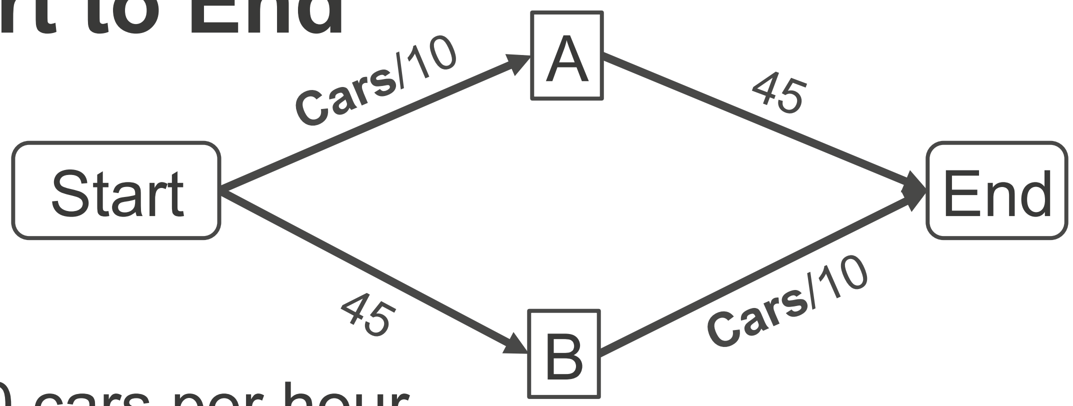
Assume there are 400 cars per hour.

The journey time depends on how many drivers choose Start → A → End and how many choose Start → B → End

Scenario 1	Cars	Time
Start → A → End	400	85
Start → B → End	0	(45)

Scenario 1	Cars	Time
Start → A	400	40
A → End	(400)	45

How long does it take to get from Start to End

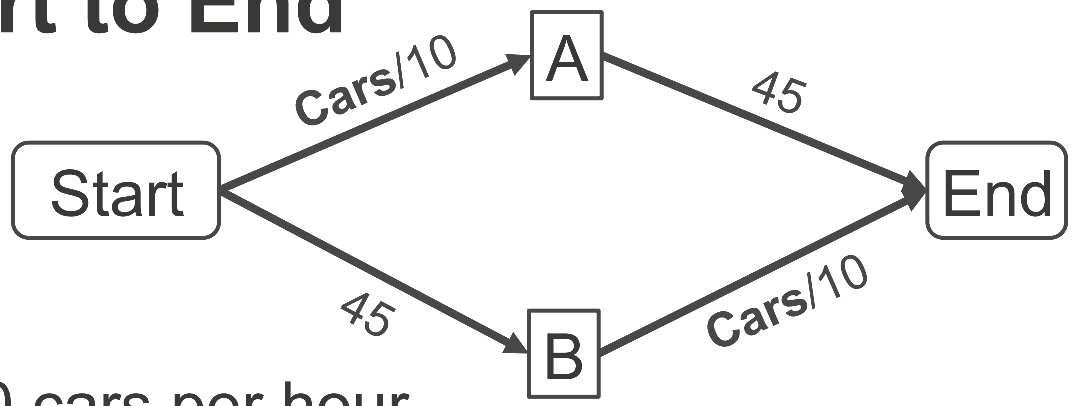


Assume there are 400 cars per hour.

Scenario 2	Cars
Start → A → End	200
Start → B → End	200

Scenario 2	Cars	Time
Start → A	200	20
A → End	(200)	45
Start → B	(200)	45
B → End	200	20

How long does it take to get from Start to End

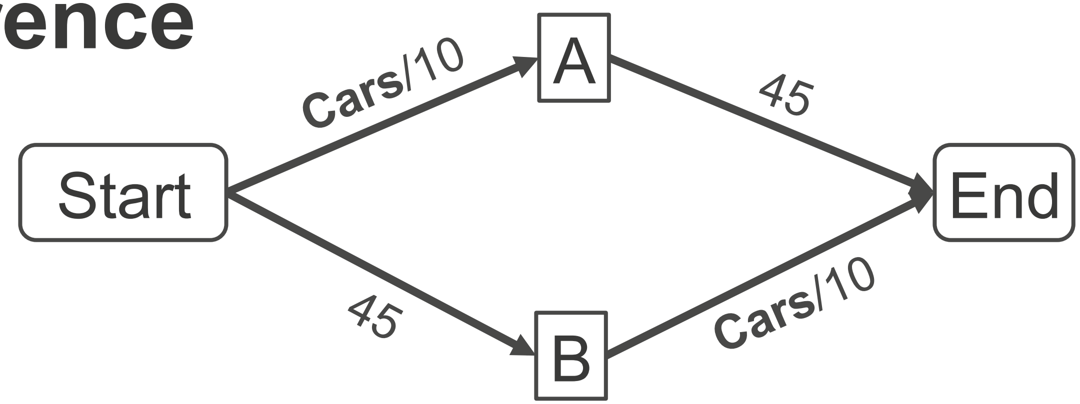


Assume there are 400 cars per hour.

Scenario 2	Cars	Time
Start → A → End	200	65
Start → B → End	200	65

Scenario 2	Cars	Time
Start → A	200	20
A → End	(200)	45
Start → B	(200)	45
B → End	200	20

Driver Preference



Scenario1

Drivers can save time by switching:

	Route	Cars	Time
1	Start → A → End	400	85
2	Start → B → End	0	(45)
	Change from route 1 to route 2	Time saved = 85 - 45 = **40**	

Scenario2

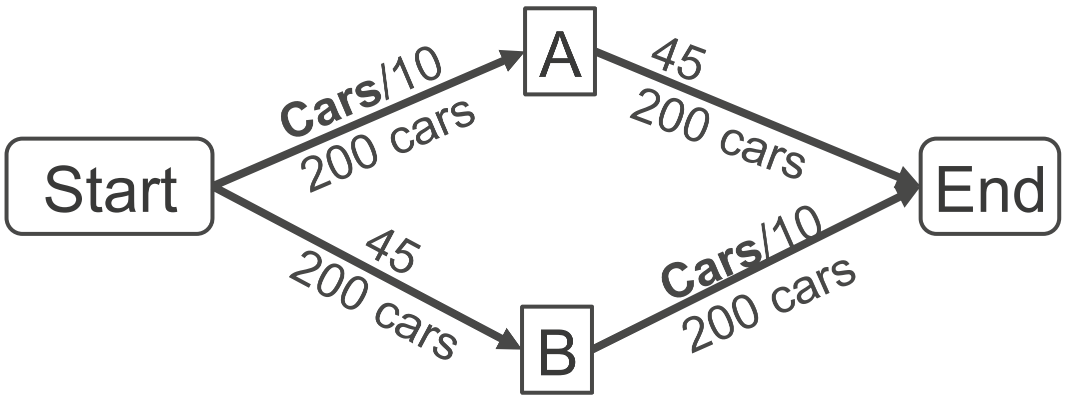
No drivers can save time by switching:

	Route	Cars	Time
1	Start → A → End	200	65
2	Start → B → End	200	65
	Change from route 1 to route 2	Time saved = 65 - 65 = **0**	

User Equilibrium

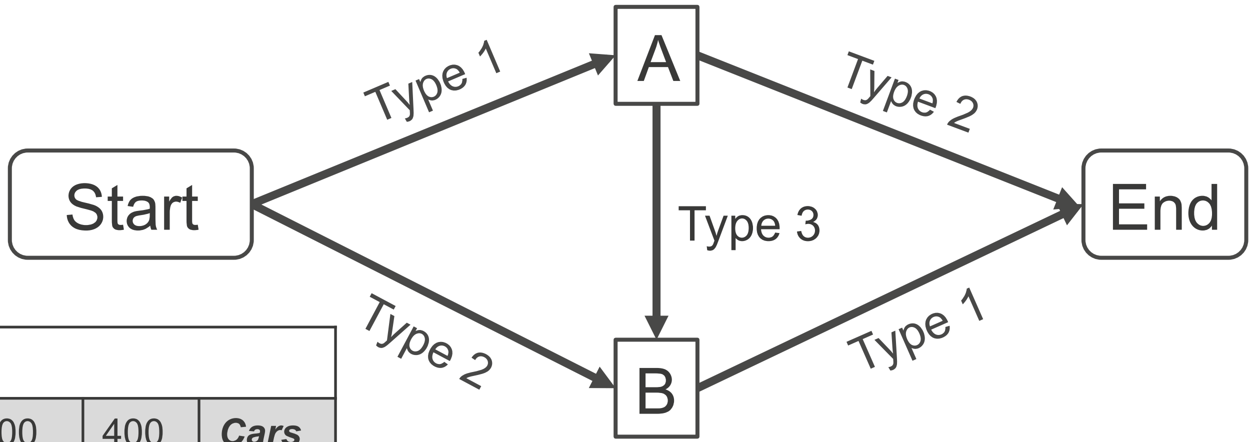
The long term traffic pattern is when all driver preferences are satisfied.

In this case, no car can reduce its journey time by switching to an alternative route



This holds in Scenario 2

The New Road

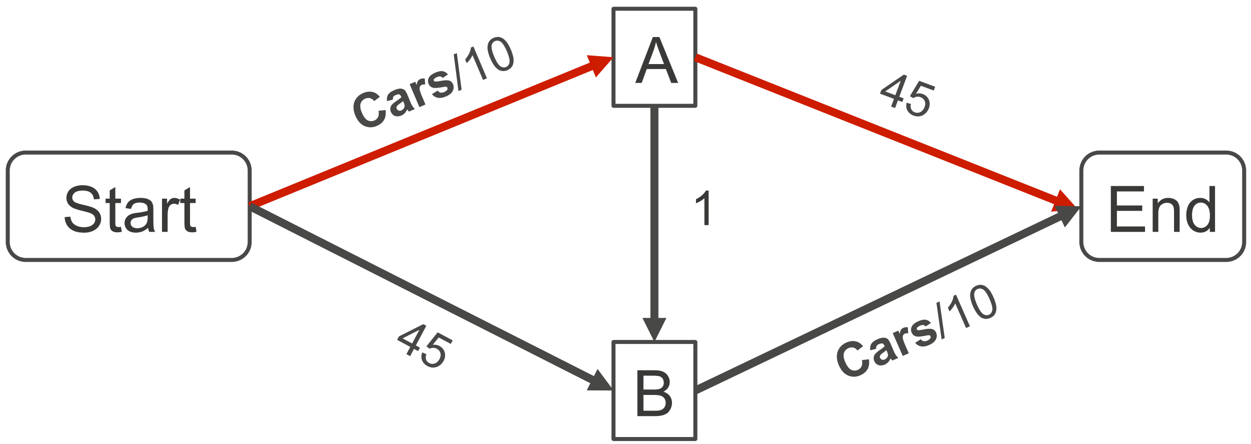


Type 1			
Cars per hour	200	400	***Cars***
Travel time	20	40	***Cars*** /10

Type 2			
Cars per hour	200	400	***Cars***
Travel time	45	45	45

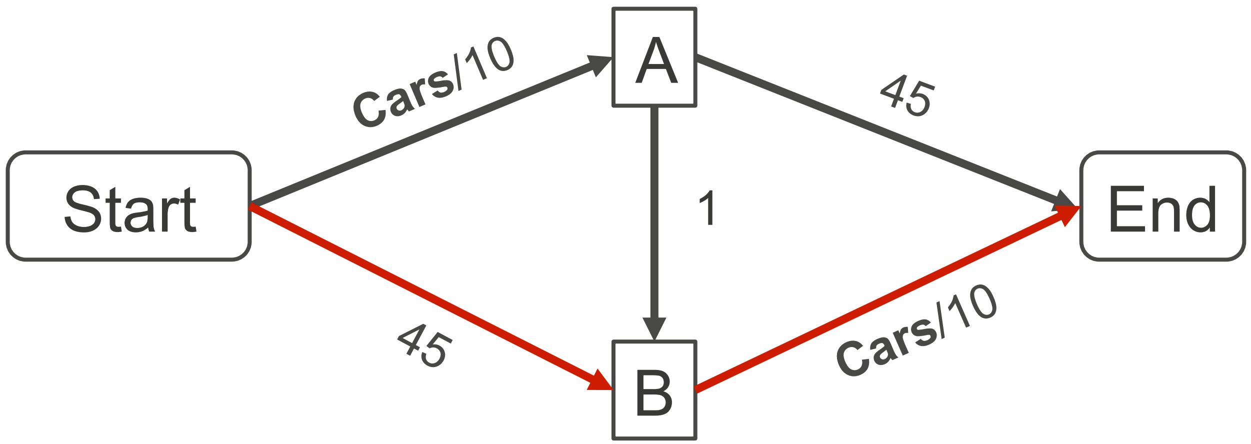
Type 3			
Cars per hour	200	400	***Cars***
Travel time	1	1	1

The New Road



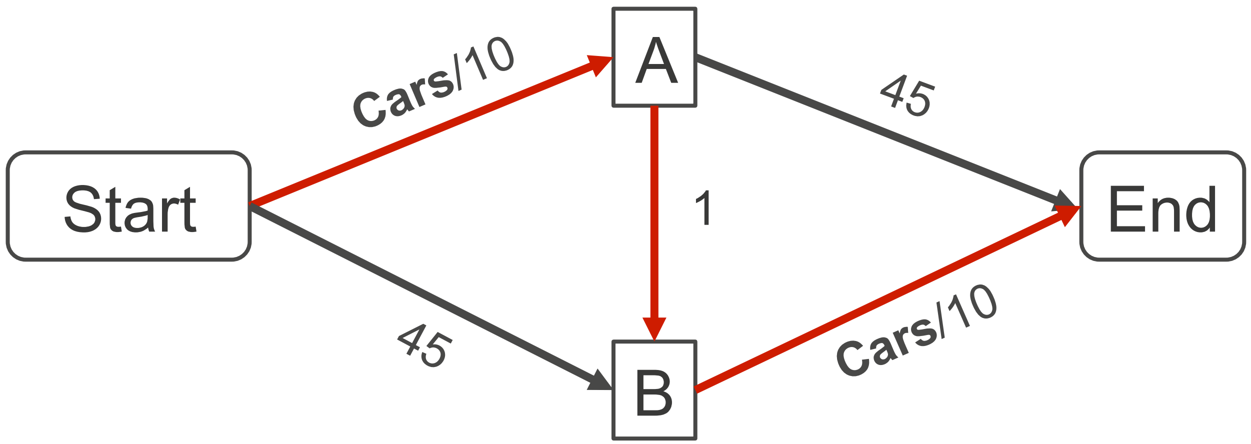
Route1

The New Road



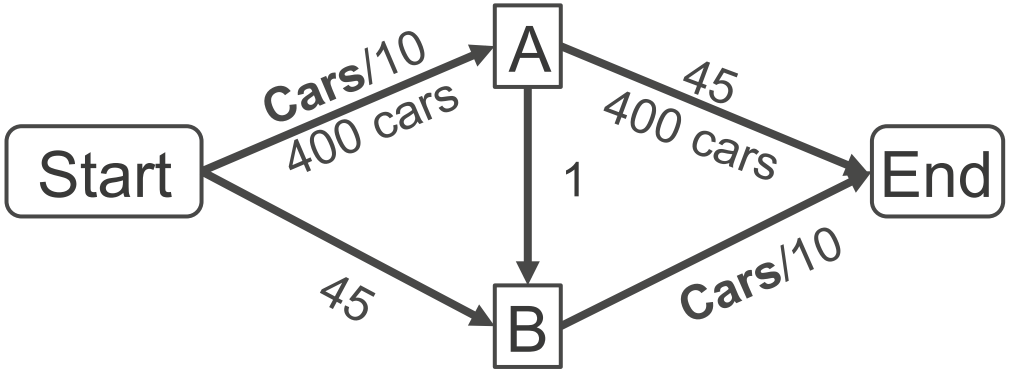
Route2

The New Road



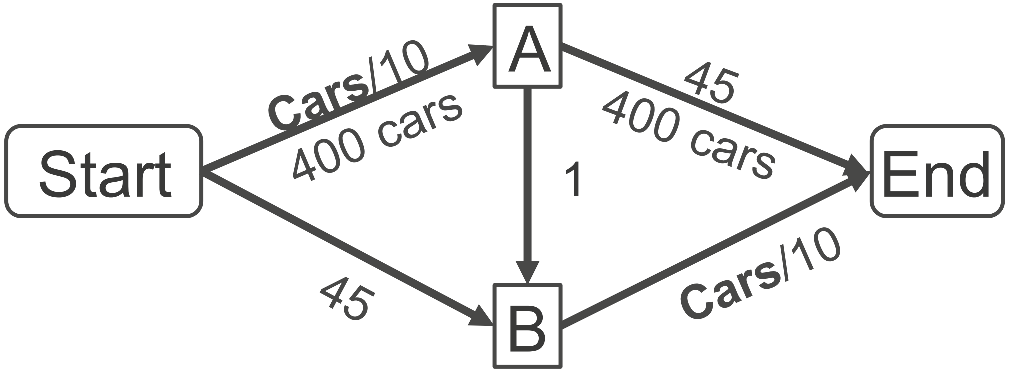
Route3

Journey Times in Scenario 1



	Cars	Road	Cost	Total
Route 1	400	S→A	40	85
		A→E	45	
Route 2	0	S→B	45	45
		B→E	0	
Route 3	0	S→A	40	41
		A→B	1	
		B→E	0	

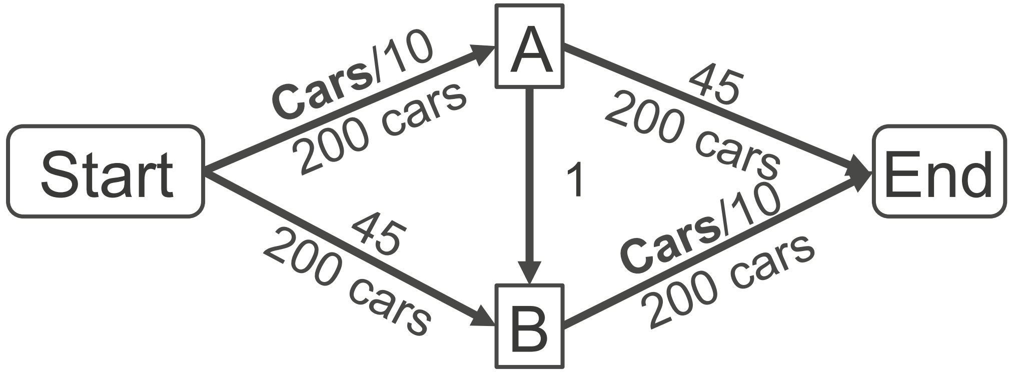
Journey Times in Scenario 1



	Cars	Road	Cost	Total	Switch	Saved	Choose
Route 1	400	S→A	40	85	R1→R2	40	Yes
		A→E	45		R1→R3	44	Yes
Route 2	0	S→B	45	45	R2→R1	-40	(No)
		B→E	0		R2→R3	4	(Yes)
Route 3	0	S→A	40	41	R3→R1	-44	(No)
		A→B	1		R3→R2	-4	(No)
		B→E	0				

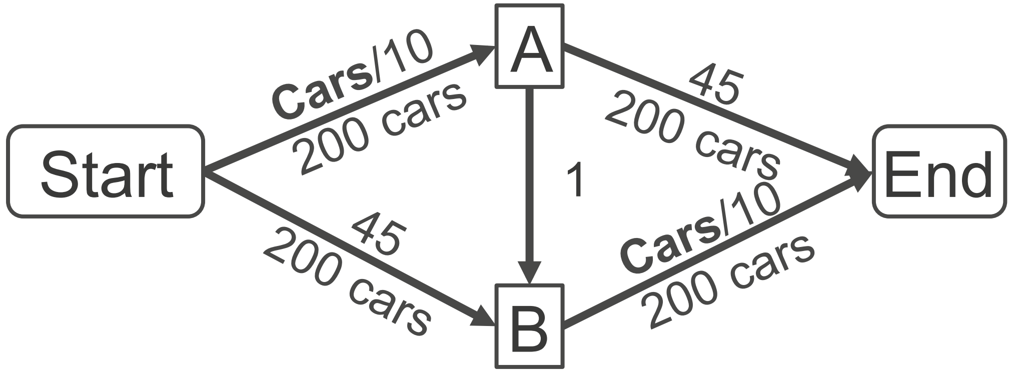
Not User Equilibrium

Journey Times in Scenario 2



	Cars	Road	Cost	Total
Route 1	200	S→A	20	65
		A→E	45	
Route 2	200	S→B	45	65
		B→E	20	
Route 3	0	S→A	20	41
		A→B	1	
		B→E	20	

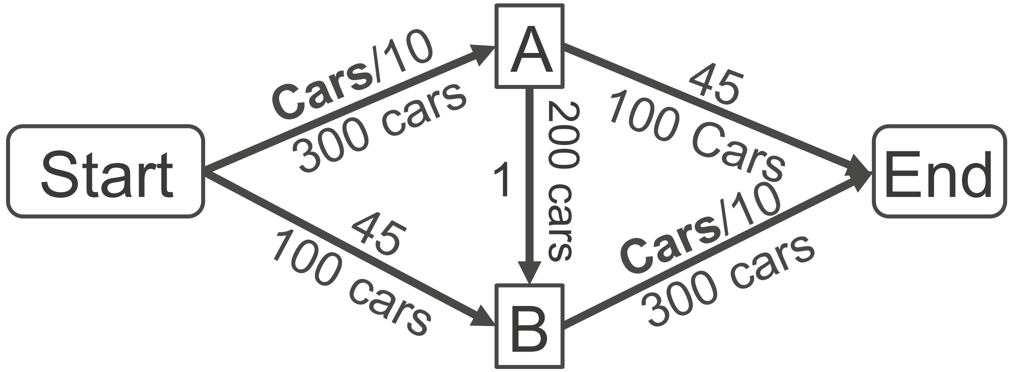
Journey Times in Scenario 2



	Cars	Road	Cost	Total	Switch	Saved	Choose
Route 1	200	S→A	20	65	R1→R2	**0**	**No**
		A→E	45		R1→R3	24	**Yes**
Route 2	200	S→B	45	65	R2→R1	**0**	**No**
		B→E	20		R2→R3	24	**Yes**
Route 3	0	S→A	20	41	R3→R1	**-24**	**(No)**
		A→B	1		R3→R2	**-24**	**(No)**
		B→E	20				

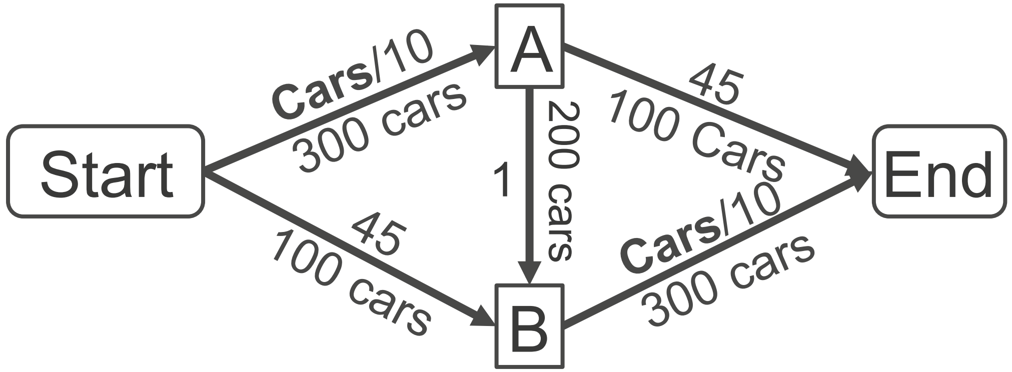
Not User Equilibrium

Journey Times in Scenario 3



	Cars	Road	Cost	Total
Route 1	100	S→A	30	75
		A→E	45	
Route 2	100	S→B	45	75
		B→E	30	
Route 3	200	S→A	30	61
		A→B	1	
		B→E	30	

Journey Times in Scenario 3



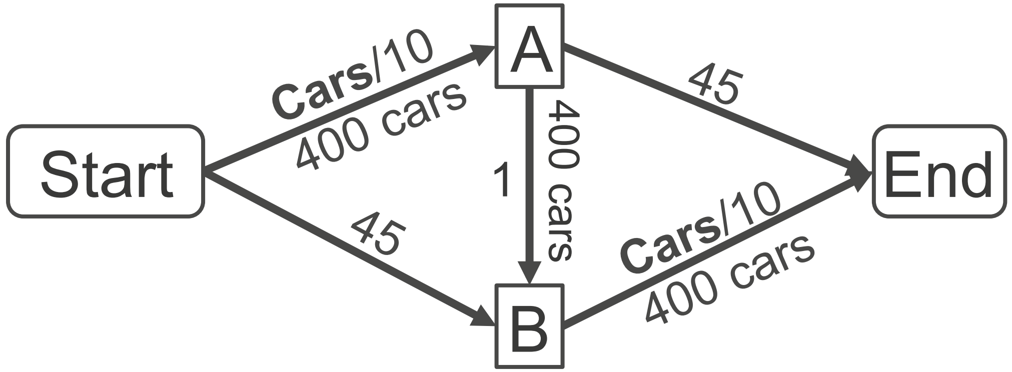
	Cars	Road	Cost	Total	Switch	Saved	Choose
Route 1	100	S→A	30	75	R1→R2	**0**	**(No)**
		A→E	45		R1→R3	14	**(Yes)**
Route 2	100	S→B	45	75	R2→R1	**0**	**(No)**
		B→E	30		R2→R3	14	**(Yes)**
Route 3	200	S→A	30	61	R3→R1	**-4**	**No**
		A→B	1		R3→R2	**-4**	**No**
		B→E	30				

Not

User

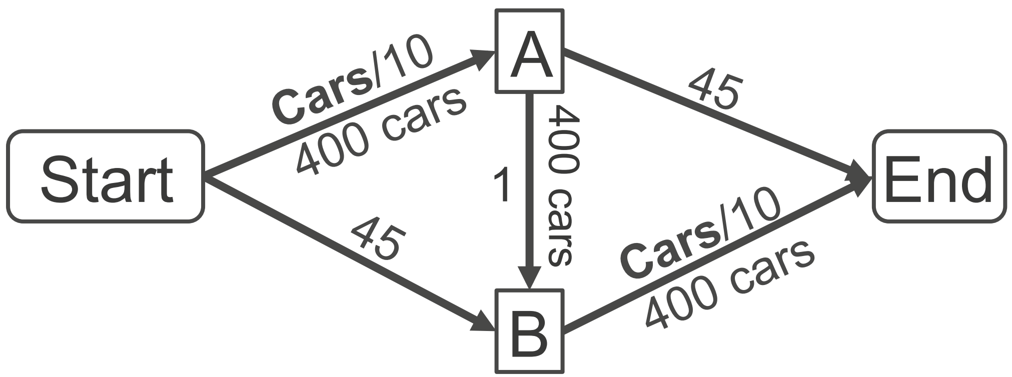
Equilibrium

Journey Times in Scenario 3



	Cars	Road	Cost	Total
Route 1	0	S→A	40	85
		A→E	45	
Route 2	0	S→B	45	85
		B→E	40	
Route 3	400	S→A	40	81
		A→B	1	
		B→E	40	

Journey Times in Scenario 3

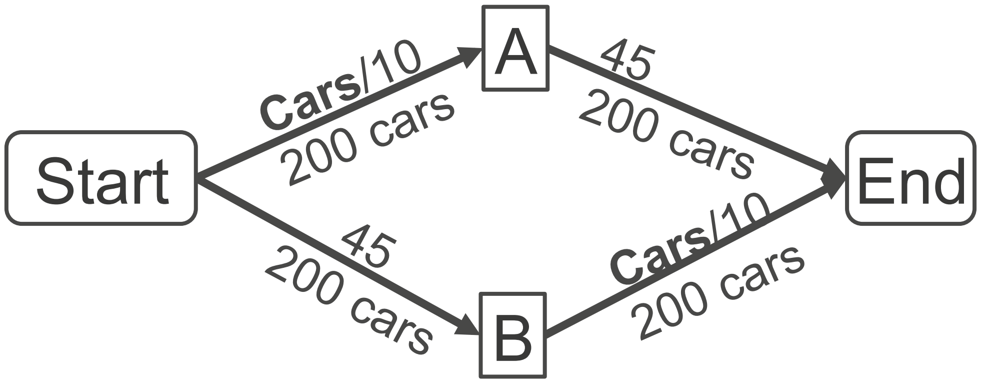


	Cars	Road	Cost	Total	Switch	Saved	Choose
Route 1	0	S→A	40	85	R1→R2	0	(No)
		A→E	45		R1→R3	4	(Yes)
Route 2	0	S→B	45	85	R2→R1	0	(No)
		B→E	40		R2→R3	4	(Yes)
Route 3	400	S→A	40	81	R3→R1	-4	No
		A→B	1		R3→R2	-4	No
		B→E	40				

User Equilibrium

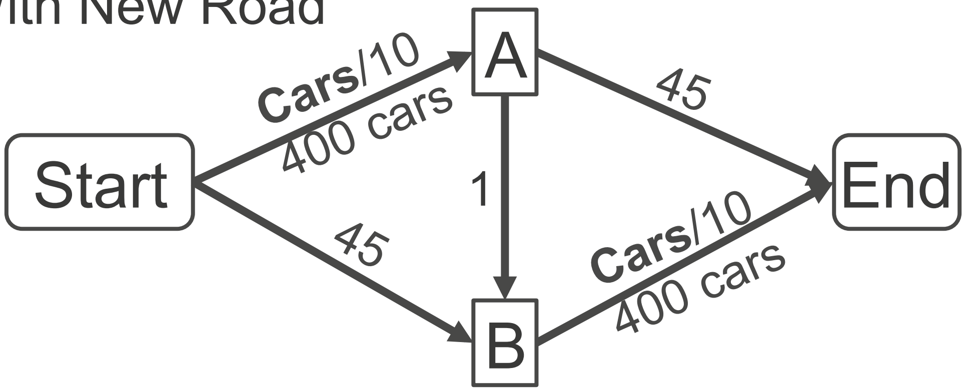
Braess' Paradox

- Without New Road



Long Term Traffic Pattern
User Equilibrium
Every journey has time **65**

- With New Road



Long Term Traffic Pattern
User Equilibrium
Every journey has time **81**

Lesson for non-mathematical decision makers

Adding new infrastructure doesn’t necessarily relieve congestion –

sometimes it can make things worse!

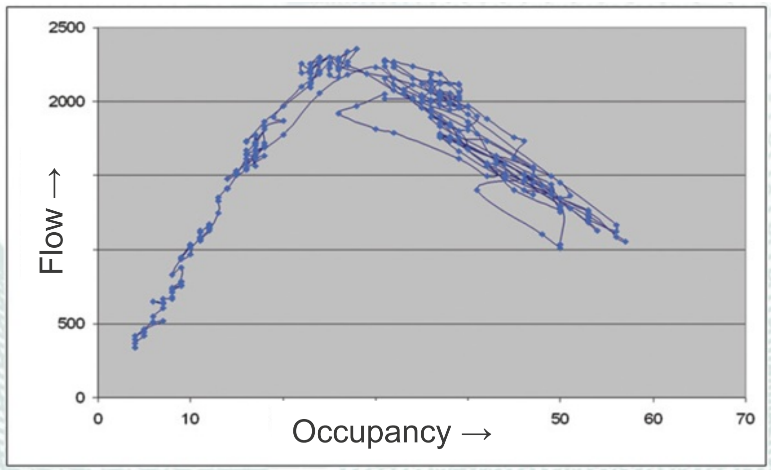
We could use the transport network we have, to make journeys quicker for everyone.

- Improved signals at traffic junctions
- Coordinated vehicle routing
- Improved public transport
- Communication
  - vehicle to vehicle
  - vehicle to roadside
- Integrated Freight Transport
- Automated vehicle control

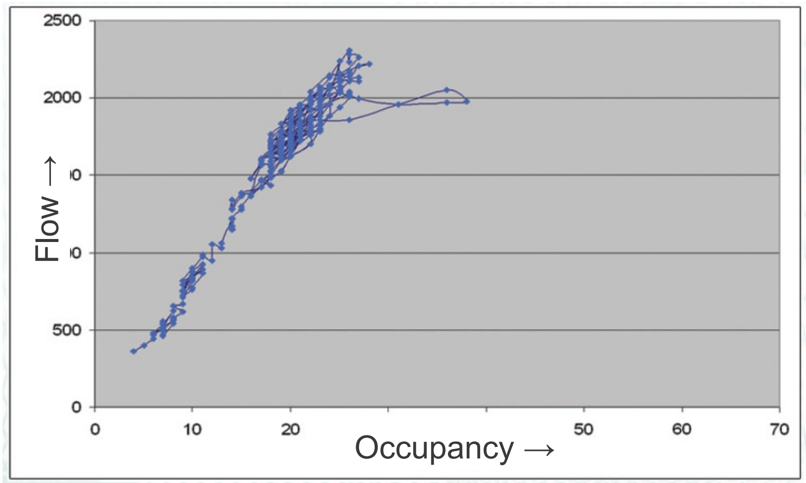
Improving Signals at Traffic Lights

Impact of Monash Ramp Signals

Impact of Monash Ramp Signals



Monash Freeway October 2007



Monash Freeway October 2008

Crashes reduced by 30%

Average travel speeds increased by 25.9% from 48.9 km to 66 km/h in peak hour traffic

Veh/hr/lane capacity increased from 1500 towards 2000

We could use the transport network we have, to make journeys quicker for everyone.

- Improved signals at traffic junctions
- **Coordinated vehicle routing**
- Improved public transport
- Communication
  - vehicle to vehicle
  - vehicle to roadside
- Integrated Freight Transport
- Automated vehicle control

Coordinated Vehicle Routing

Coordinated Vehicle Routing

- Notify the coordinated navigation system when you start a journey
- The system knows where it has sent others cars and sends yours a different route
- Claimed results show that, on average, cars taking Greenway routes make it to their destination twice as fast and use up to 20 percent less fuel.
- About 10% of drivers in a city would need to have it running for it to work optimally.

We could use the transport network we have, to make journeys quicker for everyone.

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- **Improved public transport**
- Communication
  - vehicle to vehicle
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- Integrated Freight Transport

Improved Public Transport

- **Two big reasons for public transport**
  - Reduce congestion
  - Reduce pollution

- **Curitiba, Brazil**

  - The Bus Rapid Transport System plays a large part in making this a livable city.
  - The buses run frequently—some every 90 seconds—and reliably
  - the stations are convenient, comfortable, and attractive.
  - Consequently, Curitiba has one of the most heavily used, yet low-cost, transit systems in the world.

Improved Public Transport

The problem

The Pollution Cost of Congestion

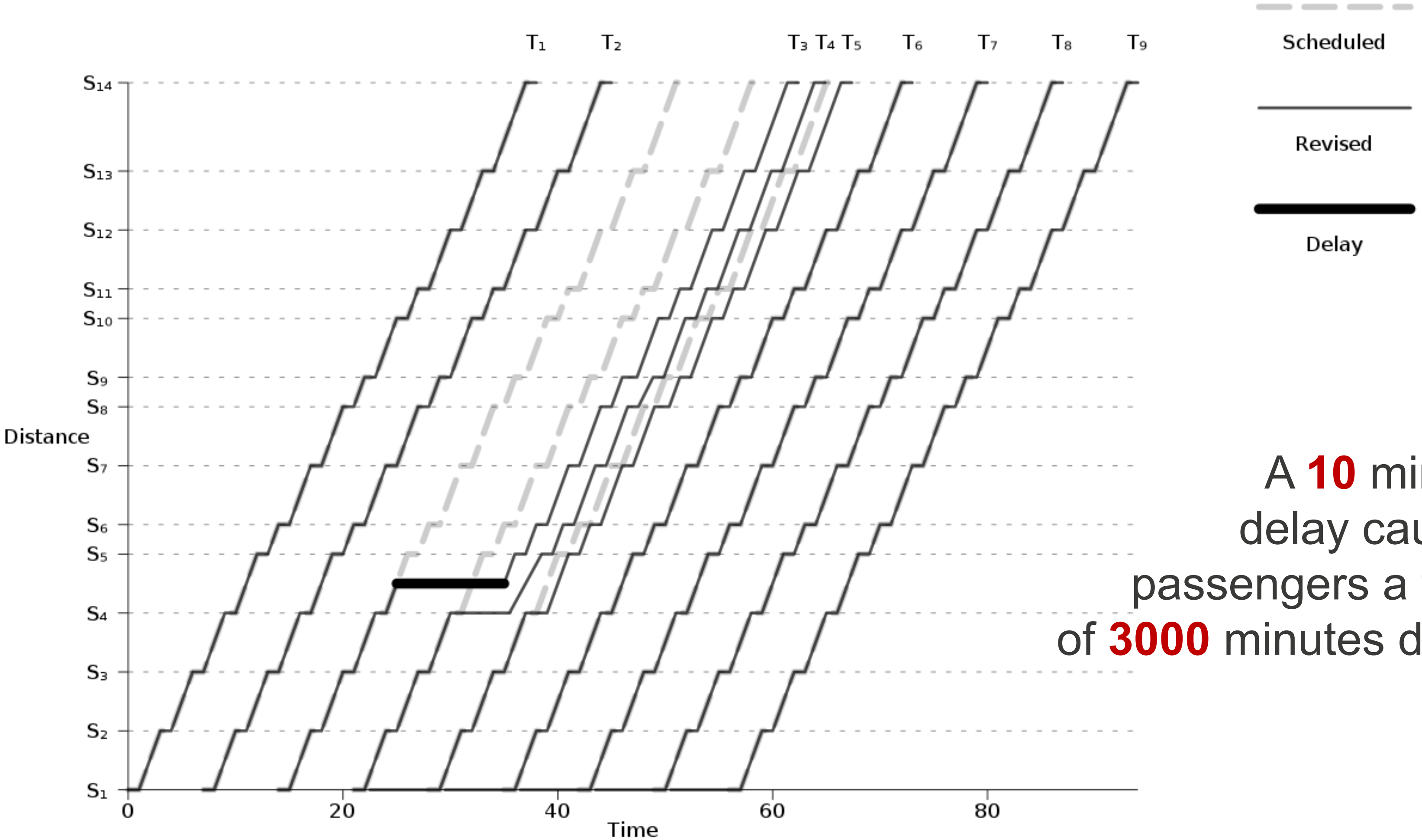
Improved Public Transport Estimates for Melbourne from BZE

- BZE has outlined a coherent bus network covering Melbourne
- Buses come every **10 minutes** at every stop
- This would only need a **doubling** of the current bus fleet
- If public transport increased from 10% to 20% of trips in Melbourne
- This would save **200,000,000** litres of fuel per year
- This translates to **500,000 tons of CO2** per year

Improved Public Transport

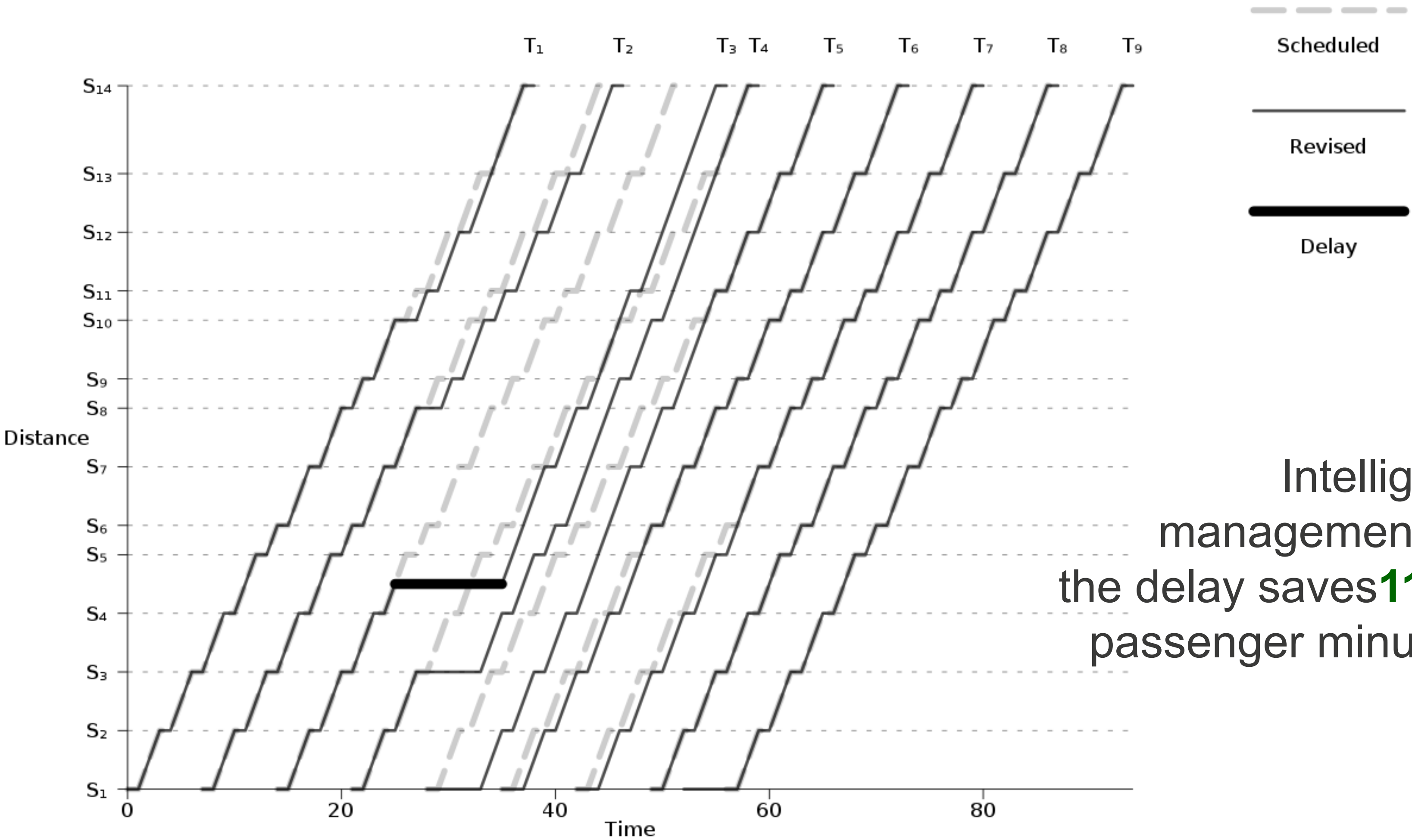
- If all users specified when and where they wanted to go
  - trains and buses could be delayed when passengers need a connection
  - when a connection is missed, bus and train schedules could be adapted to minimise passenger disruption
  - each passenger would be advised of their new route

Minimising Passenger Disruption on the Sandringham Line



A **10** minute delay causes passengers a total of **3000** minutes delay

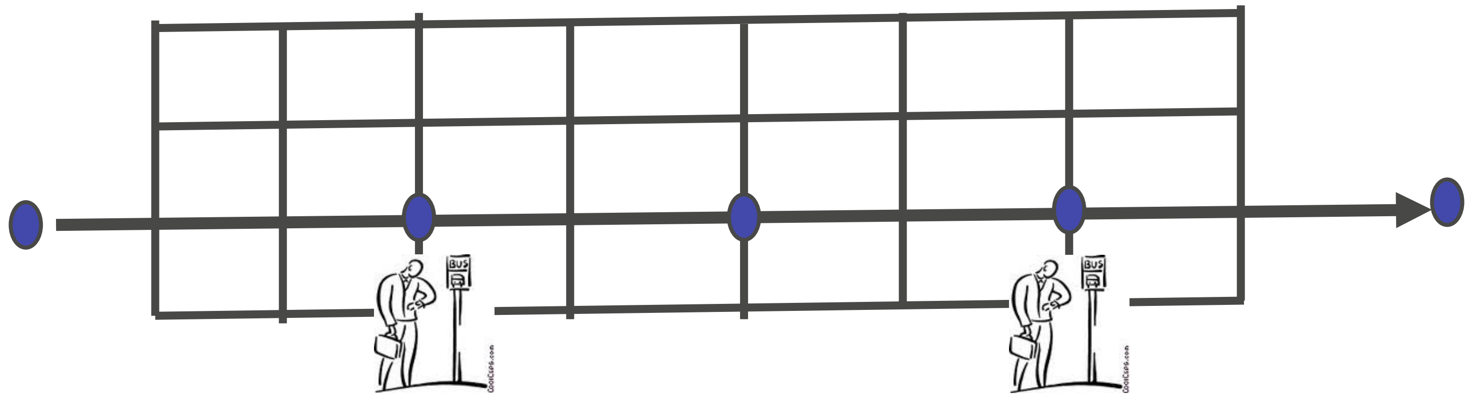
Minimising Passenger Disruption on the Sandringham Line



Intelligent management of the delay saves **1100** passenger minutes

Improved Public Transport

- If all users specified when and where they wanted to go
  - currently - bus request stops
  - instead some bus routes could require passengers to communicate their request



Improved Public Transport

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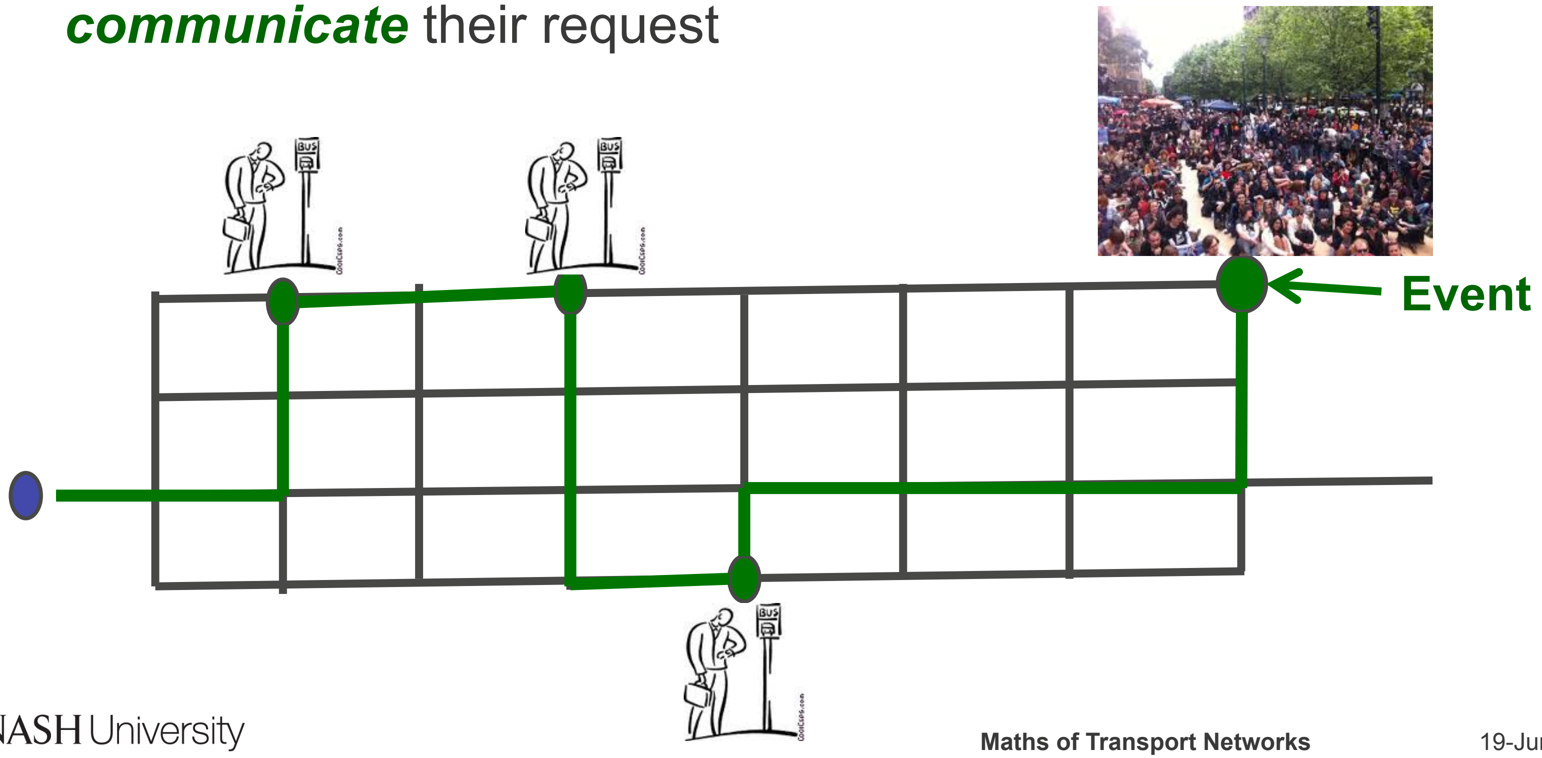
  - instead some bus routes could require passengers to ***communicate*** their request



We could use the transport network we have, to make journeys quicker for everyone.

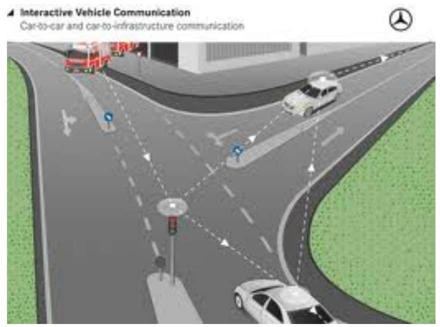
- Improved signals at traffic junctions
- Coordinated vehicle routing
- Improved public transport
- **Communication**
  - **vehicle to vehicle**
  - **vehicle to roadside**
- Automated vehicle control
- Integrated Freight Transport

Vehicle Communication

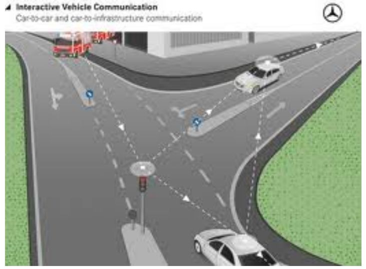
- **Vehicle Communication Supports Safety**
  - “Vehicles that don’t crash” (University of Michigan)
  - Address approximately 80% of the crash scenarios

- **Vehicle to Vehicle Warnings**
  - merging trucks,
  - cars in the driver’s blind side,
  - a vehicle ahead brakes suddenly.

- **Vehicle to Roadside**
  - entering school zone
  - workers are on the side of the road
  - upcoming traffic light is about to change.



Vehicle Communication



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- Improved signals at traffic junctions
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- Improved public transport
- Communication
  - vehicle to vehicle
  - vehicle to roadside
- **Automated vehicle control**
- Integrated Freight Transport

Automated Vehicle Control

- Platooning

Automated Vehicle Control

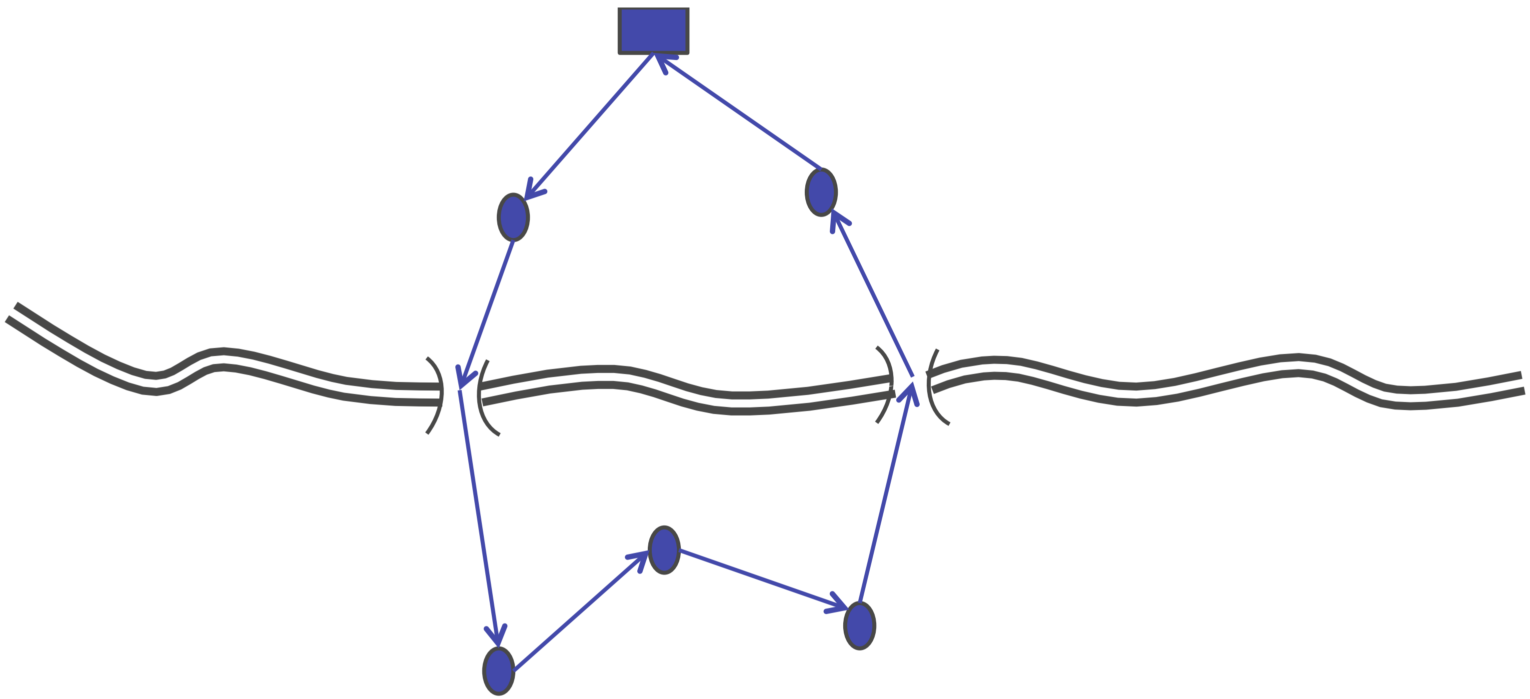
- Individual

We could use the transport network we have, to make journeys quicker for everyone.

- Improved signals at traffic junctions
- Coordinated vehicle routing
- Improved public transport
- Communication
  - vehicle to vehicle
  - vehicle to roadside
- Automated vehicle control
- **Integrated Freight Transport**

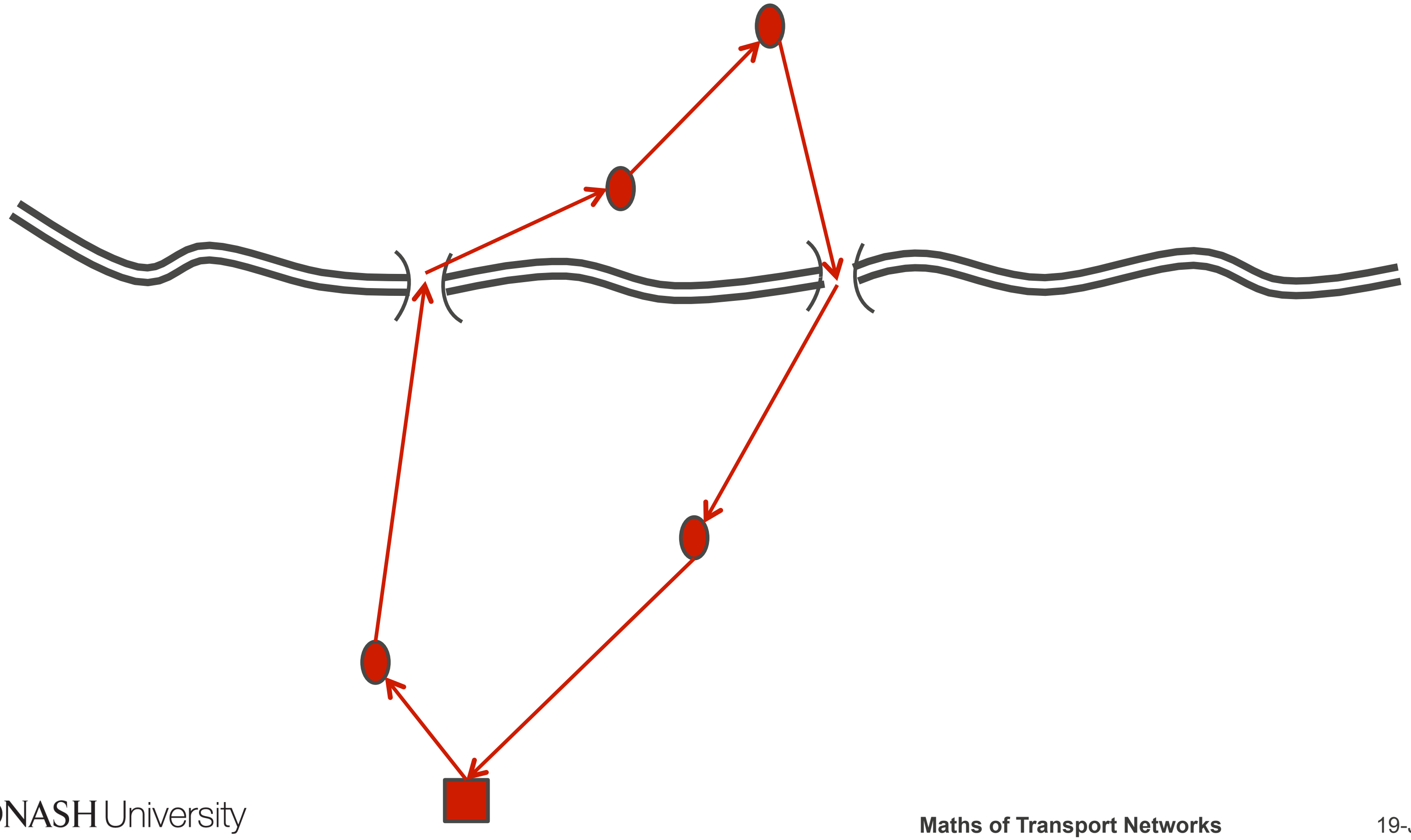
Integrated Freight Transport

Travelling Salesman Solution



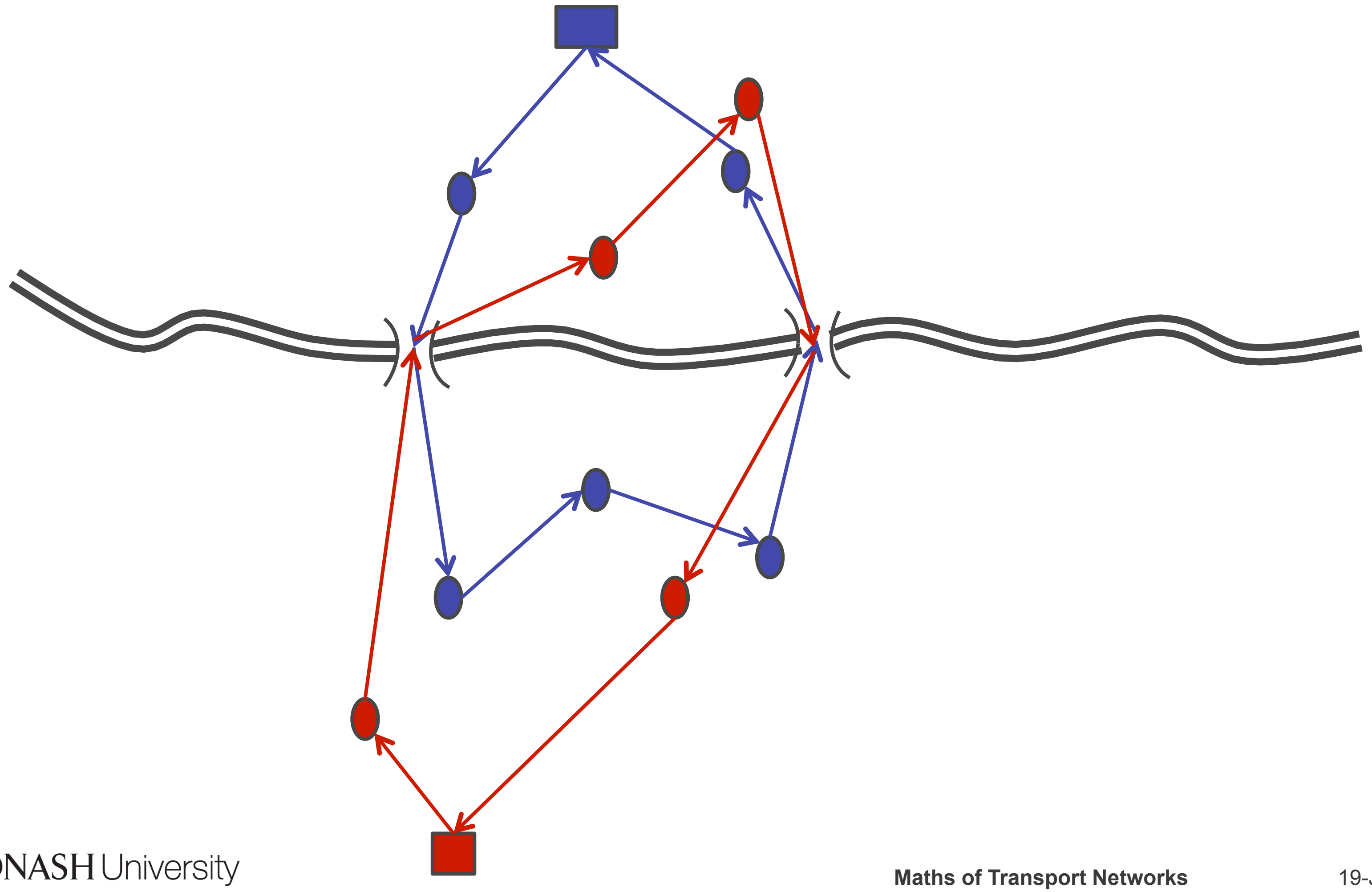
Integrated Freight Transport

Another Travelling Salesman Solution



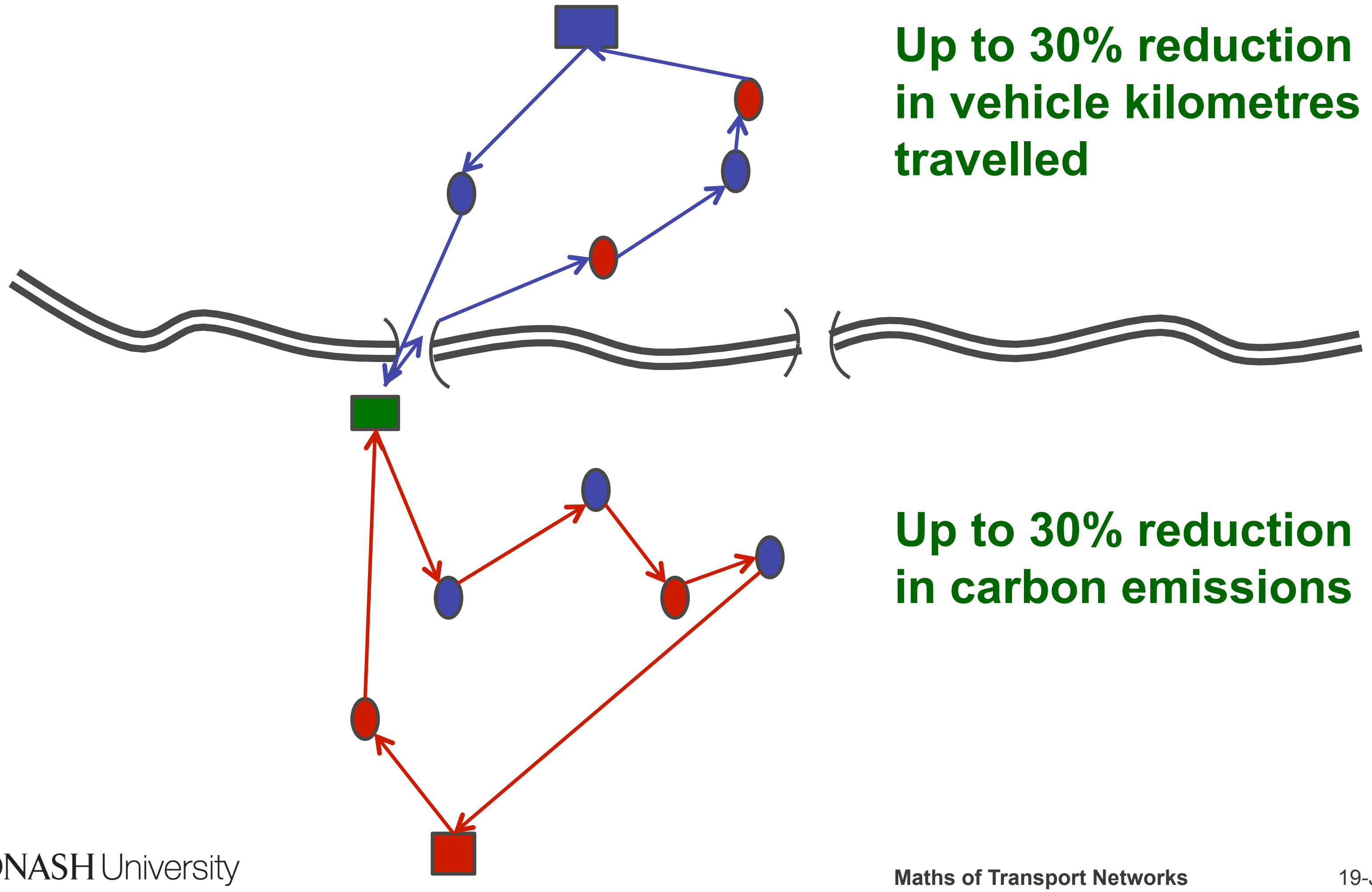
Integrated Freight Transport

Two Travelling Salesman Solutions



Integrated Freight Transport

City Logistics Solution



Up to 30% reduction in vehicle kilometres travelled

Up to 30% reduction in carbon emissions

Cheap Solutions to the Transport Problem

- Improved signals at traffic junctions - 20%
- Coordinated vehicle routing - 20%
- Improved public transport -10%
- Communication - 50%
- Automated vehicle control - 30%
- Integrated Freight Transport - 30%

Cheap Solutions to the Transport Problem

- Improved signals at traffic junctions - 20% on freeways
- Coordinated vehicle routing - 20% cars on urban roads
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Total potential reduction on urban roads:

(Freight*0.7 + Cars*0.8*0.9) / (Freight+Cars) = 0.7

Congestion could be reduced to 2/3 of its current level