Institute for Transport Studies
FACULTY OF ENVIRONMENT

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Research in Modelling Motorway Merging and Weaving

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with Thanks to:
Jiao Wang and Andyka Kusuma

SATURN UGM, 15 November 2013

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  - Research findings: empirical and microsimulation
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  - An empirical study of the traffic characteristics at a weaving

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Modelling motorway merge - current practice

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- Merging area modelled as a give-way node, via standard gap-acceptance model
- One fixed gap by time of day, by population
  - Cannot distinguish different user class/vehicle type
  - No difference in the 1st, 2nd, 3rd, … gap a driver accepts => under estimation of entry capacity
- Gaps are often inferred from average flow-delay functions
  - In SATURN, this is suggested to be the inverse of saturation flow
- Vertical queuing model
  - all vehicles wait by the stopline
- No explicit consideration of acceleration lanes

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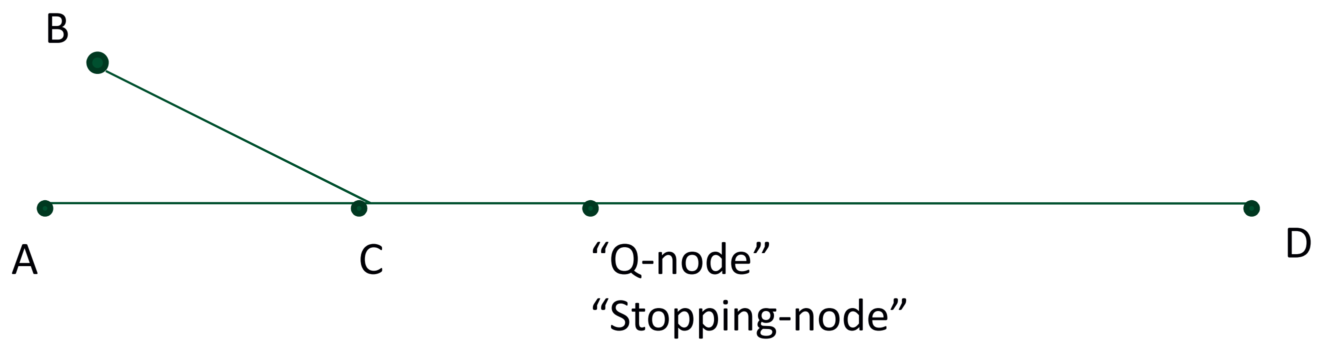
Correction methods in SATURN

- Cooperative lane choice: the use of parameter “Apresv”
  - To represent willingness of mainline traffic to accommodate merging
  - Moving a proportion of lane 1 traffic to lane 2
- Adding merge delay to post-merge traffic
  - To model delays to mainline traffic at merge
  - Insert a dummy node downstream of merge (up to 2km)
  - “Q-node” method: delay based on COBA delay function
  - “Stopping-node” method: delay due to capacity constraint



DMRB advice on modelling merge (I)

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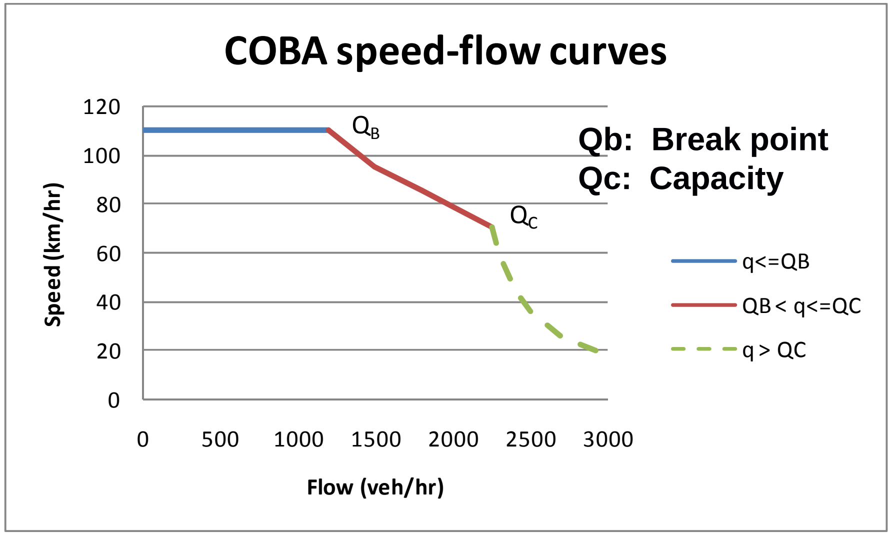
- **Link speed-flow relationships**

$$V(q)=\begin{cases} V_F & \text{q} \le \text{Q}_B \\ V_B+\dfrac{(V_C-V_B)(q-Q_B)}{(Q_C-Q_B)} & \text{for} \quad \text{Q}_B < \text{q} \le \text{Q}_C \\ \dfrac{V_C}{1+V_C(q-Q_C)/(8Q_C)} & \text{q} > \text{Q}_C \end{cases}$$



- **Capacity at merge: $Q = Q_0/[1+0.01P_{HV}(F_{HV}-1)]$ veh/hr/lane**
  - Q_0=2330 veh/hr is capacity without heavy vehicles (HV)
  - Affected only by percentage HVs (P_{HV})
  - F_{HV} =2.5 is the default pcu value of HV

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DMRB advice (II)

- **Merging area is modelled as a node with ‘no priority’**

- **Merge delay=227(V/C – 0.75) sec/veh**
  - Added on top of link speed-flow curve
  - To both mainline and merging vehicles

- **Merge influence felt up to 2km downstream**

Comparison with HCM and HBS – capacity function

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Advice	Variable	Function / Values
COBA	f_{HV}	2.5
	Q_{C2} (veh/hr/ln)	$2330/[1+0.01P_{HV}(f_{HV}-1)]$ at speed limit 112kph
		$0.9*2330/[1+0.01P_{HV}(f_{HV}-1)]$ at speed limit = 96 kph
HCM	f_{HV}	1.5, 2.5 and 4.5 for flat, rolling and mountainous
	Q_{C1}	$PHF*2300/[1+0.01P_{HV}(f_{HV}-1)]$ default PHF=0.88
	Q_{C2}	$PHF*[2300+5*(V_{Fm}-100)]/[1+0.01P_{HV}(f_{HV}-1)]$
HBS	f_{HV}	1.3 – 1.7 variable with flows
	Q_{C1}	2200 pcu/hr
	Q_{C2}	$1900/[1+0.01P_{HV}(f_{HV}-1)]$ at speed limit 120kph
		$1933/[1+0.01P_{HV}(f_{HV}-1)]$ at speed limits 80kph,100kph

Pcu value of HGV

Peak hour factor

Capacity at merge

Link capacity

Speed limit effects

Comparison with HCM and HBS - overview

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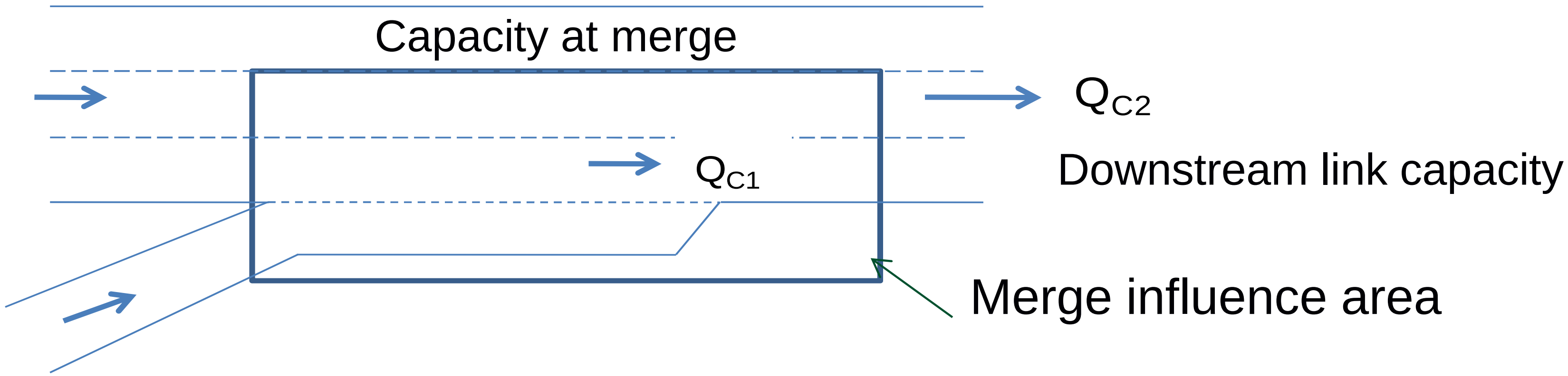
Concept of capacities and merge influence area



Concept	DMRB	HCM	HBS
Merge influence area	2km	450m, 2 lanes	1 lane
Concept of capacity	$Q_{c1} = Q_{c2}$	Q_{c1}, Q_{c2} separate	Q_{c1}, Q_{c2} separate
Measurements	15-min peak flow	15-min peak flow	
Peak flow profile correction	no	Yes	

An empirical Peak-Hour-Factor

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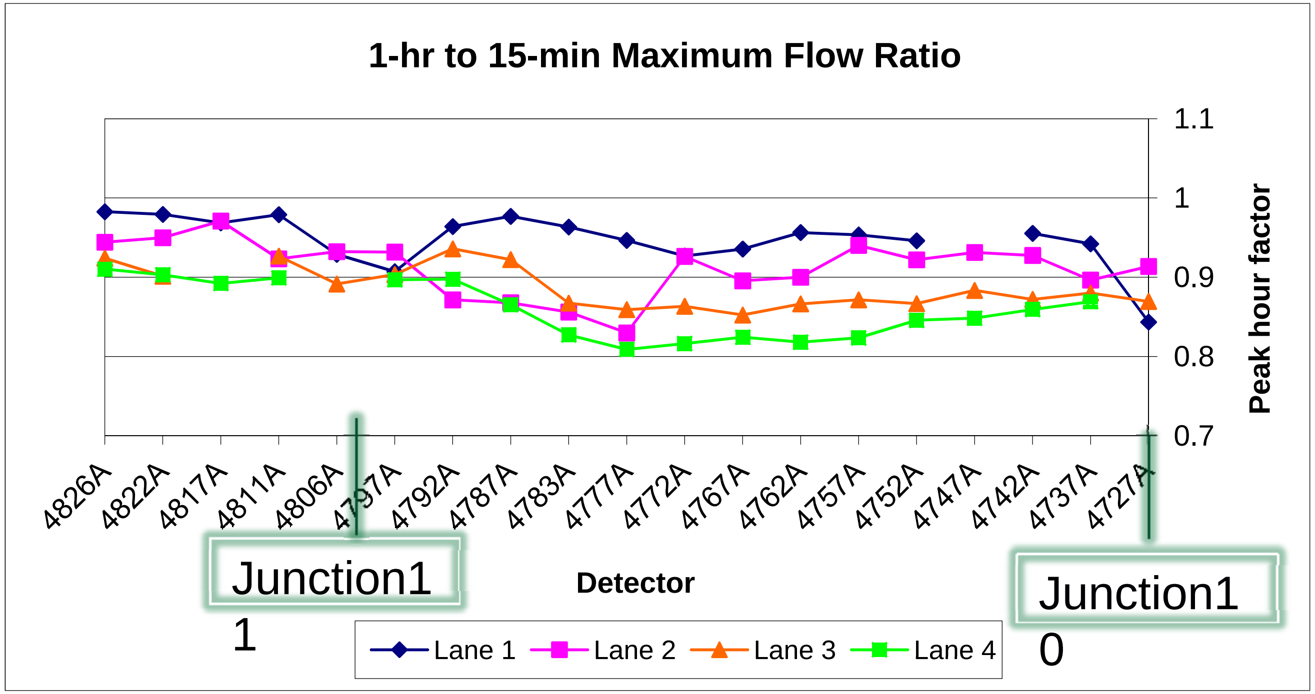
- Observation:
  - J10 – J11 (clockwise) on M25 motorway in England, 8am-9am
  - 19 MIDAS detector data on 15-min and 1-hr averaged flow



- Average observed PHF on M25 is 0.9 (HCM default 0.88)
- M25 congested most of the day; its peak period demand profile might be more uniform than other motorway networks in the UK

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A microsimulation model of merge

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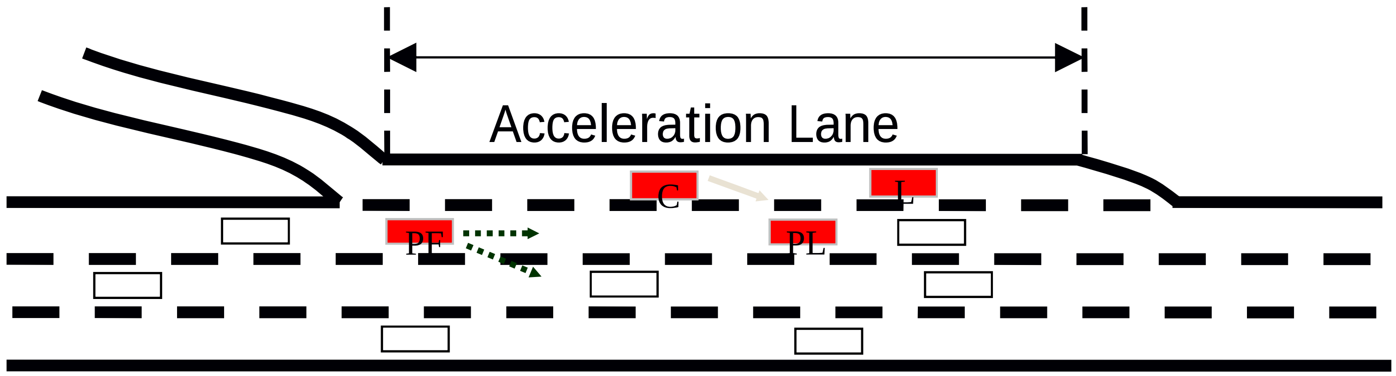

- **MergeSim** developed by Jiao Wang (2006, ITS)
  - Designed to model the microscopic behaviour at merge:
    - Merge vehicle C follows leaders L, and PL
    - Veh C takes smaller gaps as it gets closer to the end of acceleration lane
    - Cooperative lane-change at merge: Lane 1 traffic (PF) moves to Lane 2
    - Courtesy yielding: Lane 1 traffic (PF) slows down for merging vehicle

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Capacity at merge, and extend of merge influence

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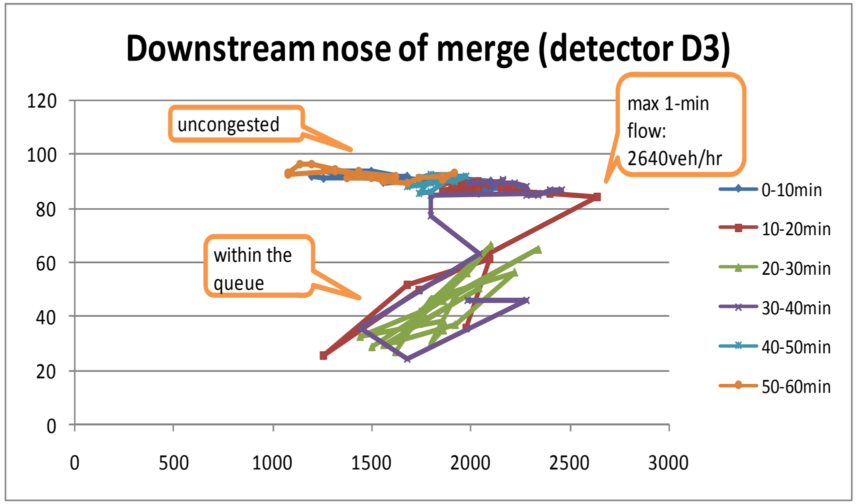
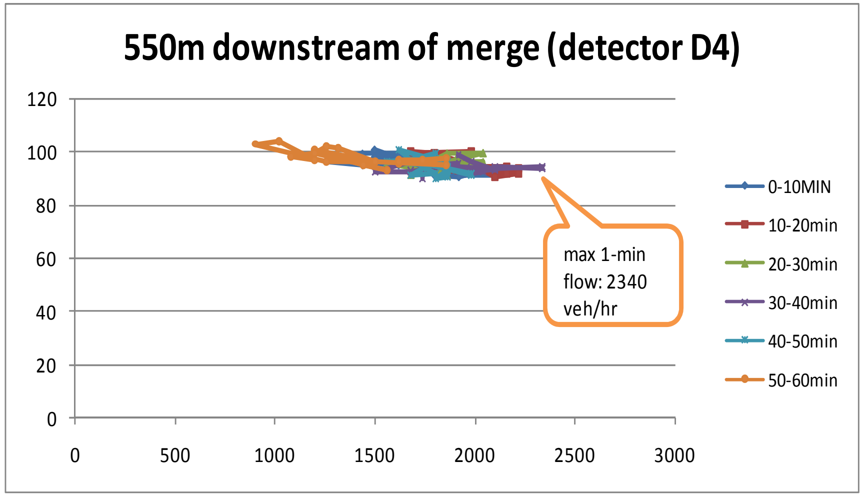
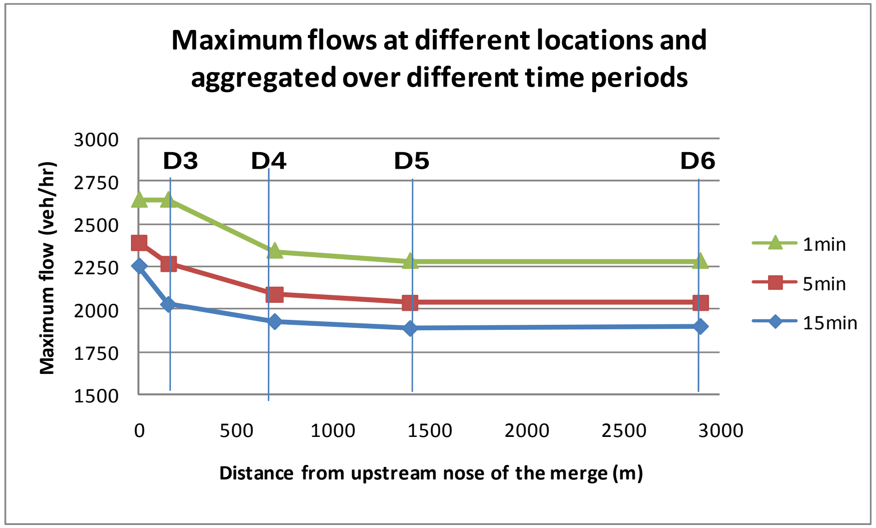
- Simulated speed-flow relationships





- Max. throughputs along road section



- Capacity higher at vicinity of merge
- Merge influence confined within 500m downstream

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Impact of traffic composition on merge capacity

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- Test scenario: seven levels of P_{HV} at 0, 5, 10, …, 30%

P_{HV} (%)		0	5	10	15	20	25	30
Capacity	DMRB(2.5)	2300	2167	2026	1902	1792	1694	1606
	Simulated Q_{c1}	2190	2104	2080	2044	2026	1976	1968
	Simulated Q_{c2}	2088	2055	2021	1984	1965	1924	1921
	DMRB(1.5)	2200	2113	2089	2053	2035	1985	1977
Pcu values	DMRB		2.5	2.5	2.5	2.5	2.5	2.5
	Simulated		1.82	1.53	1.48	1.4	1.43	1.38

- Q_{c1} higher than Q_{c2} by 60 veh/hr (3%),similar to HCM estimates at 70mph
- With F_{HV} =2.5, DMRB capacity decreases more rapidly than simulated
- With F_{HV} =1.5, DMRB capacity similar to simulated Q_{c1}

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Summary

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- Current UK method was based on studies of traffic data 20 years ago; new interpretation need to take into account:
  - Effect of peak flow profiles
  - Impacts of HVs
  - Differences between junction capacity and link capacity
  - Differences in delays to mainline and to merging traffic
- Suggestions for quick fixes:
  - An empirical PHF of 0.9 is found for M25 -> reduces capacity by 10%
  - Merge capacity higher than motorway link capacity (by 3% at 70mph)
  - DMRB capacity with F_{HV}=2.5 is overly sensitive to P_{HV}; a F_{HV}=1.5 is found a better fit the simulated result
  - Merging turbulences confine within 500m downstream
- Further empirical and detailed microsimulation analysis to help develop better (macroscopic) traffic models

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Motorway weaving

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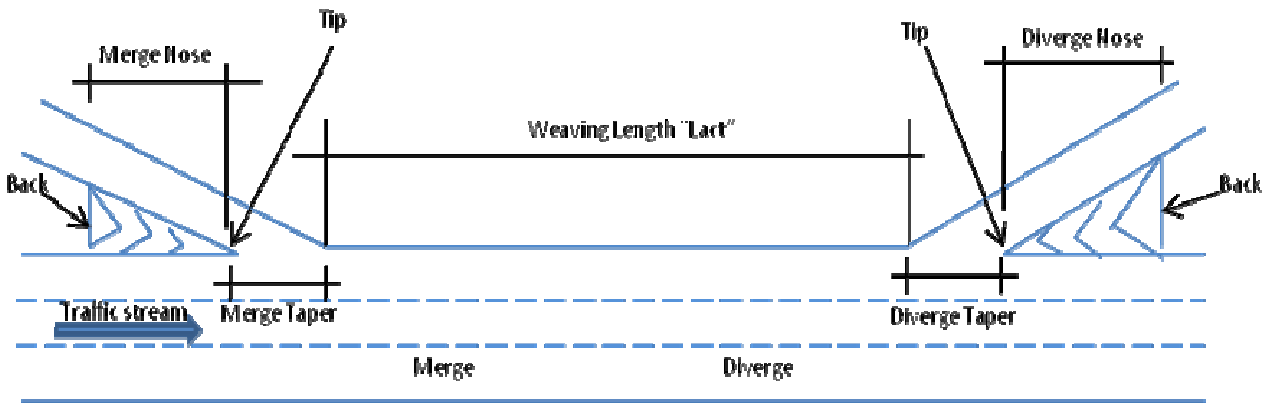
- DMRB (2006):
  - *the distance between a successive merge and diverge where vehicles have to cross the paths of vehicles that have joined the mainline at the merge*
  - the distance between merge and diverge < 2000m



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Study site 1

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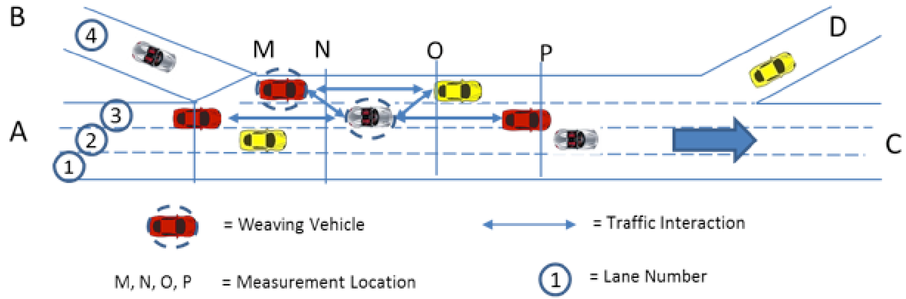
- A weaving section on a four-lane dual carriageway on A5103



- The distance between those measurement location is 50m.
- Traffic is recorded by video camera
- The extraction focuses on the highest 5 minutes period, 15.35-15.40

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Traffic Characteristic

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Data Extraction Result (5 Minutes Period)

- Vehicle Composition
  - 524 vehicles passing through the A5103, during the 5min period
  - Car (79.8%), MPV (7.1%), Van (6.7%), LGV (3.1%),HGV (1.9%), Bus/Coaches (1%) and MC (0.6%).
- Weaving movements

– 81 weaving movements observed

– 48% weaving between lanes 1 and 2

– More weaving out (26% lane-changing from lane 1 to exit slip road), than weaving in (15% from entry slip road to lane 1)

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Gap Acceptance

- The leading vehicles critical gaps are 4.03 sec (current lane) and 1.36 sec (target lane) in average.
- the following vehicles critical gaps are 2.61 sec (current lane) and 4.88 sec (target lane).
- Based on Type of Vehicle (in Seconds)

Table. Predicted critical gap (unit: seconds)

Leading Vehicle	Gap Event		Following Vehicle	Gap Event	
	Current Lane	Target Gap		Current Lane	Target Lane
Heavy	0.81	0.62	Heavy	4.62	15.33
Heavy	1.78	1.15	Small	2.60	7.44
Small	5.07	2.82	Heavy	1.01	5.97
Small	4.04	1.30	Small	2.67	4.03

Study site 2:

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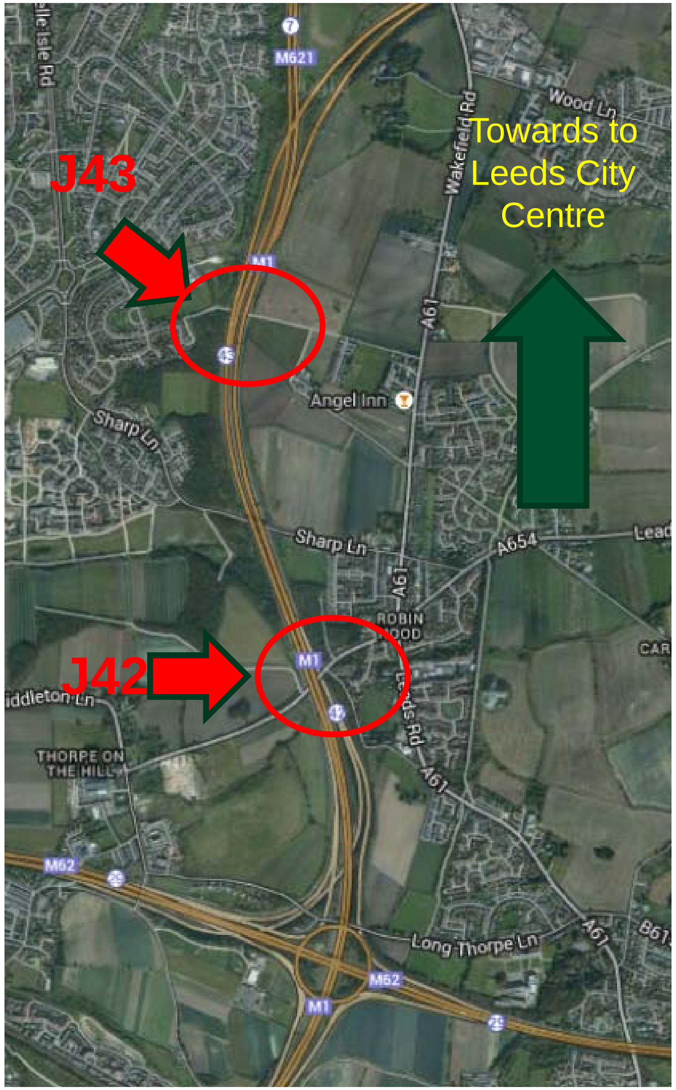
- Site
  - M1 between J42 and J43
  - A dual carriageway, five lanes each direction
  - Section length ~1400m (a weaving section)
- Observation
  - N-bound traffic merge at J42
  - Video recording of PM peak (16:00-18:30, 15 June 2013), taken over footbridge 900m downstream from J42
  - MIDAS loop detector data



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Observation and Data Extraction…

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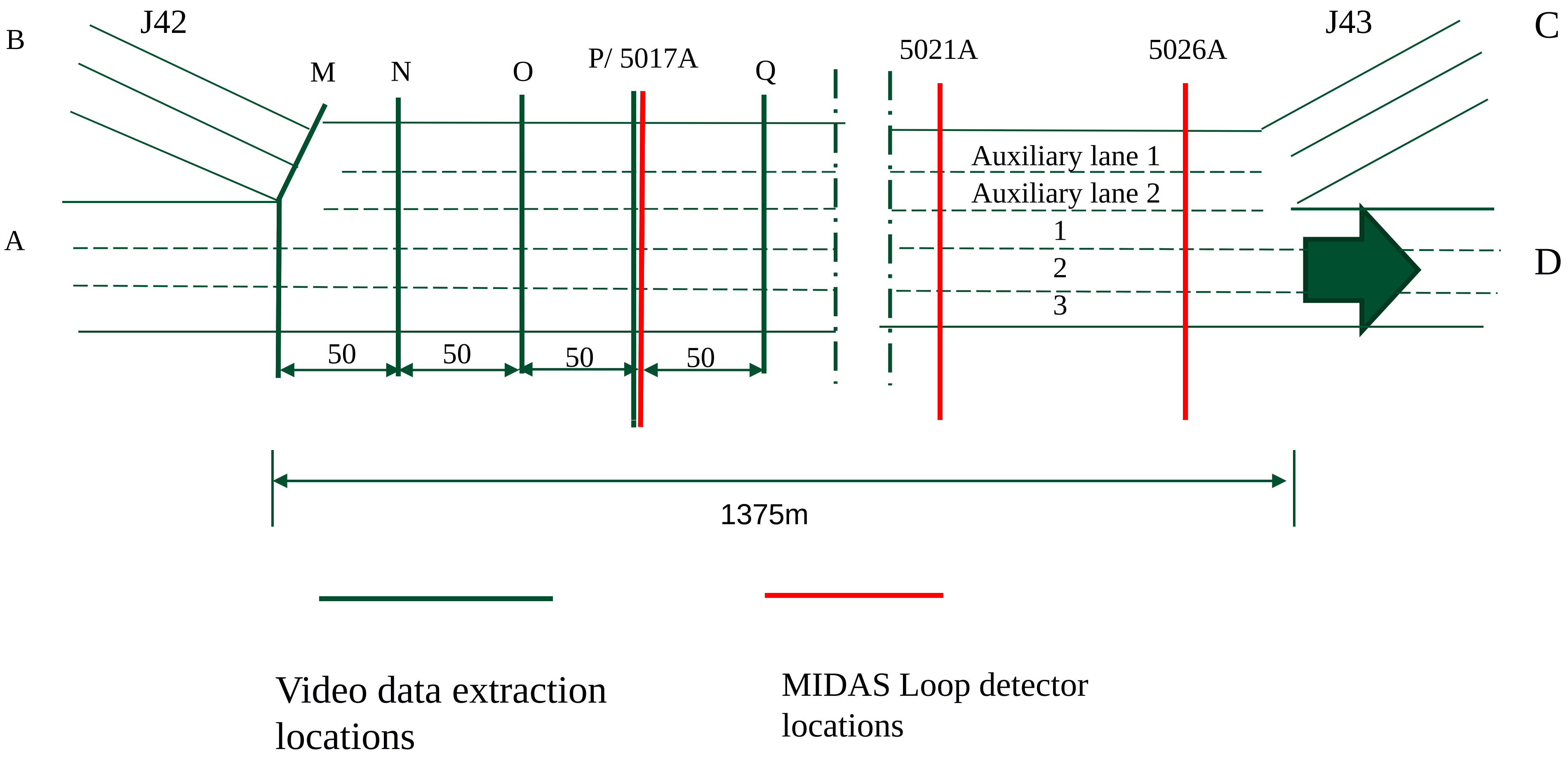

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Observation and Data Extraction…

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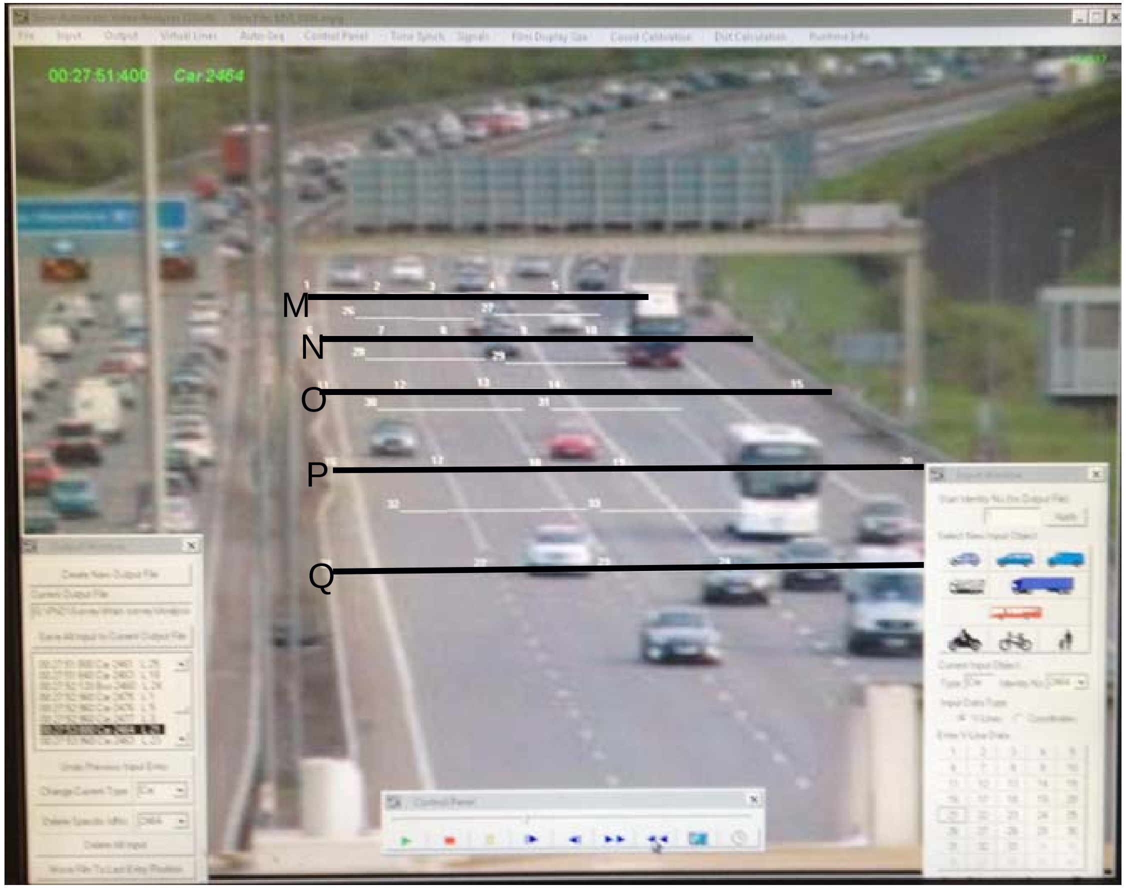
- The Data Extraction Process



Video data extraction:

- Type of Vehicle
- The passage time of the n^{th} vehicle at the measurement location
- Time and Location for lane-changing

Figure: The Data Extraction Interface (Software: Semi-Automated Video Analyser, KTH)

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Traffic Characteristic – video observations

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- Traffic Flow between 16:30-17:30 over the first 200m from J42:

Time	**Type of Vehicle (PCU value)**						**Total**	
	Car (1.0)	MPV (1.0)	Van (1.0)	LGV (1.5)	HGV (2.5)	Bus (2.5)	Vehicle	PCU
16:30-16:45	979	54	119	53	19	0	1224	1279
16:45-17:00	944	23	76	43	20	2	1108	1162
17:00-17:15	1083	40	111	9	62	1	1306	1405
17:15-17:30	1202	29	94	7	46	2	1380	1455

(The pcu value is based on the HCM 2010)

- Traffic speed (kph) for the highest 5 minutes between 17:15-17:20

Type of Vehicle	Statistic Results		
	Mean	S.D	No.Data
All	68.1	10.5	420
Car	68.2	10.4	362
MPV	69.1	10.9	29
Van	68.1	10.0	11
LGV	61.5	9.6	4
HGV	55.2	3.3	14

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Traffic Characteristic…

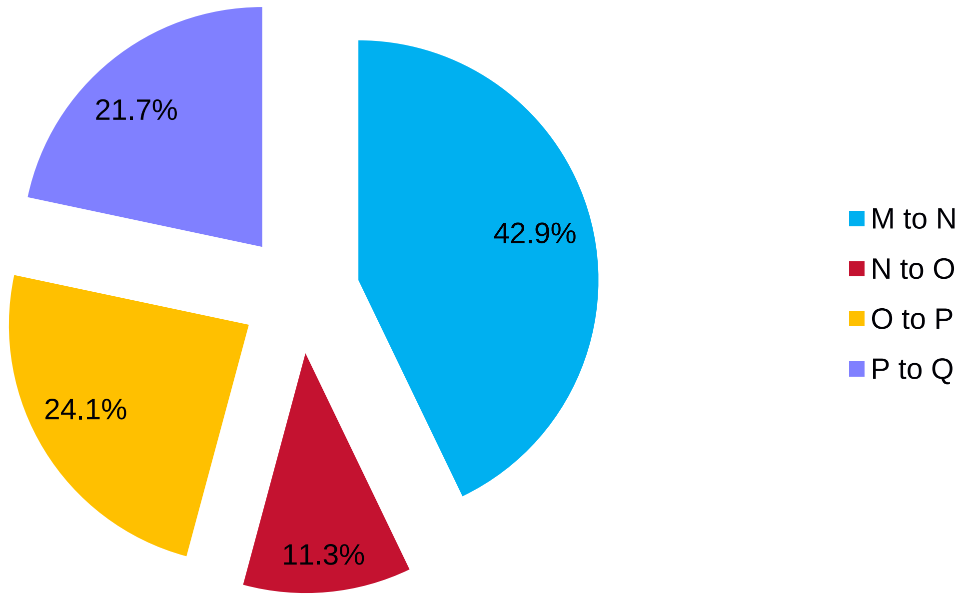

Figure. The Location of Lane Changing

- 42.9% of lane changing occurs in the first 50m (from M to N), of which
- 37.4% are weaving between Lane 1 and the two Auxiliary lanes

On-going research:

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- Incorporate MIDAS loop detector data into analysis
- Capacity analysis at weaving
- Car-following, gap-acceptance and lane-changing at weaving
- Microscopic analysis of weaving => simpler (macroscopic) models of weaving

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Thank you

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with Thanks to:
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Example analysis: consequence of changing the value of capacity

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- Test scenarios:
  - 1km section with 500 merge influence area and 500 downstream
  - 3 levels of total traffic flow, 3 capacity values
  - Travel time estimated from DMRB speed-flow and queuing delay

Flow/Capacity (veh/hr)	Link travel time (sec/veh)			Queuing delay (sec/veh)		
	Qc=2024	Qc=2112	Qc=2330	Qc=2024	Qc=2112	Qc=2330
Low flow (1600)	11.4	11.2	10.8	9.2	1.7	0.0
Medium (2000)	14.1	13.5	12.5	54.1	44.7	34.3
High flow (2400)	22.2	22.2	18.0	98.9	87.7	75.2

Total	Total travel time (sec/veh)			Difference relative to that at Qc=2330		
Low flow	20.6	12.9	10.8	191%	119%	
Medium flow	68.1	58.2	46.7	146%	125%	
High flow	121.1	109.9	93.2	130%	118%	

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Impact of traffic composition on merge delays

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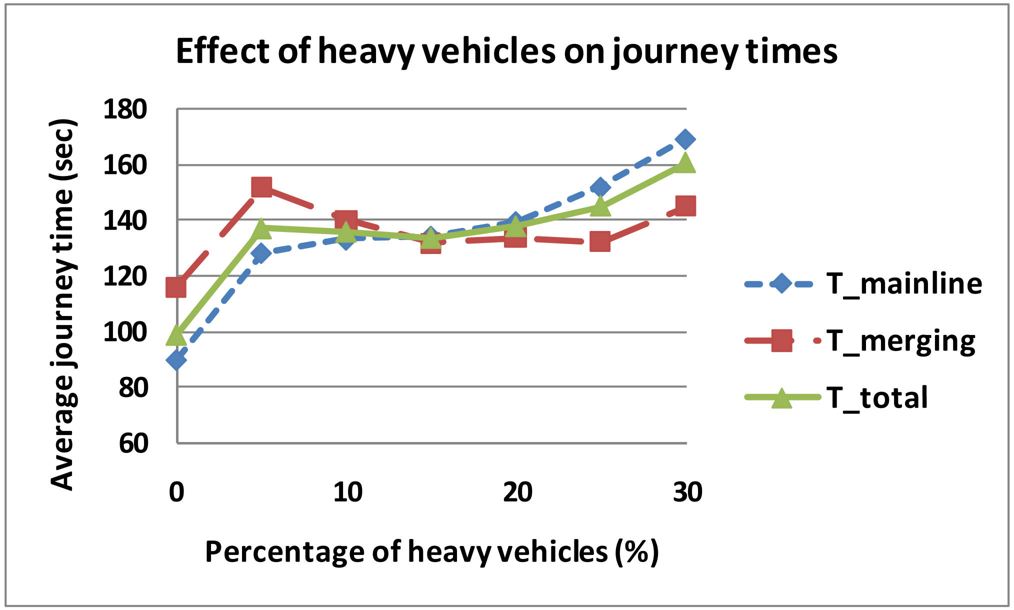
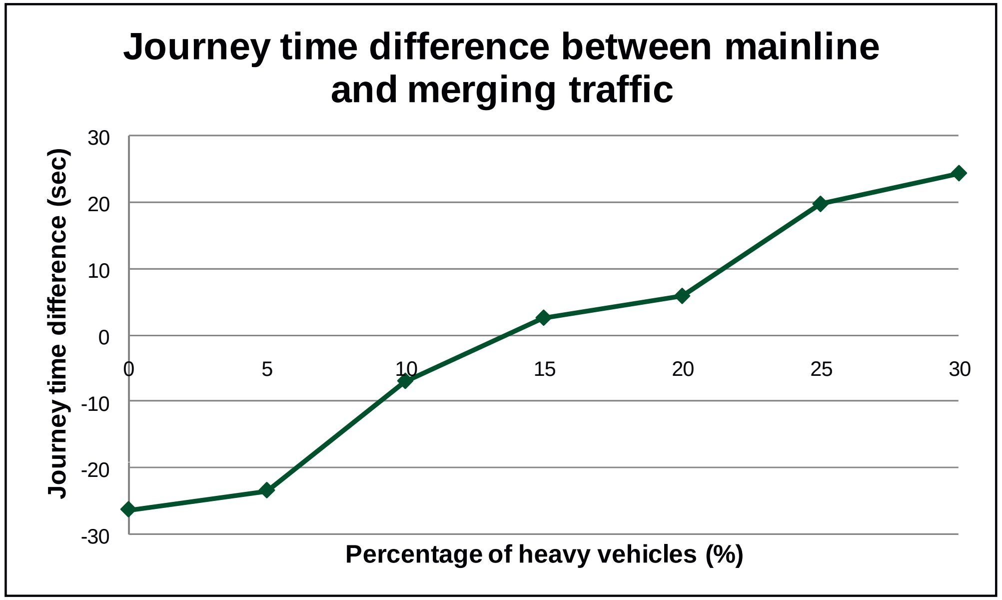


- Journey times increase with P_{HV}
- Journey time of the mainline traffic different to that of merging traffic



- Mainline to merging journey time difference steadily increases with P_{HV}
- Perhaps, with more HVs, more platoons forming, making merge easier?

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