MONASH University

Engineering

Assessment and Management of Bridge Loading using Traffic Microsimulation

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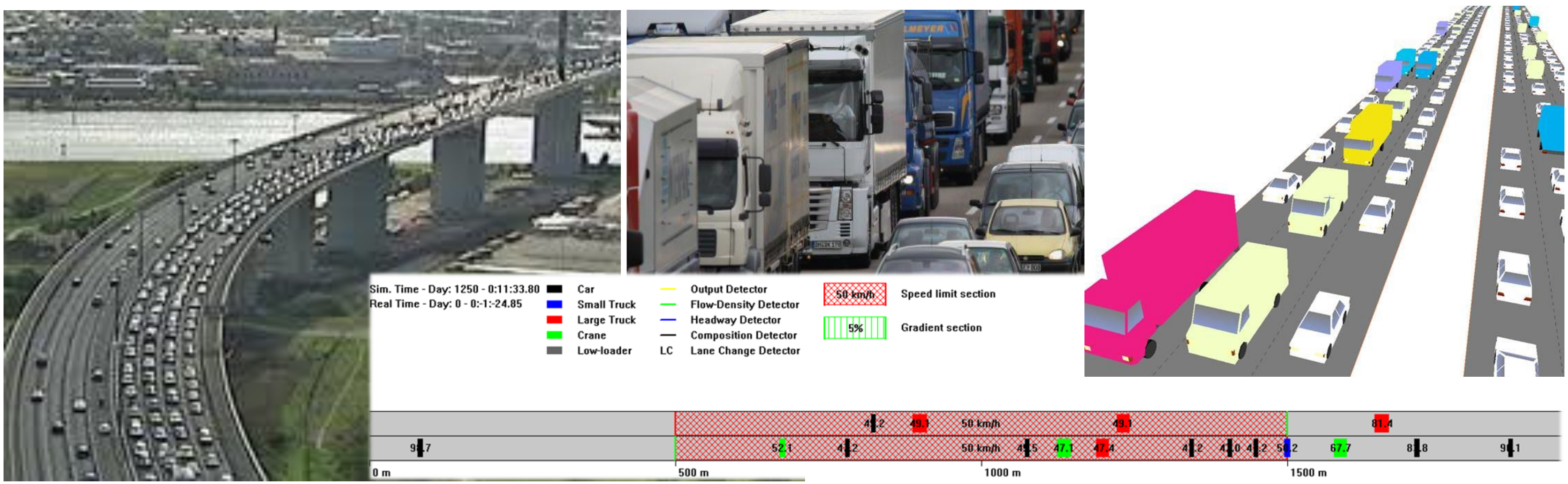


Agenda

1. **Introduction**
2. **Traffic Microsimulation**
3. **Bridge Load Assessment**
   a) Evaluation of load models
   b) Calibration of load models
   c) Assessing long span load models
   d) Determining governing conditions
4. **Bridge Load Management**
   a) Gap control
   b) Lane change control
   c) Vehicle access
5. **Summary**

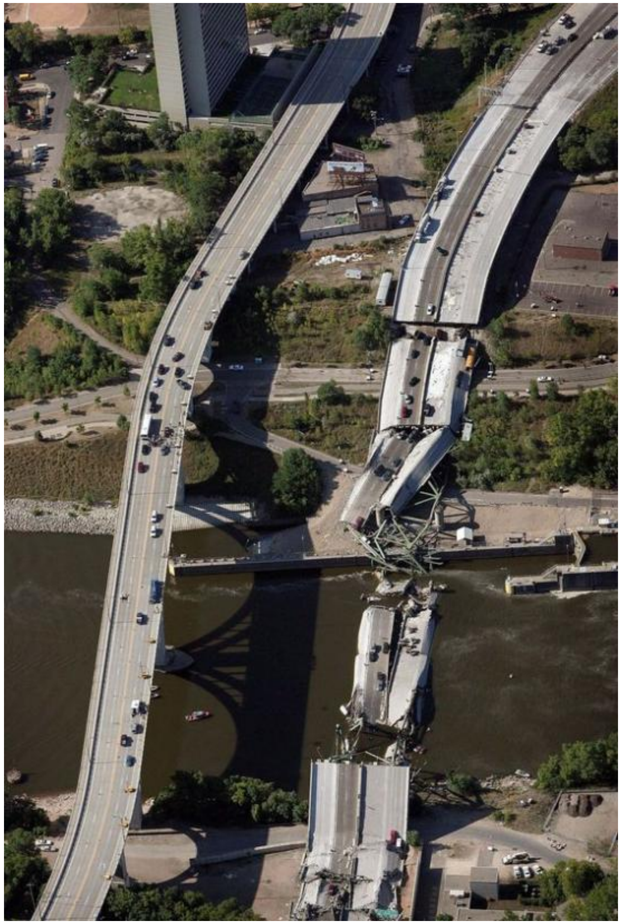
Introduction

The challenge in Europe

- Almost 50% of Europe's 1 million bridges built before 1965 and so are close to or at the end of their 50-year design lives
- Freight transport is projected to increase by 80% by 2050 compared to 2005
- Replacement cost ~30% of Gross Domestic Product so it is not feasible to replace them

The challenge in the US

- Average age of the US bridge stock is 43 years (so nearly half at the end of their design lives)
- More than 26% of the USA's bridges are structurally deficient or functionally obsolete.
- $140 billion is needed to repair already deficient or obsolete bridges.
- A $17 billion annual investment is needed but only $10.5 billion is being spent.



Minneapolis I-35W Bridge Collapse, (1 August 2007): multiple causes including heavy weight of rush hour traffic and construction equipment (NTSB 2008)

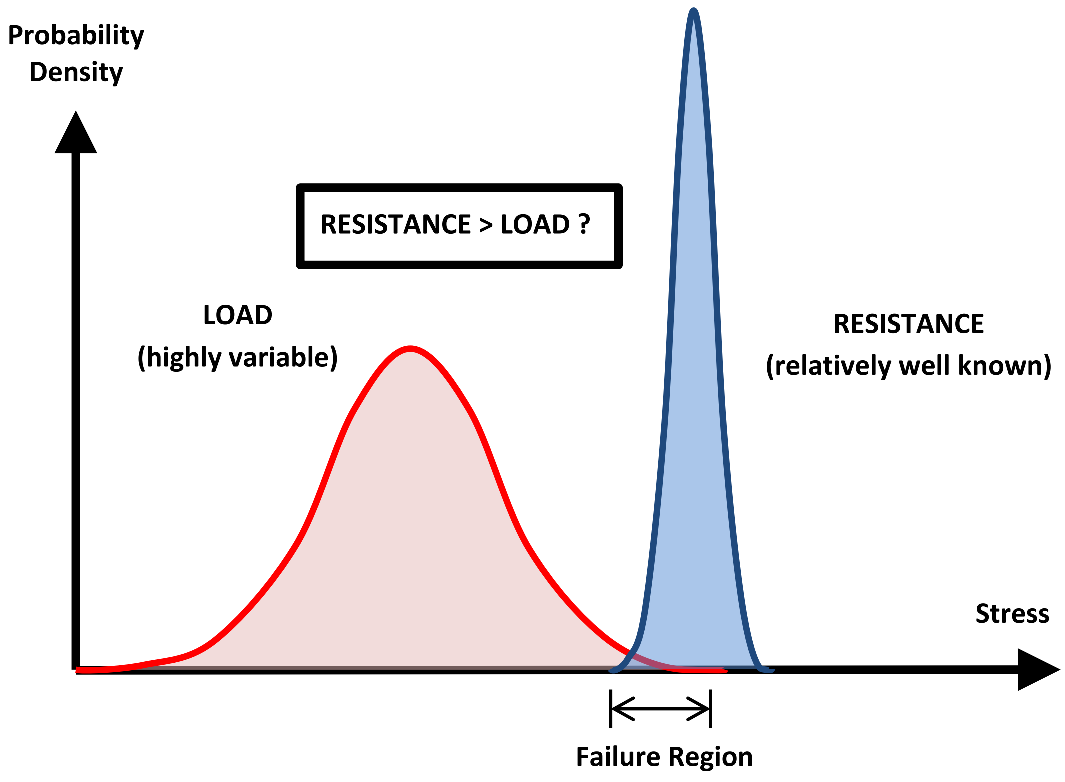
The challenge in Australia

- 70% of the bridges in Australia are ~40 years old
- Load limits are applied to around 2% of bridges in most states and deterioration is a significant problem
- Freight volume is expected to double from 2008 levels by 2030
- Extreme weather events: floods and inundations are becoming more common and can severely compromise structural integrity

Bridge Safety Crisis, Sydney Morning Herald, 1 April 2013
http://www.smh.com.au/data-point/bridge-safety-crisis-20130331-2h1h9.html

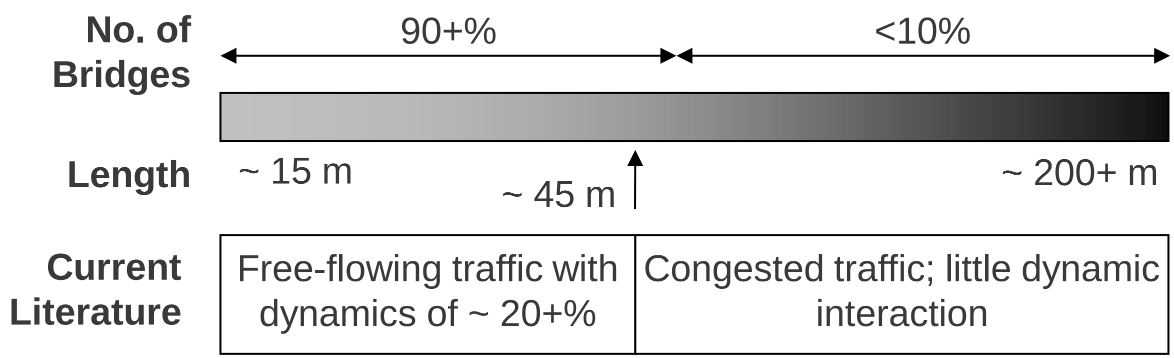
Bridge Traffic Loading

- The most variable parameter in a bridge assessment
  $\rightarrow$ accurate estimation can yield big benefits



Bridge Traffic Loading

- Classic case: Assume critical traffic is either:
  Free flow + dynamic interaction ***or*** *Congested traffic*



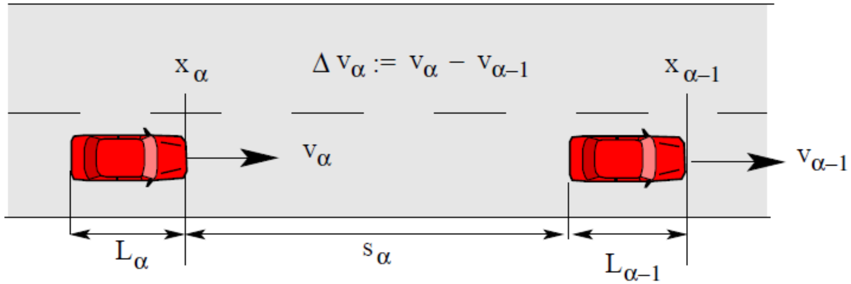
- Model chosen form of traffic through truck arrivals:
  - Free-flow: simple headway models (e.g. HeDS or Poisson)
  - Congested: assume small gaps; 5 m, 7.5 m etc and all trucks

- *Is there a better all-inclusive way?*

Traffic Microsimulation

Traffic Microsimulation

- Traffic microsimulation models driving behaviour in discrete time intervals.
- The Intelligent Driver Model (IDM) is used.
- Parameters include:
  - Desired velocity;
  - Comfortable acceleration;
  - Comfortable deceleration;
  - Safe time headway.
  - Different parameters for cars and trucks.



after Treiber & Helbing (2002)

- Different parameters for cars and trucks
- Lane changing model is MOBIL – based on acceleration advantage

Longitudinal movement

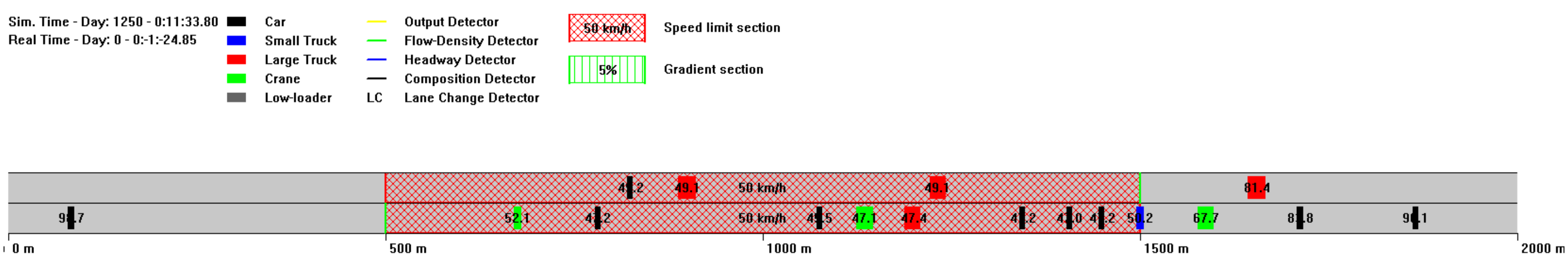
Parameter	Cars	Trucks
Desired velocity, v_0	120 km/h (±20)	80 km/h (±20)
Safe time headway, T	1.2 s	1.7 s
Maximum acceleration, a	0.80 m/s^2	0.40 m/s^2
Comfortable deceleration, b	1.25 m/s^2	0.80 m/s^2
Minimum jam distance, s_0	1.0 m	1.0 m
Elastic jam distance, s_1	10.0 m	10.0 m

Acceleration function:

$$\frac{dv}{dt} = a\left[1 - \left(\frac{v}{v_0}\right)^{\delta} - \left(\frac{s^*}{s}\right)^{2}\right]$$

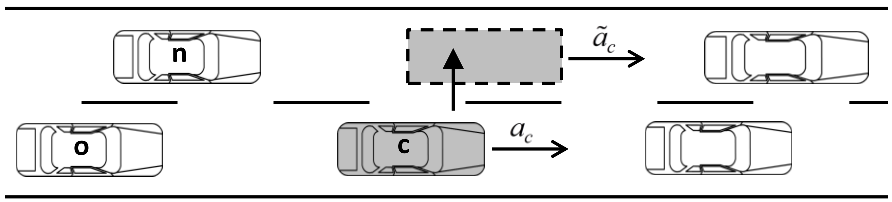
Desired distance to vehicle in front:

$$s^* = s_0 + s_1\sqrt{\frac{v}{v_0}} + vT + \frac{v(\Delta v)}{2\sqrt{ab}}$$



Lane changing

- What is involved?
  - spatial arrangement,
  - relative velocities
  - mechanical performance
  - psychological nature of driver (aggressiveness, perception, and reaction times)



Acceleration advantage:

$$\tilde{a}_c(t) - a_c(t) \geq \Delta a_{th} + p\left[\left(a_n(t) - \tilde{a}_n(t)\right) + \left(a_o(t) - \tilde{a}_o(t)\right)\right]$$

Safety criterion:

$$\tilde{a}_n(t) \geq b_{\text{safe}} = -12 \text{ m/s}^2$$

Asymmetric passing bias:

$$\Delta a_{bias}$$

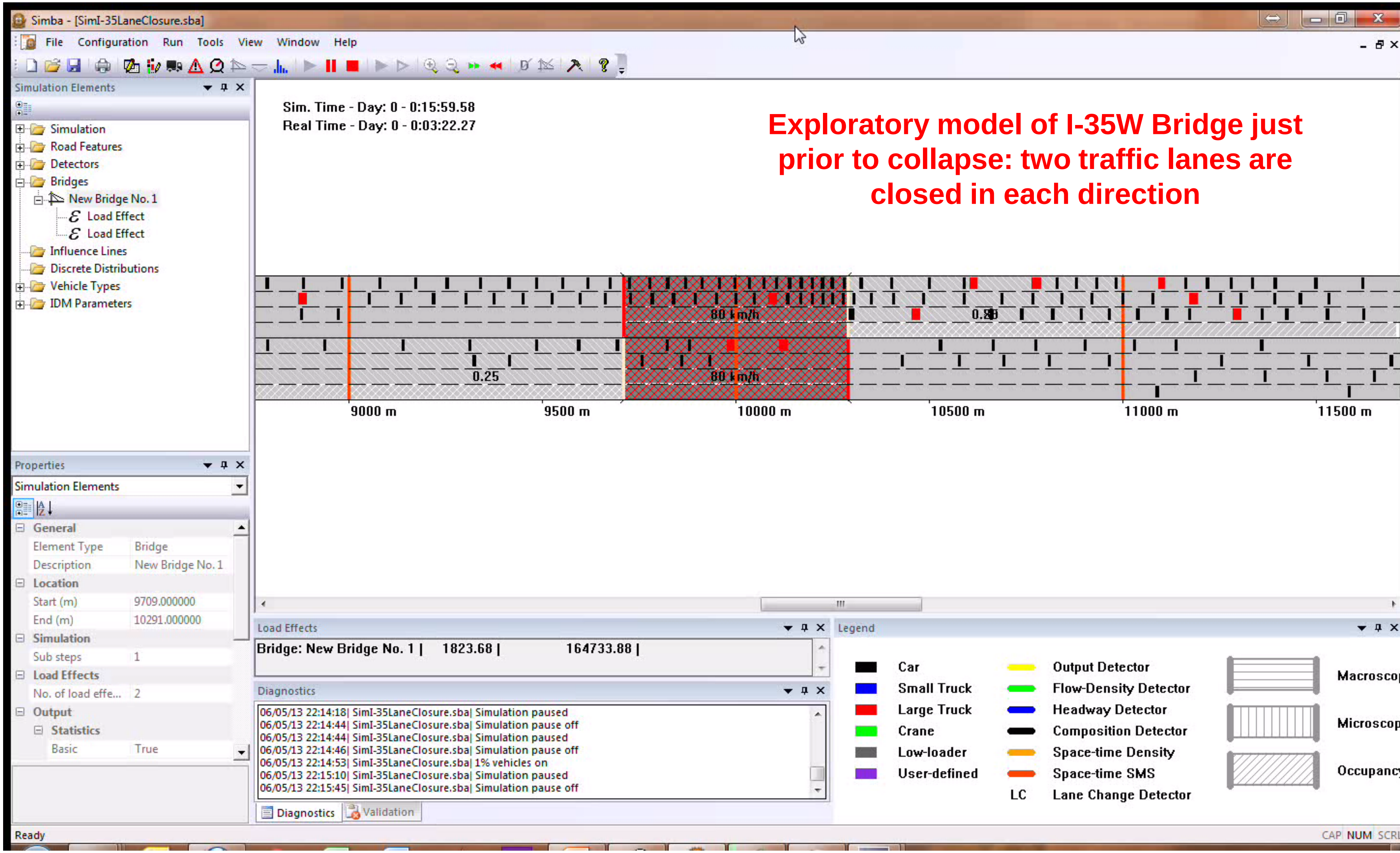
Parameter	Cars	Trucks
Politeness factor, *p*	0.25	0.25
Changing threshold, Δa_{th}	0.1 m/s^2	0.14 m/s^2
Maximum safe deceleration, b_{safe}	12 m/s^2	12 m/s^2
Bias for the slow lane, Δa_{bias}	0.30 m/s^2	0.3 m/s^2

Implementation

Simba: _Sim_ulation for _B_ridge _A_ssessment (2006-13)

- Up to 10 lanes each direction, straight road of any length
- Vehicles read from Weigh-In-Motion file and passed along the road
- Lane closures, speed limits, lane change ban, gap control regions, etc
- Multiple types of traffic detector output
- 6 vehicles types (user-defined)
- Stochastic driving parameters:
  - Various parametrized distributions
  - Discrete distributions
- Load effects calculated:
  - User-defined or built-in influence line,
  - lateral distribution

Simba - Simulation for **B**ridge **A**ssessment


Simba - [SimI-35LaneClosure.sba]
File Configuration Run Tools View Window Help
Simulation Elements
Simulation
Road Features
Detectors
Bridges
New Bridge No. 1
Load Effect
Load Effect
Influence Lines
Discrete Distributions
Vehicle Types
IDM Parameters
Sim. Time - Day: 0 - 0:15:59.58
Real Time - Day: 0 - 0:03:22.27
Exploratory model of I-35W Bridge just prior to collapse: two traffic lanes are closed in each direction
80 km/h
0.25
80 km/h
9000 m
9500 m
10000 m
10500 m
11000 m
11500 m
Properties
Simulation Elements
General
Element Type Bridge
Description New Bridge No. 1
Location
Start (m) 9709.000000
End (m) 10291.000000
Simulation
Sub steps 1
Load Effects
No. of load effe... 2
Output
Statistics
Basic True
Load Effects
Bridge: New Bridge No. 1 | 1823.68 | 164733.88 |
Diagnostics
06/05/13 22:14:18| SimI-35LaneClosure.sba| Simulation paused
06/05/13 22:14:44| SimI-35LaneClosure.sba| Simulation pause off
06/05/13 22:14:44| SimI-35LaneClosure.sba| Simulation paused
06/05/13 22:14:46| SimI-35LaneClosure.sba| Simulation pause off
06/05/13 22:14:53| SimI-35LaneClosure.sba| 1% vehicles on
06/05/13 22:15:10| SimI-35LaneClosure.sba| Simulation paused
06/05/13 22:15:45| SimI-35LaneClosure.sba| Simulation pause off
Diagnostics Validation
Legend
Car
Small Truck
Large Truck
Crane
Low-loader
User-defined
Output Detector
Flow-Density Detector
Headway Detector
Composition Detector
Space-time Density
Space-time SMS
LC Lane Change Detector
Ready
CAP NUM SCRL

Bridge Load Assessment

Bridge Traffic Load Assessment

- Microsimulation can model all real traffic states
  - Different flows, densities, and loadings through time
  - Previous assumption of free-flow *or* congested flow is thus overly simplistic and accounted for naturally

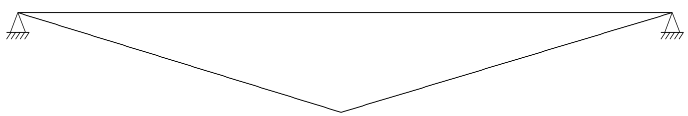
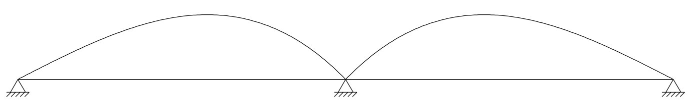
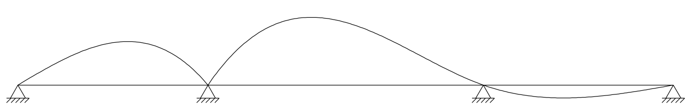
- Microsimulation has been used for:
  - Evaluating the Eurocode load model (LM)
  - Calibrating a simple congested traffic load model
  - Assessing long span load models
  - Determining the governing traffic conditions

Evaluating the Eurocode Load Model

- 1000 hours of single-lane traffic heavy congestion simulated, representing 1 year of very busy traffic.
- Extrapolated to a 1000-year return period

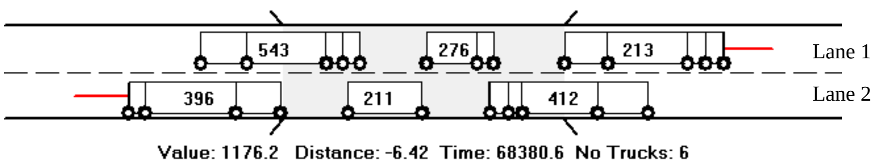
Lipari et al (2012)

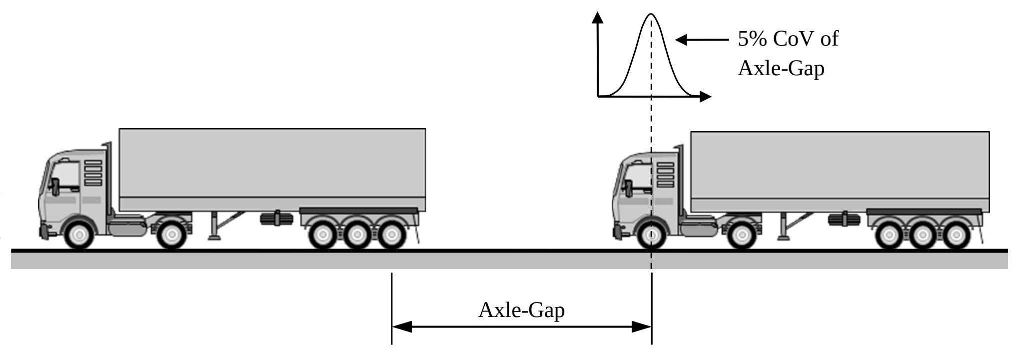
- Ratio of real traffic to Eurocode found:

	Bridge Details	Load effect	Ratio to EC1.3
50 m 1-span		Sagging moment	**0.75**
100 m 2-span		Hogging moment	**0.81**
200 m 3-span		Hogging moment	**0.71**

Calibration of a congestion load model

- Very heavy congestion passed over bridges (20 to 60 m), considering a range of load effects and transverse distribution of loading.
- A simple model was calibrated to give the same 1000-year load effects.



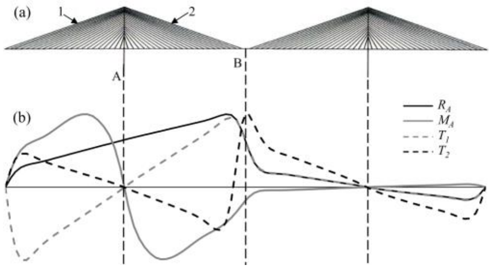


- Mean nominal axle gaps found were:
  7.40 m, 8.48 m, 9.94 m, for 0%, 50% and 80% cars

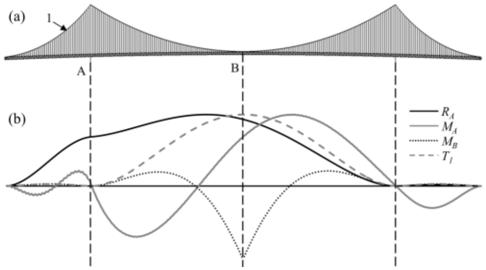
Caprani (2012a)

Assessing long-span load models

- Alabama (US) WIM data:
  - 21 million trucks
  - 11 sites



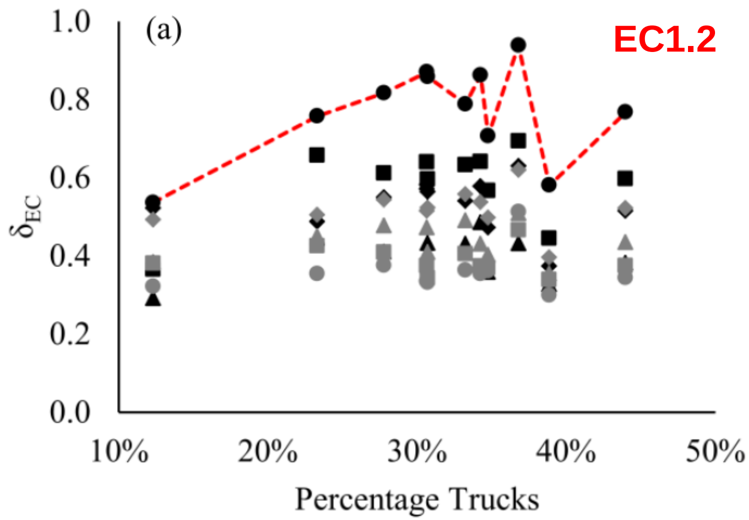
Sidney Lanier Bridge

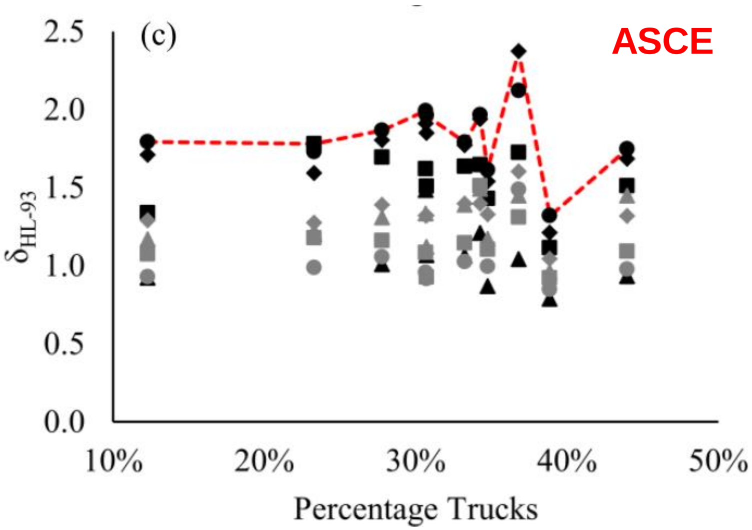


Golden Gate Bridge

- Ratio of actual to load model:

Enright et al (2013)



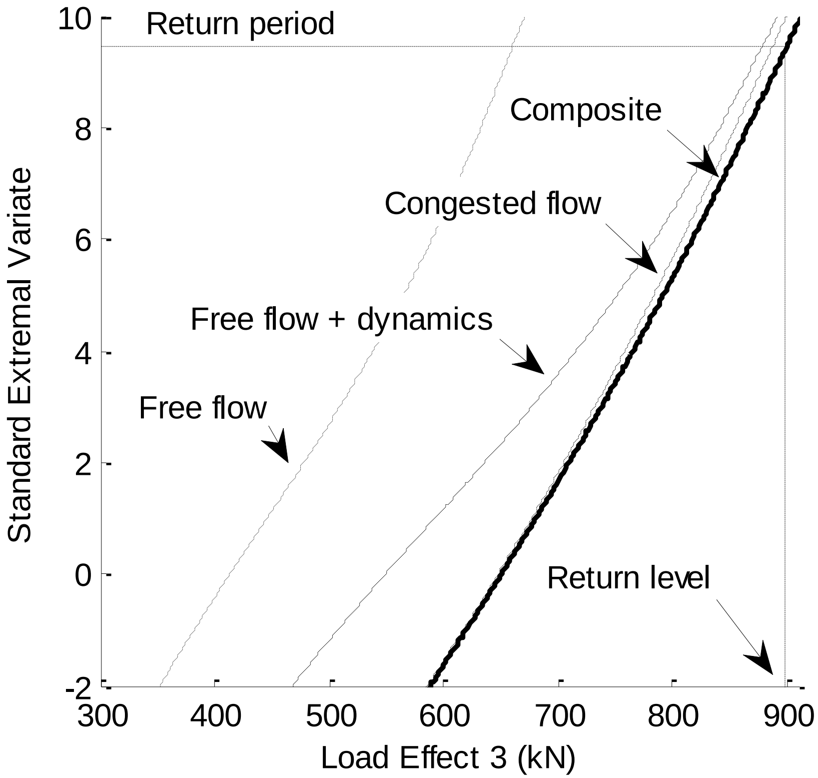


Determining the governing traffic form

- Statistical approach to finding governing traffic state
- Critical Traffic Index:
  - free-flow + dynamics (C = 1)
  - congestion (C = -1)
  - Mixture of traffic states C ~ 0

$$G_T(x) = \left[D(\cdot)\, G_{C,FF}(x) \right] G_{C,CF}(x)$$

Total Load Effect	Dynamic Amplification Factor Function	Free-Flow Composite Load Effect	Congested Flow Composite Load Effect



Caprani (2012b)

Critical traffic indices

- Free flow (+1), Congestion (-1)

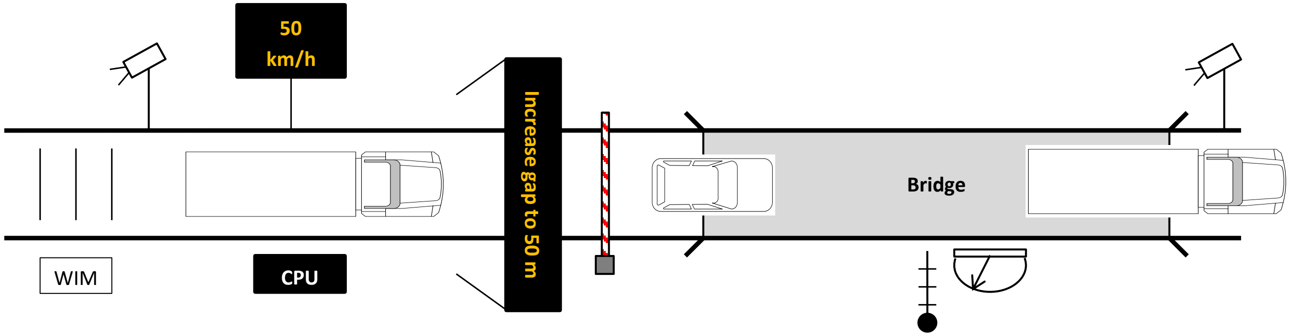
Traffic Composition		0% Cars					80% Cars				
Bridge length (m)		20 m	30 m	40 m	50 m	60 m	20 m	30 m	40 m	50 m	60 m
DAF Model	Load Effect										
AASHTO-LRFD	LE 1	-0.85	C	-0.91	-0.26	F	C	C	C	C	C
	LE 2	0.58	0.88	C	F	F	C	C	C	C	C
	LE 3	C	-0.77	0.28	F	F	C	C	C	C	C
EC	LE 1	0.87	0.79	F	F	F	C	C	C	C	0.53
	LE 2	F	F	0.55	F	F	C	C	F	F	F
	LE 3	-0.49	0.89	F	F	F	C	-0.93	C	F	F
GDAF	LE 1	F	F	F	F	F	F	F	0.28	F	F
	LE 2	F	F	F	F	F	0.72	F	F	F	F
	LE 3	F	F	F	F	F	0.91	0.89	0.41	F	F

- DAF model has significant influence; traffic composition less so

Bridge Load Management

Bridge Load Management

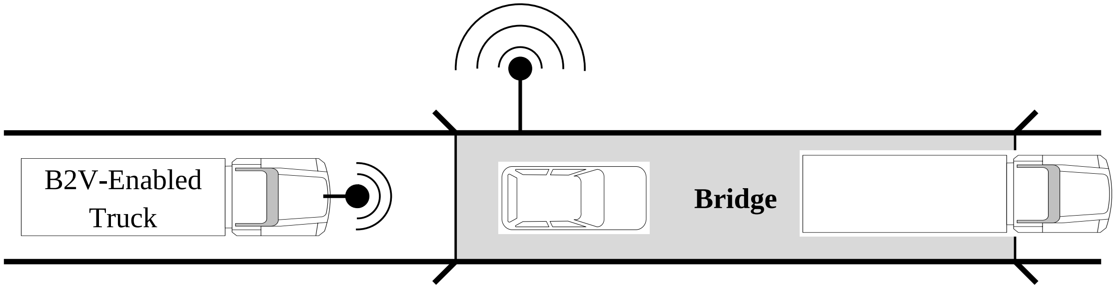
- Microsimulation allows the evaluation of possible traffic control measures relative to the status quo
  - Facilitates problem bridges to be kept operational



- Recent work has examined:
  - Controlling gaps between vehicles
  - Controlling lane changing
  - Controlling vehicle access

Controlling gaps

- Bridge-To-Vehicle (B2V) communication
  - Informing driver of the appropriate gap to front vehicle
  - Parameters examined using microsimulation:
  - Compliance rates
  - Broadcast distance
  - Required time gap

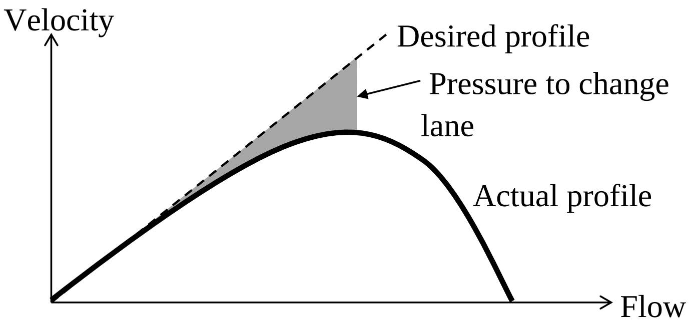


- Results:
  - If 10% trucks respond: loading drops by 10%
  - 90% respond: loading reduces by up to 47%
  - Significantly, it does not cause traffic disruption

(Caprani 2012c, Caprani et al 2013)

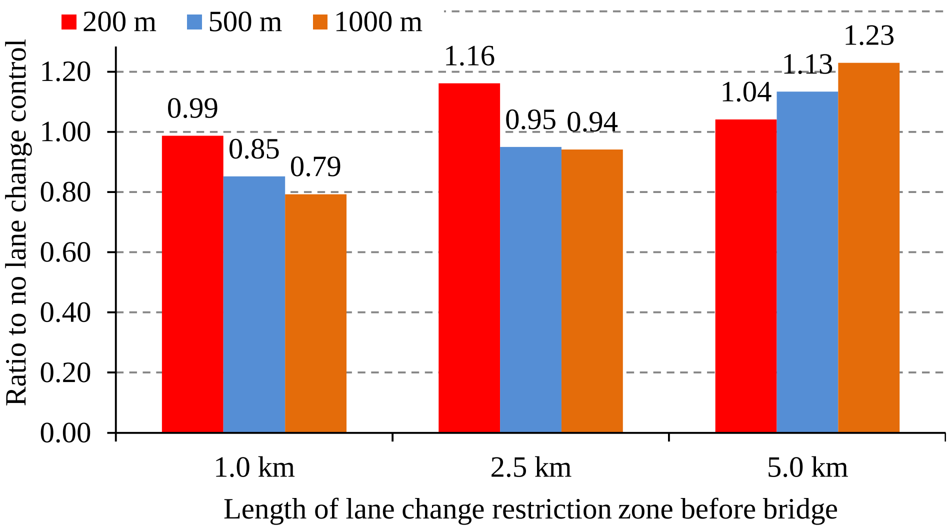
Controlling lane changing

- Lane changing:
  - trucks have lower desired velocity
  - cars pull out from between trucks
  - truck platoons are formed
  - critical loading situation



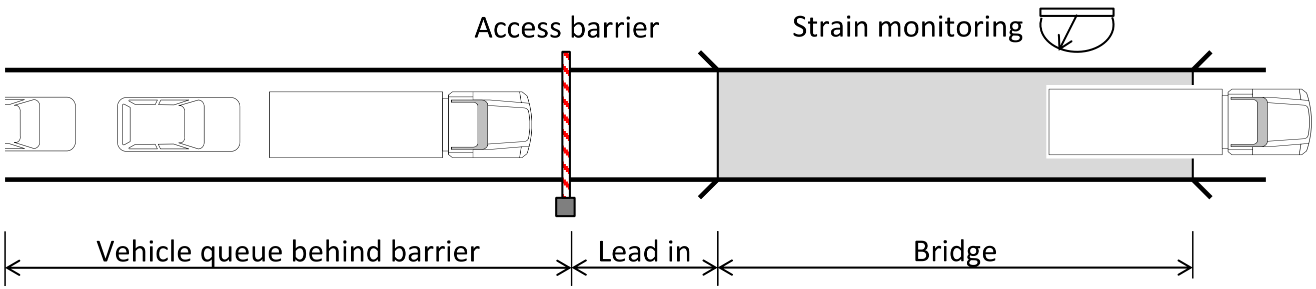
- Results are varied:
  - Up to 21% reduction
  - But very sensitive, and could make it worse

(Caprani et al 2012)

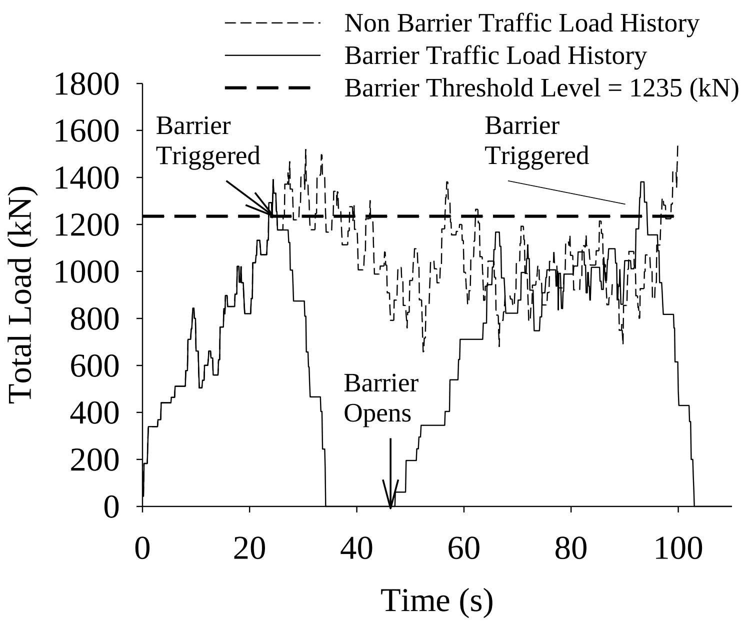


Controlling vehicle access

- If loading threshold exceeded, prevent access:



- Queue dispersion model of traffic from behind barrier
- Results:
  - reductions ~2-12%
  - Interrupts traffic stream
  - 'Lead-in' distance important



(Renehan & Caprani 2012)

Summary

Summary

- Traffic loading is the main source of uncertainty in bridge assessment: it's accurate estimation can make large savings possible.
- Traffic microsimulation is the ideal tool to explore traffic loading for assessment and management
- For assessment, the accuracy of current traffic load models can be assessed, and new ones calibrated.
- For management, new strategies can be explored and refined, facilitating the retention and operation of existing bridges

Acknowledgements

- Colleagues & collaborators:

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- Students:

Colm Carey, Brian Dunbar, Dr Alessandro Lipari, Neal Renehan, Mark Treacy

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Thank you for your kind attention!