

TRB Joint Traffic Analysis and Modeling Workshop, 6 August 2024

**TRB Committee on Highway Capacity & Quality of Service (ACP 40)
and TRB Standing Committee - Traffic Simulation (ACP80)**

Traffic modeling: micro-analytical meets micro-simulation

TRB Joint Traffic Analysis and Modeling Workshop

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Authoring Language: English (United States)

Presentation Contents



This presentation includes the following sections:

1. The Big Picture
2. Model Cross-Verification
3. Key Model Elements
4. Conclusion

Note: The author is the developer of the commercial **SIDRA INTERSECTION** "micro-analytical" software. He has also developed and used **micro-simulation** programs for research. These are referred to in this presentation.



Traffic modeling: micro-analytical meets micro-simulation



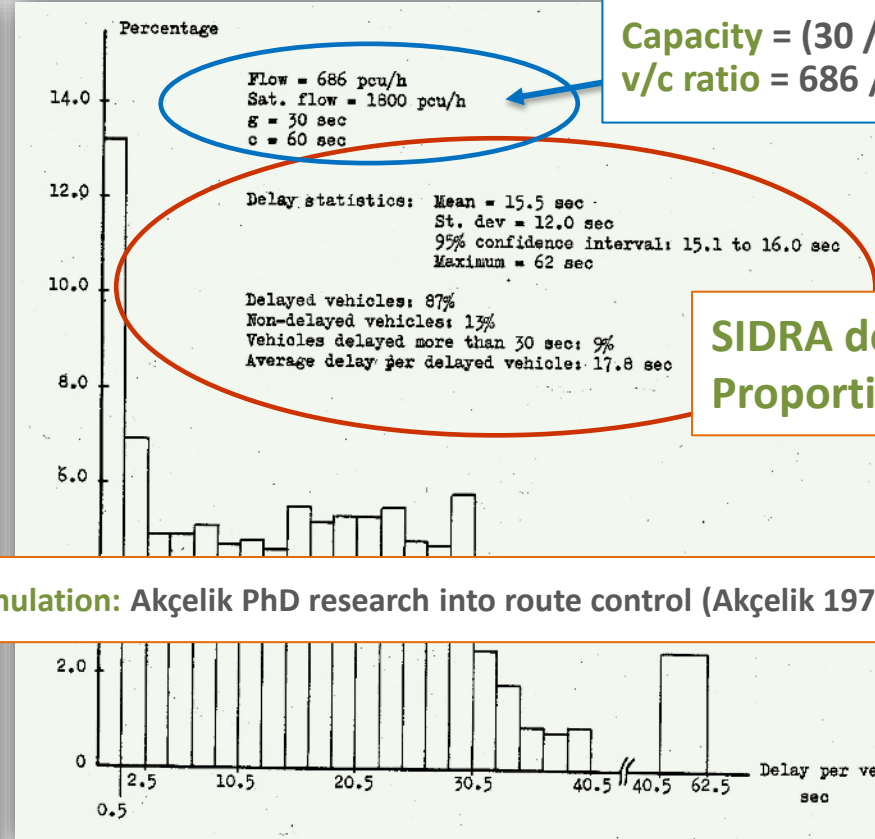
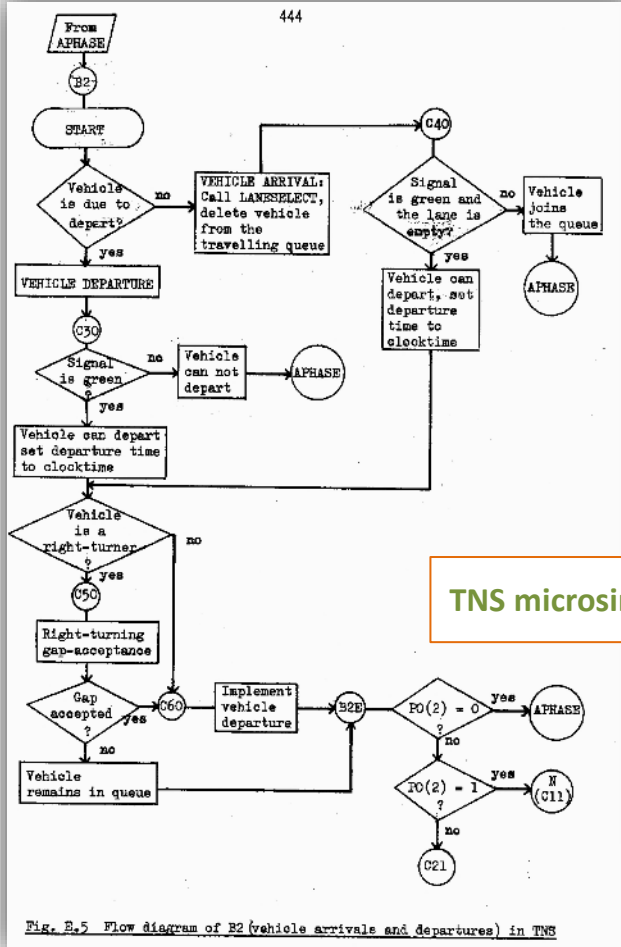
1. The Big Picture



As a saying goes (from *The San Diego Union*, 1930) ...

A man with **a watch** knows what time it is,
but a man with **two watches** is never sure!

TNS microsimulation (1970-74)



$$\text{Capacity} = (30 / 60) * 1800 = 900 \text{ pcu/h}$$

$$\text{v/c ratio} = 686 / 900 = 0.76$$

SIDRA delay = 15.3 s
Proportion queued = 0.87

TNS microsimulation: Akçelik PhD research into route control (Akçelik 1974, 1978).

MODEL C microsimulation

MODEL C: Single intersection microsimulation model

Used for calibrating some parameters of the SIDRA analytical models

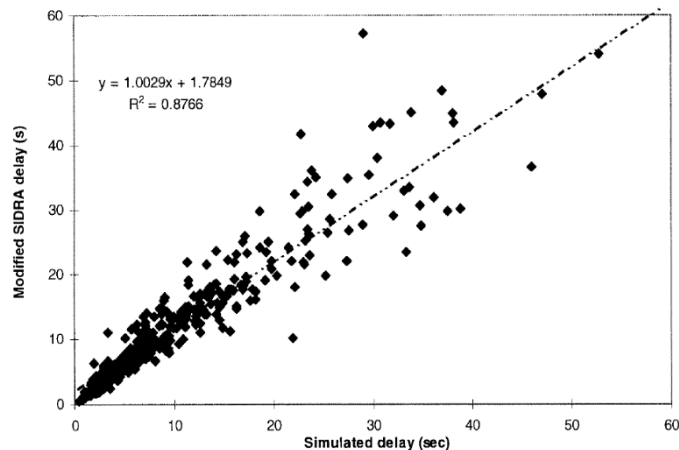


Fig. 7b - Predicted vs simulated delay for the modified SIDRA delay model using simulated capacity values

Akcelik, Christensen, and Chung (1998).

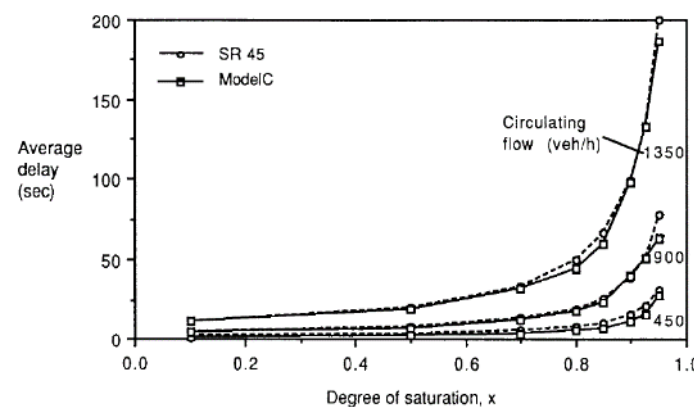


Fig. 4 - The comparison of steady-state delays from SR 45 and Model C for low, medium and high circulating flows (as a function of the degree of saturation)

Chung, Young and Akcelik (1992).

SR 45: ARRB Special report on Roundabout Capacity

Case Study: Richmond Rd and Garfield Rd Intersection, Marsden Park, NSW, Australia

An Australian research project (AUSTROADS NS 1371: **Guidelines for Selecting Techniques for the Modelling and Analysis of Network Operations**) compared the performance of micro-analytical (SIDRA INTERSECTION) and microsimulation (VISSIM) models of this intersection including comparison against field measurements.

The study found that “**Cycle average queue estimates of the two models were within one vehicle of field measurement**”. [They also compared the "Resources (i.e. labor and software) used to develop and run the (two) models" (Espada, Luk and Yoo 2010).]

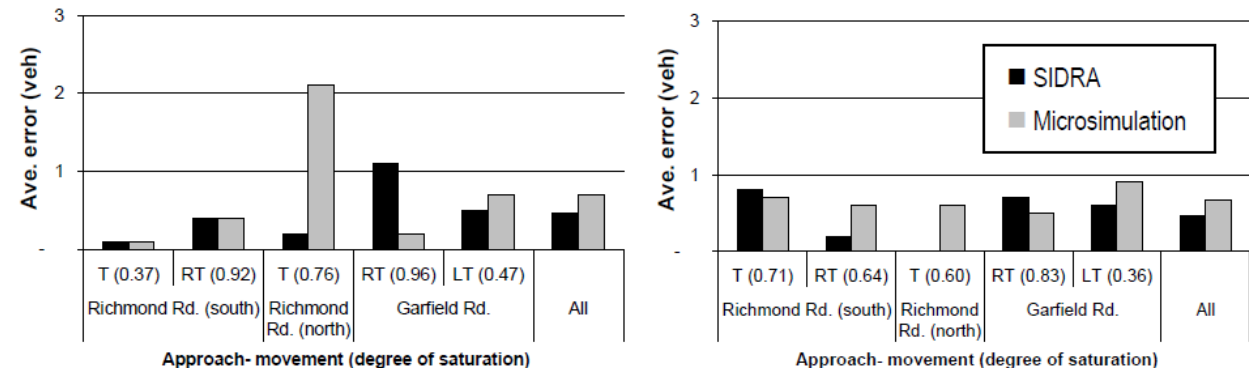


Figure 2: Richmond Rd. and Garfield Rd. cycle average queue estimates

We are modeling a COMPLEX SYSTEM

The road traffic / transport system we are modelling is a **Complex System**:

Multiple conflicting objectives

- **Diversity of road users:** cars, bicycles, buses, light rail, freight vehicles, **pedestrians**.
- **Diversity of areas of concern:** safety, operations, environment, economy.

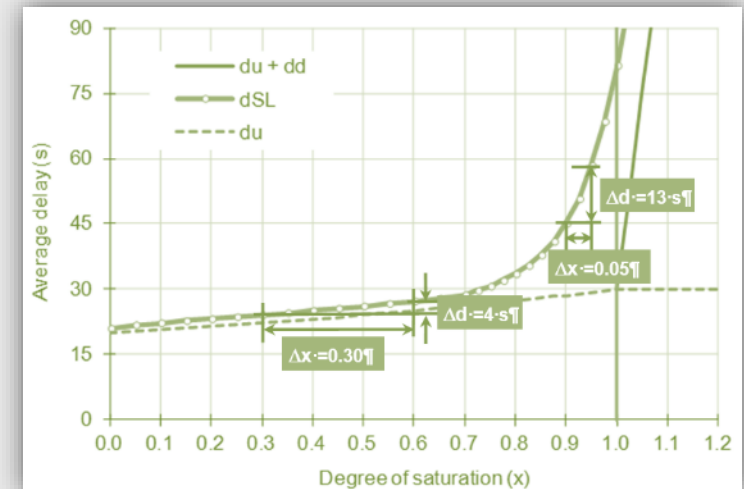
The **best solution** for one group of road users or one area of concern may not be the best solution for another.



We are modeling a COMPLEX SYSTEM

Understanding the characteristics of the **road traffic / transport system we are modelling**:

- ❖ **High variability** of travel demands and operating conditions
(hourly, daily, weekly, yearly changes – even changes within an hour can have significant effect).
- ❖ **Non-linearity, sensitivity** and **uncertainty** of operating conditions increase at a high rate when demand approaches and exceeds the capacity of the system.
- ❖ The **human element** adds greatly to the variability of the system as drivers, riders and pedestrians **adapt to varying conditions**, e.g. traffic conditions have an effect on aggressive vs relaxed behaviour.
- ❖ The **diversity of** transport and traffic engineering / planning / control practices and **emergence of new practices** over time add to the complexities.



Global software: Local Conditions and Model Calibration

Different

- driver behaviour,
- vehicle characteristics and
- traffic engineering practices

in different **countries** (and to a lesser degree, in different **regions** of a country) require **local calibration**. An example is given here.

For example, the **SIDRA** software setup for the **US Highway Capacity Manual (HCM)** has a significantly different default system.



Two-way Give-Way (YIELD)
common in Australia & UK
NOT USED in USA & Canada



All-Way Stop Control
common in USA & Canada
NOT USED in Australia & UK

Multimodal analysis

In transport planning and engineering practice, there has been a shift to **multimodal design**.

The objective of the **Multimodal** approach tends to be expressed as **Demand management** **instead of** **Capacity management**.

Keeping the balance between the **Demand management** and **Capacity management** is important.

Example: "**Movement and Place**" approach

Analytical and Microsimulation models need to support this **changing emphasis in practice**.

Managing **CAPACITY**



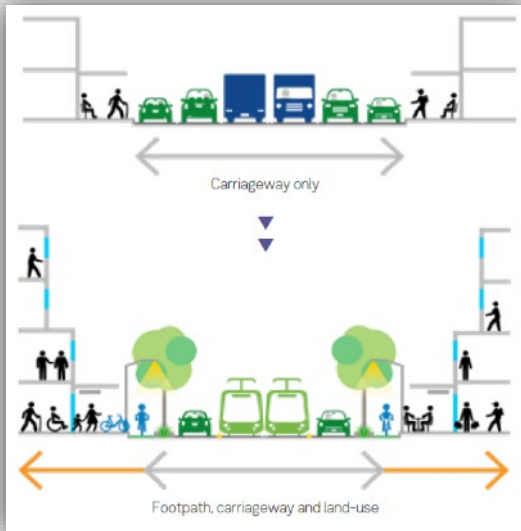
Managing **DEMAND**



"Movement and Place" approach

*"From Functional Classification systems that group roads and streets by their **CAPACITY** to keep vehicles moving*

... to a Movement and Place approach that takes a multi-modal approach to network planning."



(DOT Victoria 2019)



Traffic modeling: micro-analytical meets micro-simulation



2. Model Cross-Verification (Benchmarking)



Software for Smart Modelers



We want our **software users** to be **SMART MODELERS**:

- The software should encourage and help the users to **understand** the traffic / transport models used by the software including model **concepts**, **assumptions** and **limitations**.
- The software should increase the modelers' **knowledge** as they gain **experience** with it.
- Model users should be able to think in terms of the “**first principles**” in interpreting complicated looking software results. Simple **rules of thumb** help.
- **Smart modelers** appreciate that many **different mathematical constructs** are possible to **model the same phenomenon**, and many **different approaches (techniques)** are possible to model the same reality. They think less about the “**right model**” and the “**wrong model**”!

This will enable the **model users** to **question the model output**, make **choices** about alternative treatments (analysis scenarios) they have tested, and make **decisions** considering **uncertainties** in model results.

Model Transparency

Cross-verification of analytical and microsimulation models should aim to provide **model transparency** which is essential for the model users to **understand** the **model output** that software generates.

I quote from the **Transparency** discussion from a book on Artificial Intelligence (highly recommended).

Brian Christian (2020, p. 319) on Machine Learning and Human Values

"In developing architectures that lend themselves to explanations, whether visual or verbal, there are several things to be on guard for. ...

...

*Caution is warranted that we do not simply create systems optimised for **appearance of explanation**, or for the sense they give us that we **understand them**. Such systems could wield this ability deceptively ... "*

Publications on micro-analytical and micro-simulation models

Refer to our **papers and presentations** about discussions on micro-analytical and micro-simulation models:

- AKÇELIK, R. (2023). **What is good about analytical traffic modelling?** Technical Note. Akcelik and Associates Pty Ltd, Melbourne, Australia.
- AKÇELIK, R. and BESLEY, M. (2001). **Microsimulation and analytical methods for modelling urban traffic.** Conference on Advanced Modeling Techniques and Quality of Service in Highway Capacity Analysis, Truckee, California, USA, July 2001.
- AKÇELIK, R. (2007). **Microsimulation and Analytical Models for Traffic Engineering.** Presentation at the ARRB - AUSTROADS Microsimulation Forum, Sep 2007.

These are available for download from
<https://www.sidrasolutions.com/publications>

Car-following theory to fundamental q-v-k models - an example of synergy

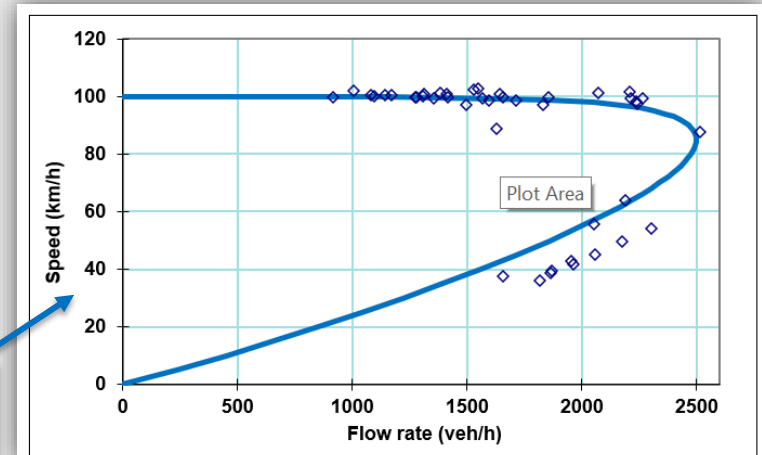
Differential equation based on car-following theory:

$$dv/dk = -c v^m k^{l-2}$$

(v = speed, k = density, and c , m , l = constants).

Various fundamental Flow-Speed-Density (q-v-k) models were derived from the above equation. This was discussed in Akçelik, Roper and Besley (1999).

Model	l	m	v_n / v_f	k_n / k_j
Linear (Greenshields 1934)	2.0	0	0.500	0.500
Parabolic (Drew 1965-1966)	1.5	0	0.333	0.444
Parabolic (Pipes 1967)	2.0	0.5	0.444	0.333
Polynomial (Akçelik 1974)	2.5	0.5	0.563	0.397
Polynomial for freeway traffic (May and Keller 1967, 1968)	2.8	0.8	0.590	0.278
Polynomial for freeway traffic (Akçelik, Roper and Besley (1999))	5.0	0.99	0.781	0.222



"Individual vehicles" and "traffic movements"

The concepts and parameters used in **analytical modeling** are for "traffic movements (traffic streams)".

This modeling approach converts "individual vehicle" movement characteristics such as **car following**, **lane change**, **acceleration and deceleration** to more aggregate and measurable "traffic" characteristics.

The **example about car-following and fundamental flow-speed-density models** may show the way for **model cross-verification** (cross-checking / benchmarking). This is discussed in the next section.

Individual Vehicles



Traffic Movements



Traffic modeling: micro-analytical meets micro-simulation



3. Key Model Elements



Model Cross-Verification (Benchmarking)

Comparison of specific microsimulation and analytical model components as a **benchmarking method for model cross-verification** was suggested previously (Algers 2000; Yoshii 1999; Fox 2000).

The specific **model elements** to be considered for this purpose are listed and discussed briefly in the following slides.



Key Elements for Model Cross-Verification and Calibration

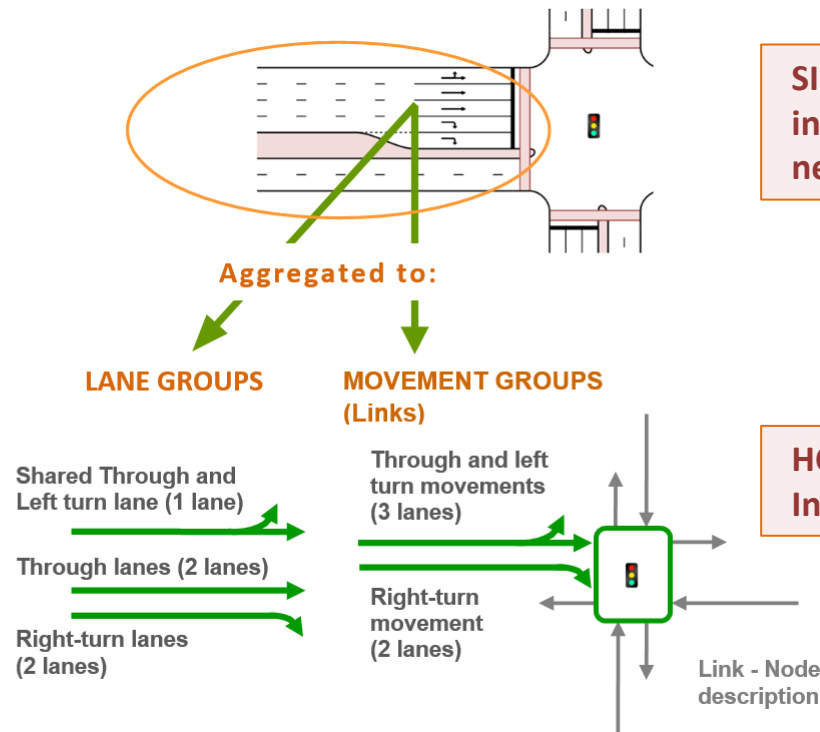
- **Lane-based model**
- **Lane use** at intersection approaches and midblock lane changes
- **Models** reflecting the effects of **road geometry**, **driver behavior** and **vehicle characteristics** including **acceleration - deceleration** models
- **Definitions** and **measurement methods** for consistency of **traffic performance variables**
- **Environmental objectives**
- **Capacity analysis**
- **Near-Saturated and Oversaturated conditions**
- **Queue discharge**
- **Gap-acceptance**
- **Headway distributions and bunching models**
- **Lane blockage and capacity constraint in Networks**

Lane based models

Cross-verification is facilitated by the use of **lane-based modeling** in micro-analytical and micro-simulation methods.

Lane-based modeling is **common** for microsimulation models but **uncommon** for analytical models.

Use of Movement Groups and Lane Groups is **common** for analytical models but **uncommon** for microsimulation models



SIDRA model for all intersection types and networks is lane based

HCM Edition 7 Signalized Intersection Model (Chapter 19)

HCM Roundabout capacity model is lane based.

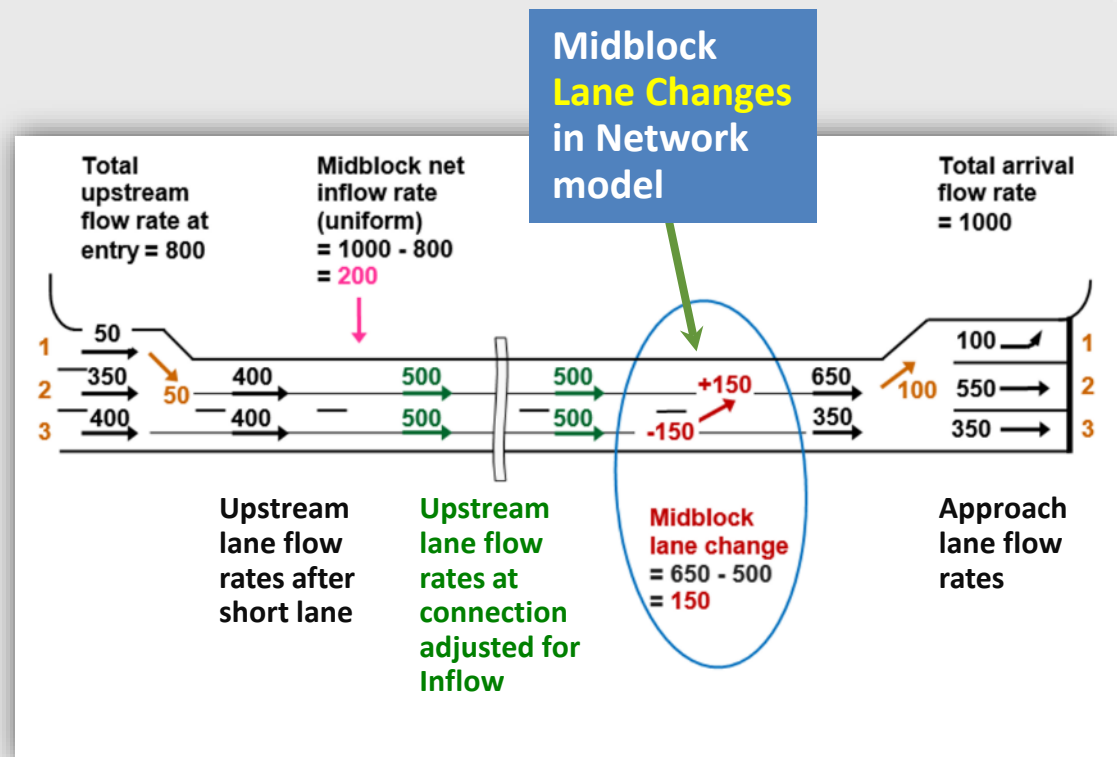
Lane use at intersection approaches and midblock lane changes

Lane flows are determined using **lane choice** and **lane change** models

- Shortest queue vs shortest delay
- Many factors causing lane underutilisation

Midblock lane changes affect **platoon arrival patterns** at signals

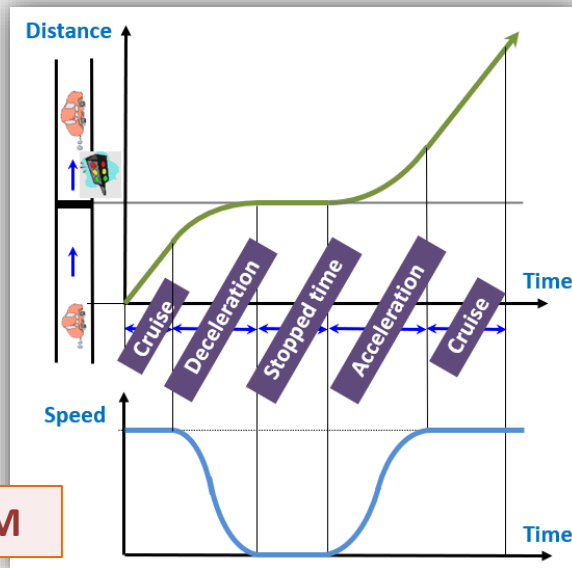
Low demand for this lane at this time



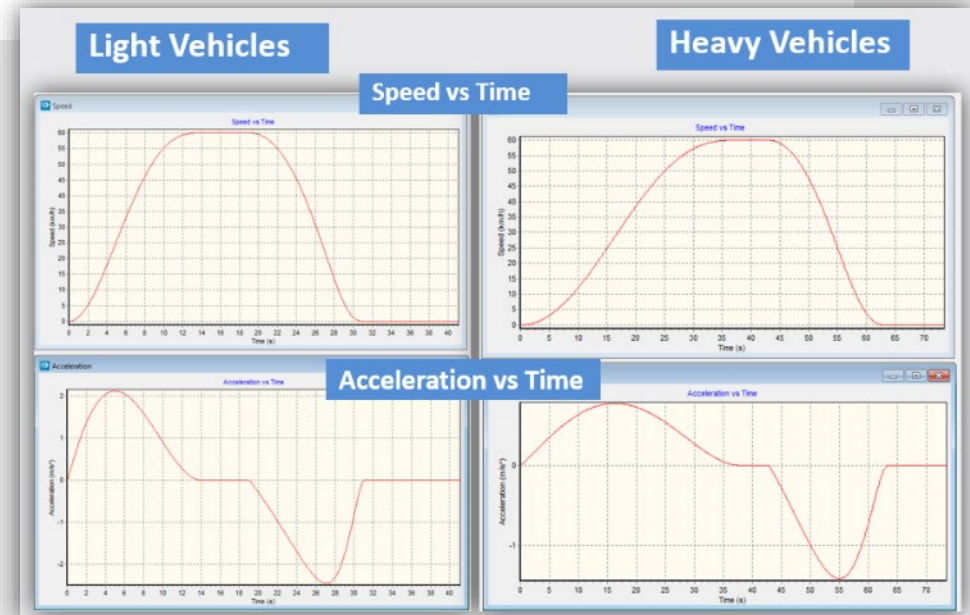
Road geometry, driver behavior and vehicle characteristics

Models should reflect the effects of **road geometry, driver behavior and vehicle characteristics**:
For example, roundabout analytical models based on **intersection geometry only** and **gap acceptance behavior only**

Acceleration - Deceleration: Important role in energy, emission, operating cost and geometric delay models



NOT in the HCM



Definitions and measurement methods for consistency of traffic performance variables

Queue definition issue

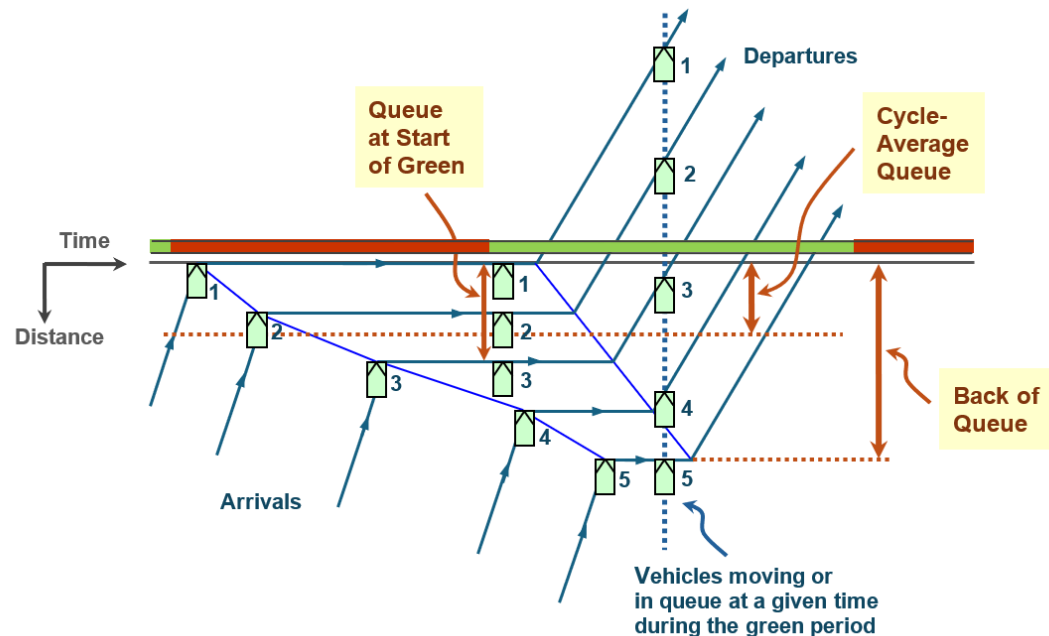
There are many useful definitions of **queue length** as shown here.

Average queue and **percentile queue** apply to each of these.

Back of Queue should be used for all intersection types for modeling

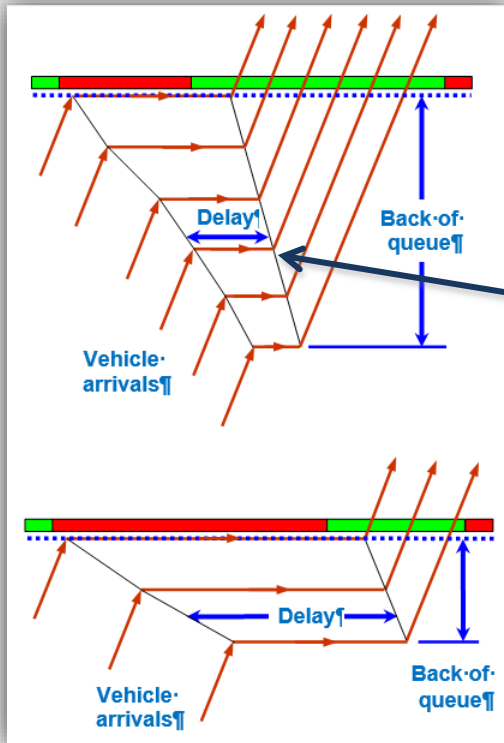
- **upstream lane blockage** in networks
- **approach short lane capacity**

HCM uses Back of Queue for signals but it uses Cycle-average Queue for roundabouts and sign control



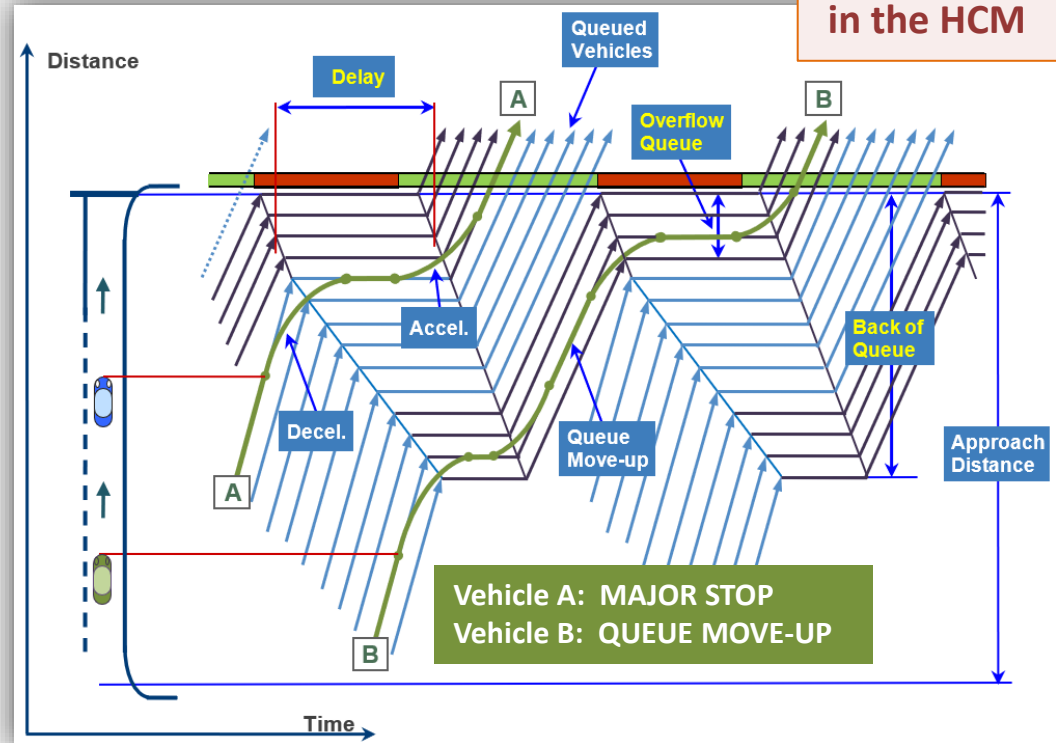
Back of Queue, Delay, Stops, Queue Move-ups

Long Queue - Short Delay vs Short Queue - Long Delay



Long moving queue cannot be indicated by the Cycle-average queue due to low delay

Relationship Between Queue Move-ups (Multiple Stops) and Back of Queue



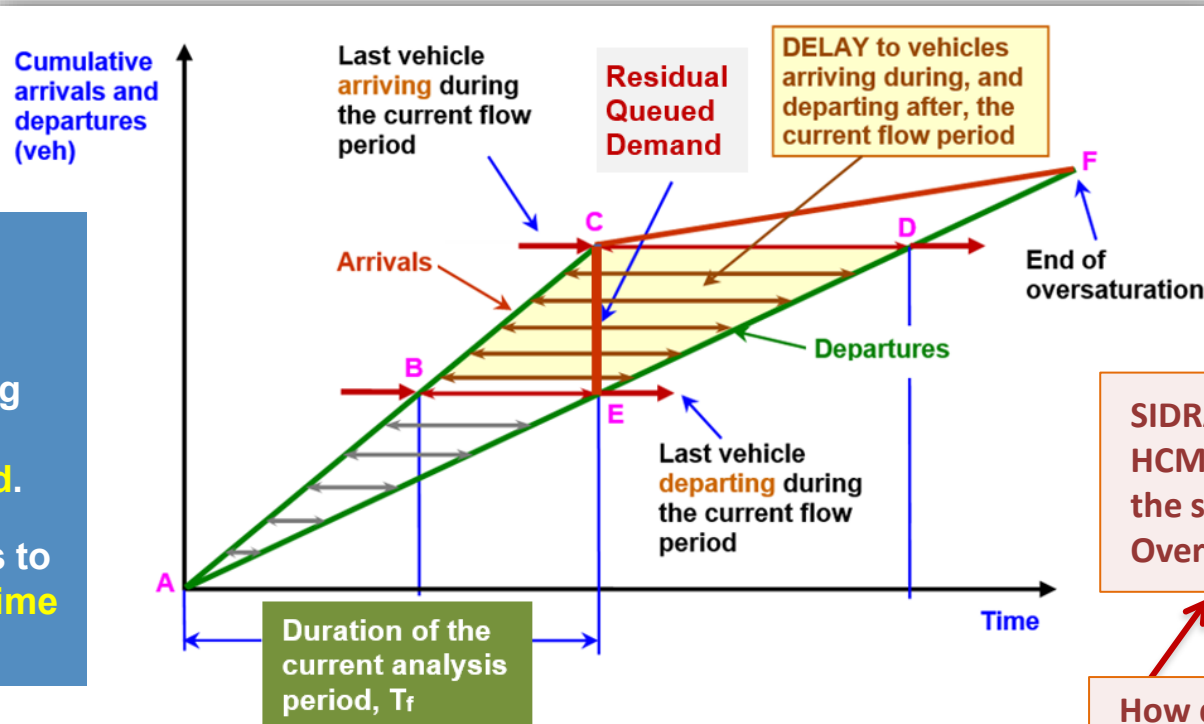
No STOPS model in the HCM

Residual Queue and Oversaturation Delay after the Peak Analysis Period

Delay definition issue

In this **analytical model**, delay experienced by vehicles departing after the analysis period is **included**.

This corresponds to **in-stream travel time survey method**.



SIDRA Standard and HCM Delay Models use the same definition of Oversaturation Delay

How does microsimulation match these?

Time dependence of performance functions:
Delays and queue lengths are larger with longer duration of demand, T_f

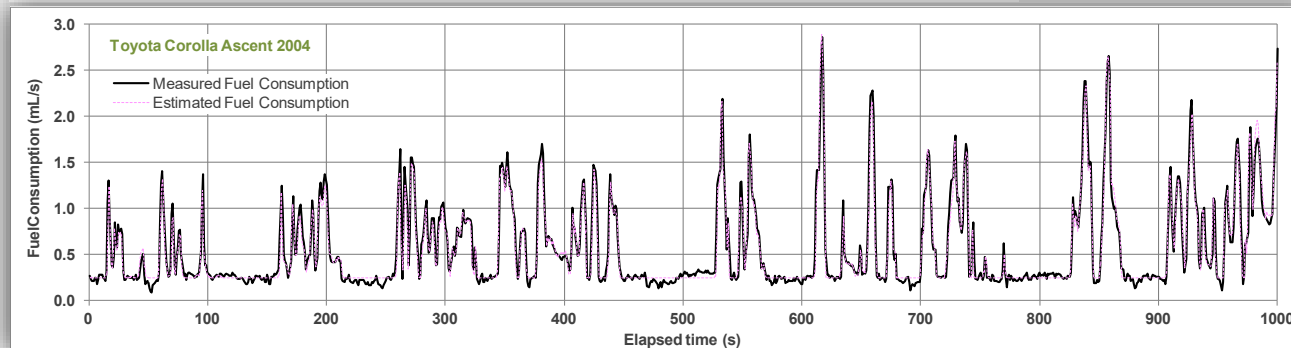
Environmental objectives

Analytical and Microsimulation models need to support **environmental objectives** in traffic analysis

Energy and Emission modelling requires:

- modelling of **stop-starts** as a performance measure
- **acceleration - deceleration** modeling for different vehicle movement classes
- Frequent updating of **energy and emission** model parameters for vehicles

Estimated vs measured instantaneous fuel consumption rates



Articles on Fuel Consumption and Emission Model Calibration:
<https://www.sidrasolutions.com/publications>

Capacity analysis

CAPACITY is a dynamic concept by definition:

It is the highest sustainable flow rate that can be achieved during a specified time period under given (prevailing) road, geometric, traffic, environmental and control conditions.

Demand flow levels cause significant capacity variations for

- movements subject to gap acceptance (at roundabouts, two-way stop and give-way / yield sign-controlled intersections, signals, and merge lanes at freeway entry ramps and at exit short lanes at intersections);
- Short lane capacities and lane blockages by downstream queues.

Measurement of capacity by microscopic models needs discussion.

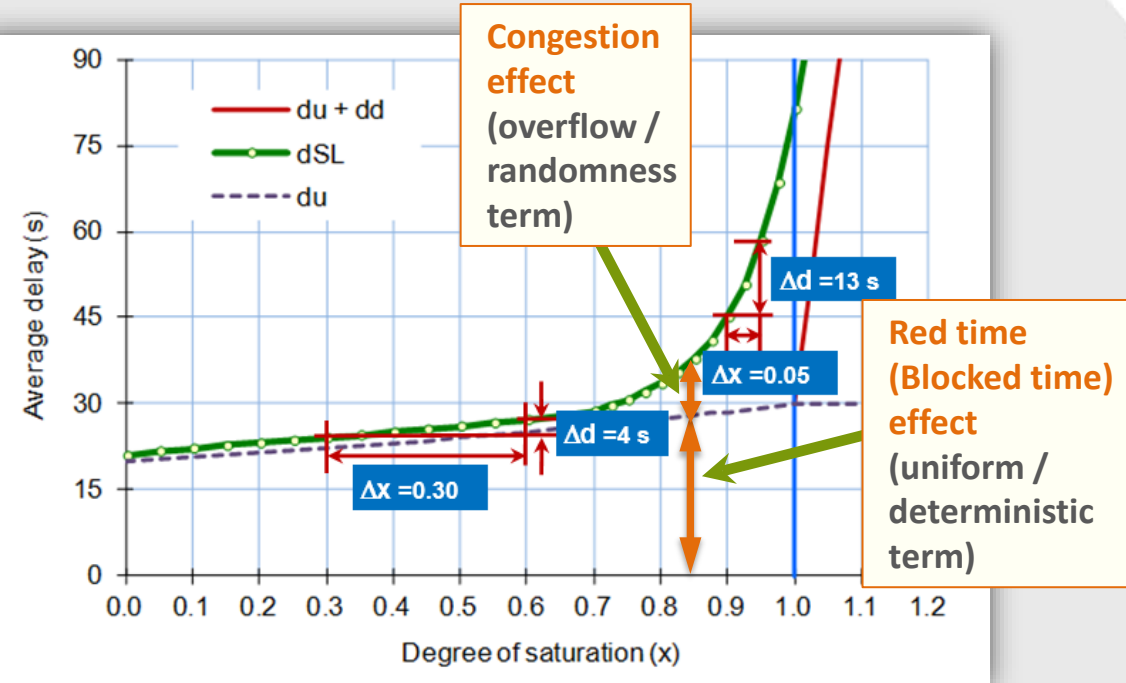
- The capacity is achieved under high demand (fully saturated) conditions when queued vehicles use all opportunities provided by green periods and gaps in opposing streams.
Creating these conditions in microsimulation cannot be reliable since traffic elements are highly interactive (especially in closely-spaced intersection networks) and changed conditions of these elements cannot be controlled reliably. (Akçelik 2023)
- Therefore, applying cross-verification to model elements used in microsimulation may be more productive.

Near-Saturated and Oversaturated conditions

Errors in capacity estimation are not much of a problem for **low v/c (undersaturated)** conditions since performance parameters (delay, queue length and stop rate) have low sensitivity to the v/c ratio for those conditions.

For roundabouts, near-saturated and oversaturated conditions may trigger **unbalanced flow conditions** resulting in reductions in capacity.

Not in the HCM



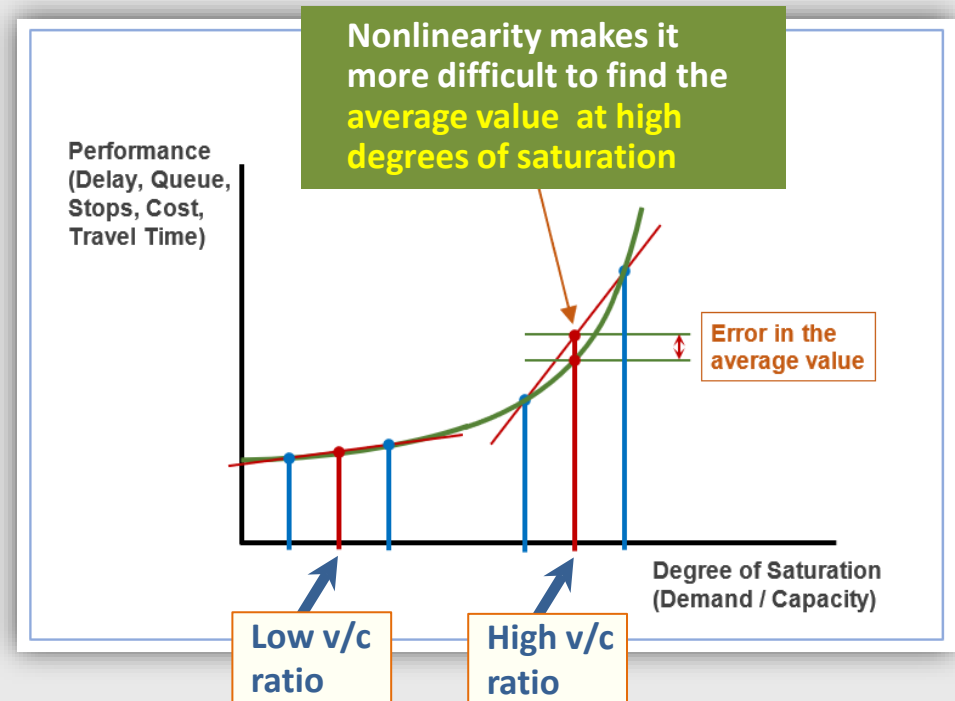
SIDRA and HCM performance models use this structure

x: Degree of Saturation (v/c Ratio)
dSL: Stopline delay
dd: Deterministic oversaturation delay

Number of microsimulation runs required

The **number of microsimulation runs required** to control the randomness effects also needs discussion. This is important for **reliable comparison of analysis scenarios**.

- For **oversaturated conditions**, it would be wrong to run simulation for **longer periods for convergence** since **queues would build up persistently** because of demand exceeding capacity. An **increased number of simulations is needed** instead.
- For **near-saturated conditions** when the average demand is less than but close to capacity, significant **overflow queues will also** occur due to randomness of arrival flows. Therefore, average results require a large number of simulations.



Queue discharge

Saturation Flow Rate, s is the **maximum departure (queue discharge) flow rate** achieved by vehicles departing from the queue during the **green (or unblocked) period** ($s = 3600 / h_s$).

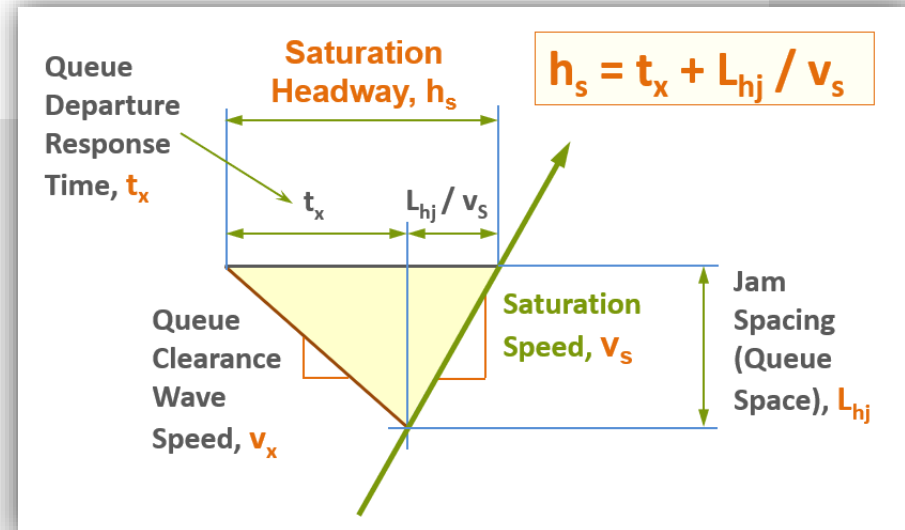
Saturation Headway, h_s should be measured according to the standard saturation flow definition.

Saturation Speed, v_s : The steady speed value associated with the queue discharge (saturation) flow rate.

These are observed at the **stop line**.

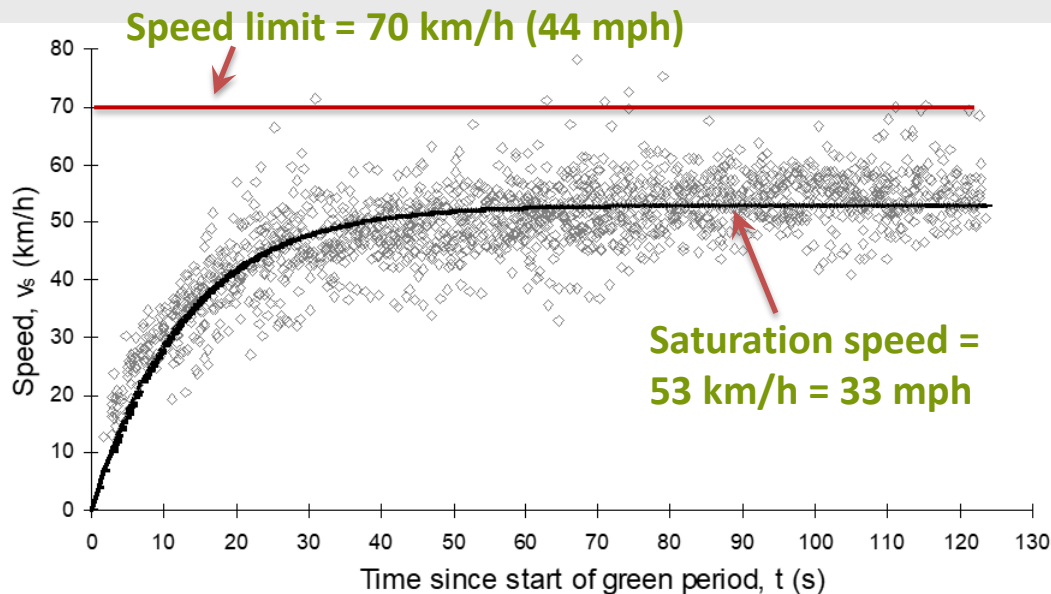
Parameters that affect these should be clearly given in **microsimulation** output for cross-verification:

- Car following model specific to queue discharge
- Acceleration profile (acceleration to cruise speed?)
- Saturation Speed
- Specific queue start response time
- Queue Space (Jam Spacing)

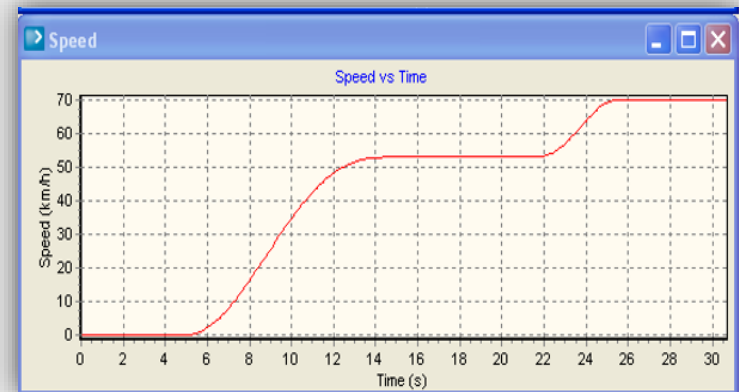


Saturation Speed

Measured and predicted queue discharge speeds for
General Holmes Drive and Bestic St in Sydney (through lane at isolated intersection):
Steady queue discharge speed is maintained after **two minutes of green time**.

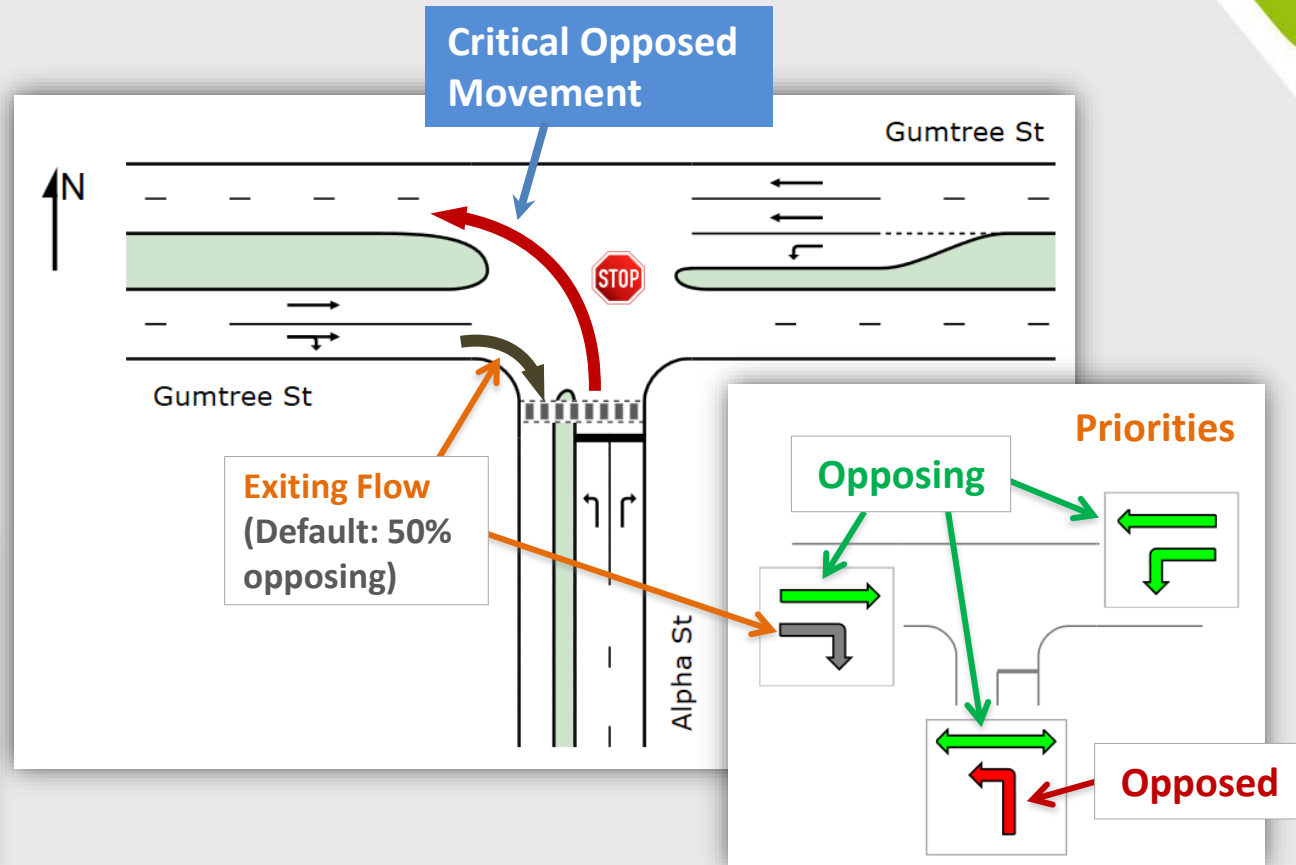


Acceleration with Saturation Speed:
0 - 53 - 70 km/h
(SIDRA TRIP software speed - time graph
emulating acceleration of a single vehicle)



Gap Acceptance

- Follow-up Headway and Critical Gap parameters depend on intersection geometry, control type and driver behavior
- Exiting Flow effect (default: 50%)
- Pedestrian effects on capacity: HCM Model

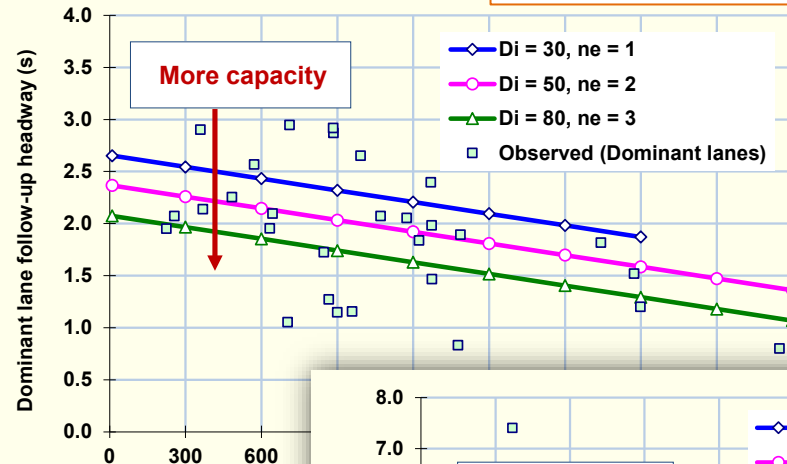


Roundabout model features

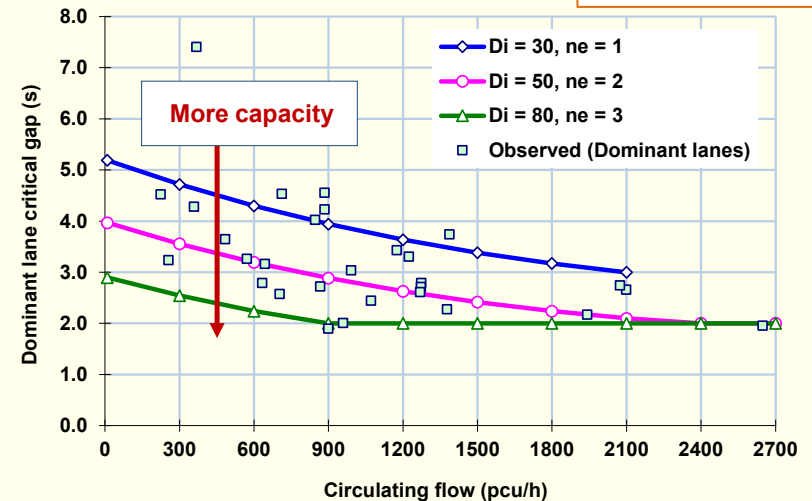
- Follow-up Headway and Critical Headway values decrease with increased circulating flows
- Capacity Constraint
- Unbalanced flows
- Upstream signal effects (extra bunching)
- Roundabout metering signals

NOT in the HCM Roundabout Capacity Model

Follow-up Headway



Critical Gap



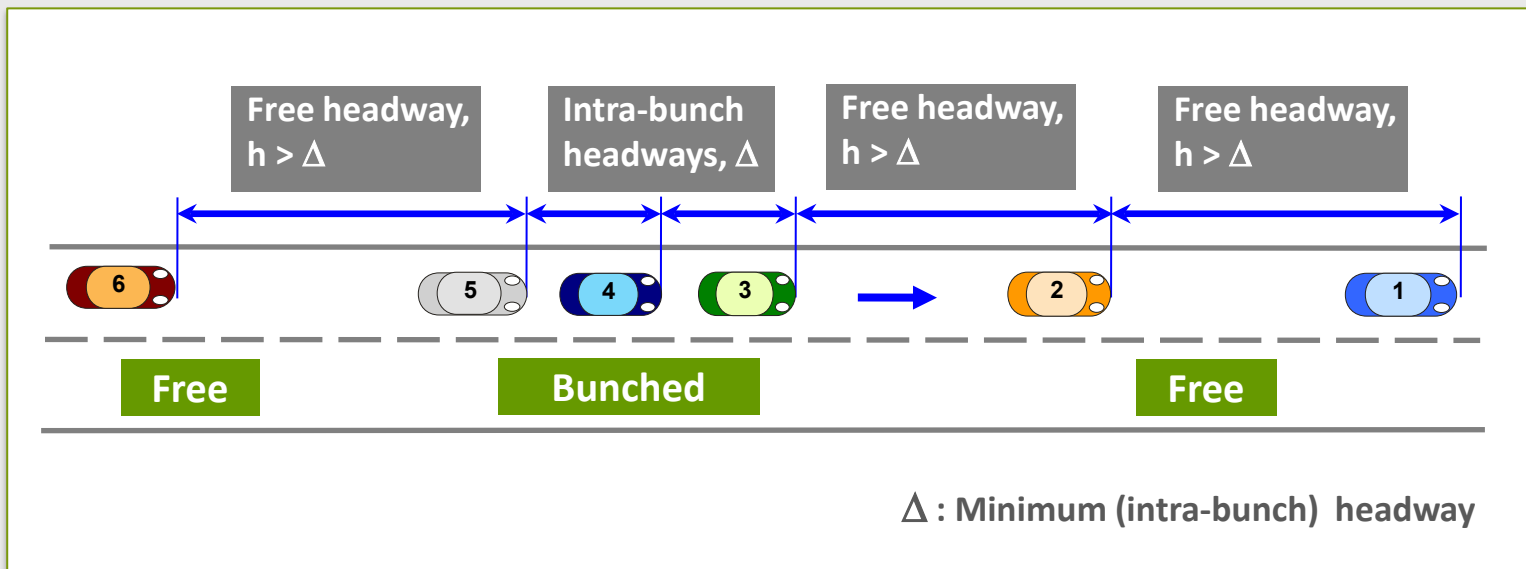
Bunching Model

An important parameter for uninterrupted flows as well as

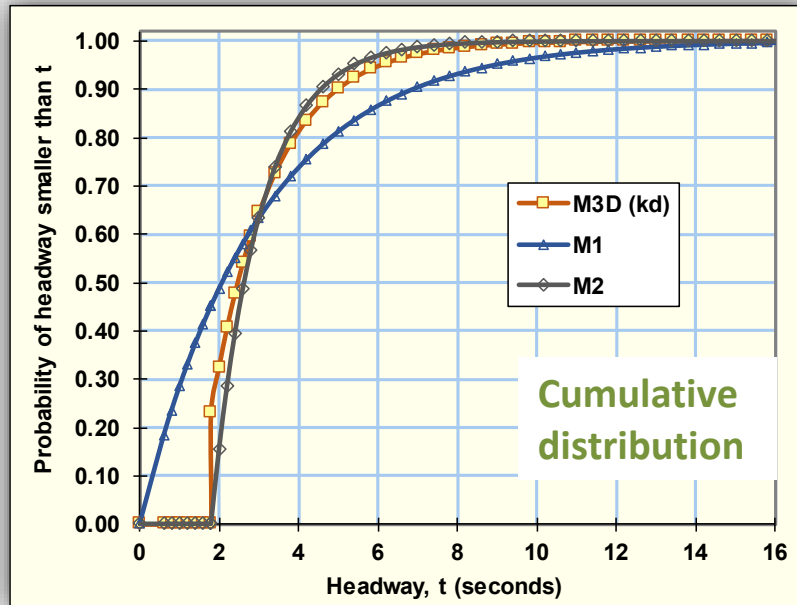
- ❖ Arrival headway distributions
- ❖ Speed-flow relationships

Applies to roundabout circulation flows as well

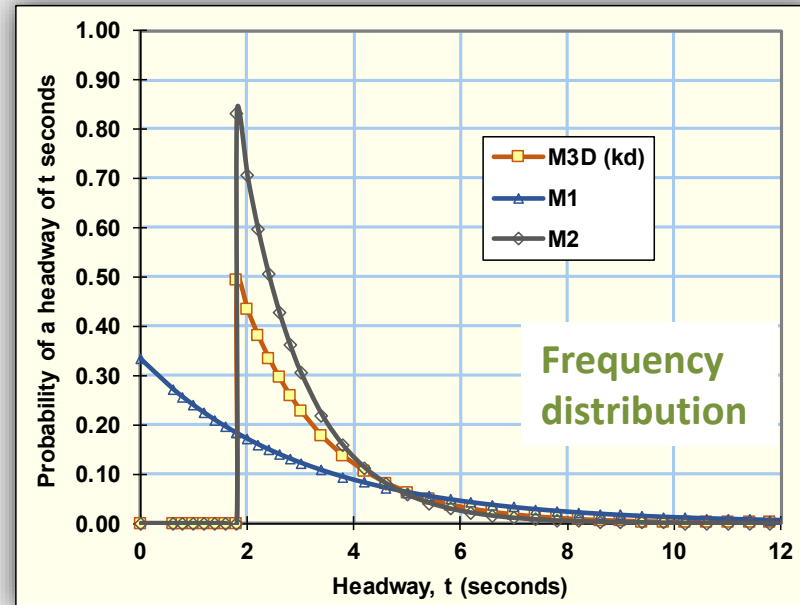
Bunched Exponential (M3) Headway Distribution Model (Cowan 1975)



Arrival Headway Distributions



M3D: Bunched Exponential
M1: Negative Exponential
M2: Displaced Negative Exponential



HCM uses the M1 Model (no bunching)
SIDRA uses the M3D model
(Cowan 1975; Akcelik 2006)

Lane Blockage and Capacity Constraint

Two basic model elements that are highly interactive with opposing effect:

Backward spread of congestion (reduced upstream capacity)



Capacity constraint (reduced downstream arrival flows)

- Backward spread of congestion and capacity constraint are common to all intersection types.
- A convergent solution requires an iterative process to find a solution that balances these opposing effects.
- Capacity losses due to downstream queue blockages (especially if this causes oversaturation) lead to an increased number of iterations for analytical models and the need for an increased number of simulations by microsimulation models.



Traffic modeling: micro-analytical meets micro-simulation



4. Conclusion



Conclusion

Powerful concepts have been developed and used in traffic modelling for a long time. These apply to key elements of analytical models and are related to methods used in microsimulation models.

These concepts are understood by the profession. They provide a common language for communication.

The concepts that apply to a number of the key model elements have been discussed in this presentation.

It is recommended that formal procedures (guidelines) are developed for cross-verification and calibration of analytical and microsimulation models using the well-established micro-analytical and microsimulation concepts.



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Abstract

Powerful concepts have been developed and used in traffic modelling for a long time. These apply to key elements of analytical models and are related to methods used in microsimulation models. This presentation recommends that formal procedures are developed for cross-verification (benchmarking) and calibration of analytical and microsimulation models using the well-established micro-analytical and microsimulation concepts. This effort should aim to provide model transparency which is essential for the model users to understand the model output that software generates. The presentation discusses a number of key concepts that apply to analytical and microsimulation models. These include the importance of lane-based modeling, lane use at intersection approaches and midblock lane changes, acceleration - deceleration, definitions and measurement methods for consistency of traffic performance variables, environmental objectives, capacity analysis, near-saturated and oversaturated conditions, queue discharge, gap-acceptance, arrival headway distributions and bunching models, and lane blockage and capacity constraint in networks.

Presenter

Dr Rahmi Akçelik is a leading scientist and software developer with 50 years of practical, research and training experience in the area of road traffic operations, traffic engineering, management and control. He is Director of Akcelik and Associates Pty Ltd (trading as **SIDRA SOLUTIONS**), a company based in Melbourne, Australia. He has about 400 technical publications in his area of expertise. He is the author of the **SIDRA INTERSECTION** and **SIDRA TRIP** software packages.

Awards received by Dr Akçelik include the **2014 Roads Australia Award for Technical Excellence**, **2008 ITE ANZ Contribution to the Transportation Profession Award**, and **1999 Clunies Ross National Science and Technology Award** for outstanding contribution to the application of science and technology.



END OF PRESENTATION

Thank you!