Workshop 172
Simulation: Looking Back and Looking Ahead
Constantinos Antoniou, National Technical University of Athens, Greece; Robert Lawrence Bertini, Portland State University, presiding
Sponsored by Traffic Flow Theory and *Characteristics Committee*

The focus of this year's SimSub simulation workshop is consistent with the meeting's theme, "Celebrating Our Legacy, Anticipating Our Future." Top experts in the field will provide discussion papers on the history, current status, and future of traffic simulation. The audience will be asked to provide input and frame a forward-looking discussion of future trends and research needs. Join us for this popular annual event. The intent is to publish a circular containing the material presented.

No	Paper	PPT	Title/Author
1	x	x	Traffic Flow Modeling: A Genealogy Femke van Wageningen-Kessels, Delft University of Technology, Netherlands
2	x	x	History of the Use of Simulation in Traffic Analysis Edward Lieberman, KLD Associates, Inc.
3	x	x	Evolution of the TEXAS Model and Traffic Simulation Thomas W. Rioux, Rioux Engineering
4			History of VISSIM Development Peter Vortisch, PTV AG
5	x		Evolution of SUMO Simulation Model Peter Wagner, German Aerospace Center
6			Thoughts on Traffic Simulation Models Alexander Skabardonis, University of California, Berkeley
7		x	Future Directions for Managing Uncertainty in Stochastic Traffic Models Vincenzo Punzo, University of Naples Federico II, Italy
8	x	x	Big Data and the Calibration and Validation of Traffic Simulation Models Kaan Ozbay, Rutgers University
9	x	x	Looking Back and Forward at Modeling the Safety System William Young, Monash University, Australia

Traffic Flow Modeling
A Genealogy

Femke van Wageningen-Kessels

Serge Hoogendoorn, Kees Vuik, Hans van Lint

2014 TRB-AM, Workshop 172 - Simulation: Looking Back and Looking Ahead

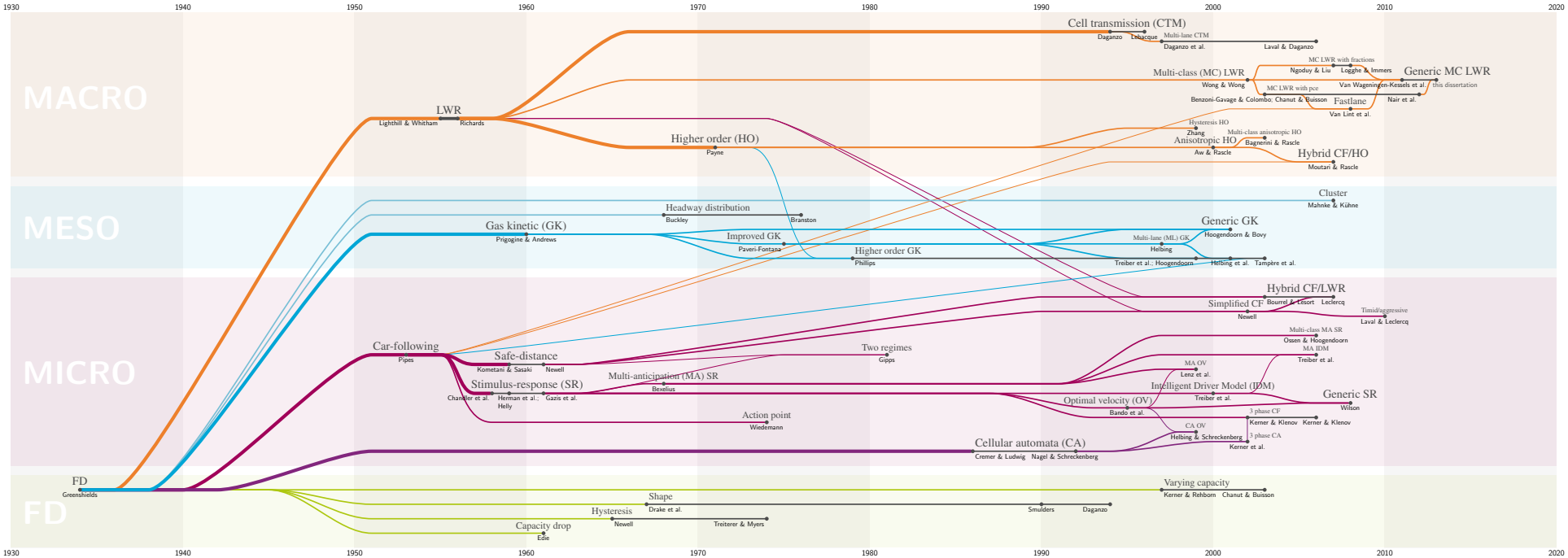
Aim of Traffic Flow Model

- Describe and predict vehicular flows on roads
- Number of vehicles
- Positions, speeds, accelerations
- Core of simulation tool

Applications

- Prediction of congestion, emissions, safety
- Design of roads / transport systems
- Traffic management
- Understanding of human behavior

Genealogy / Family tree / Model tree



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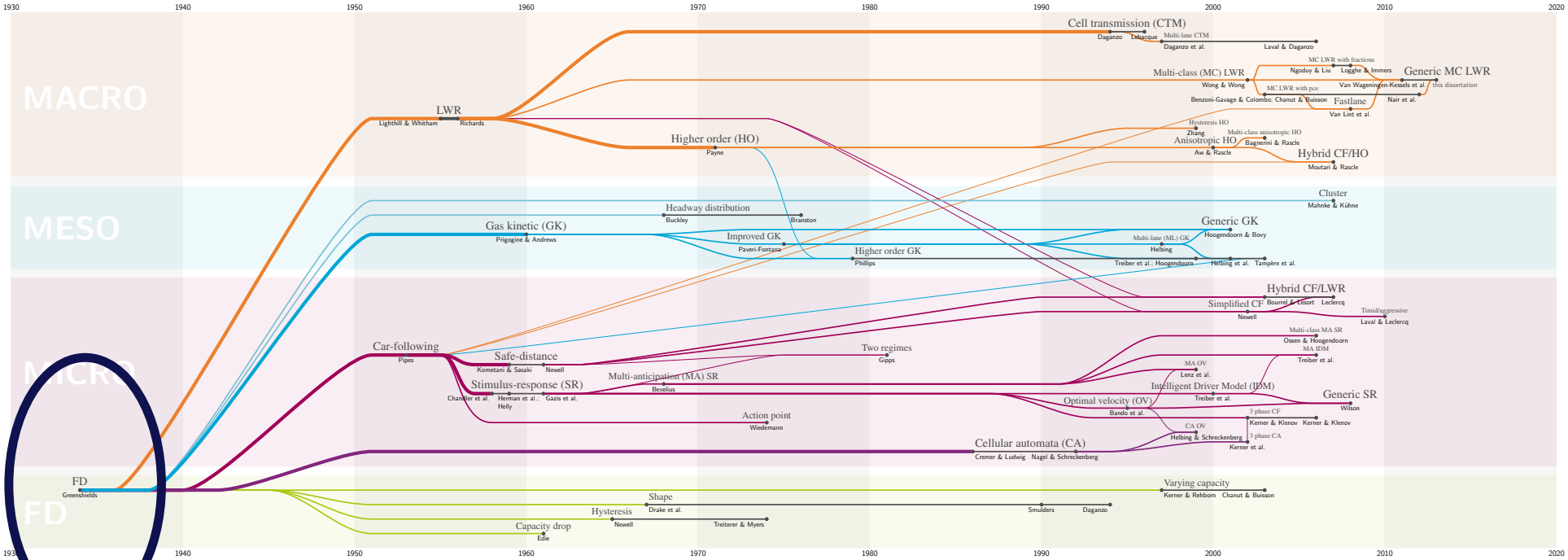
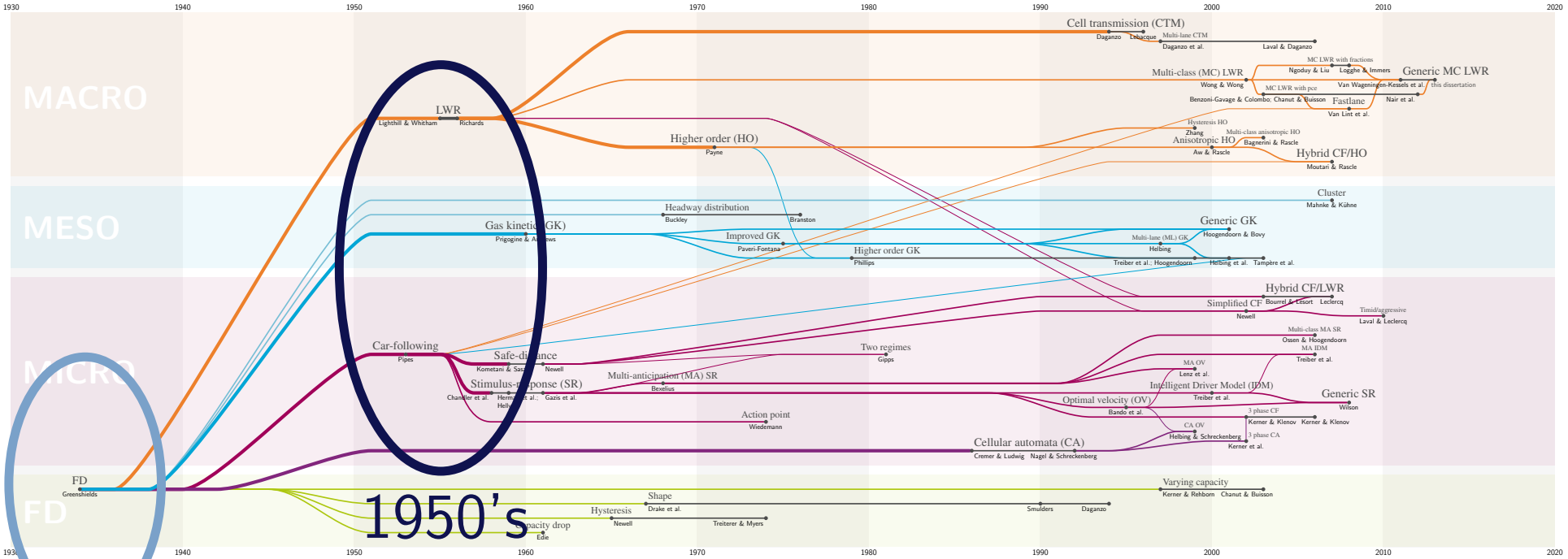


1934

Foundation of traffic flow modelling:
Fundamental diagram (FD)

Genealogy / Family tree / Model tree



1950's

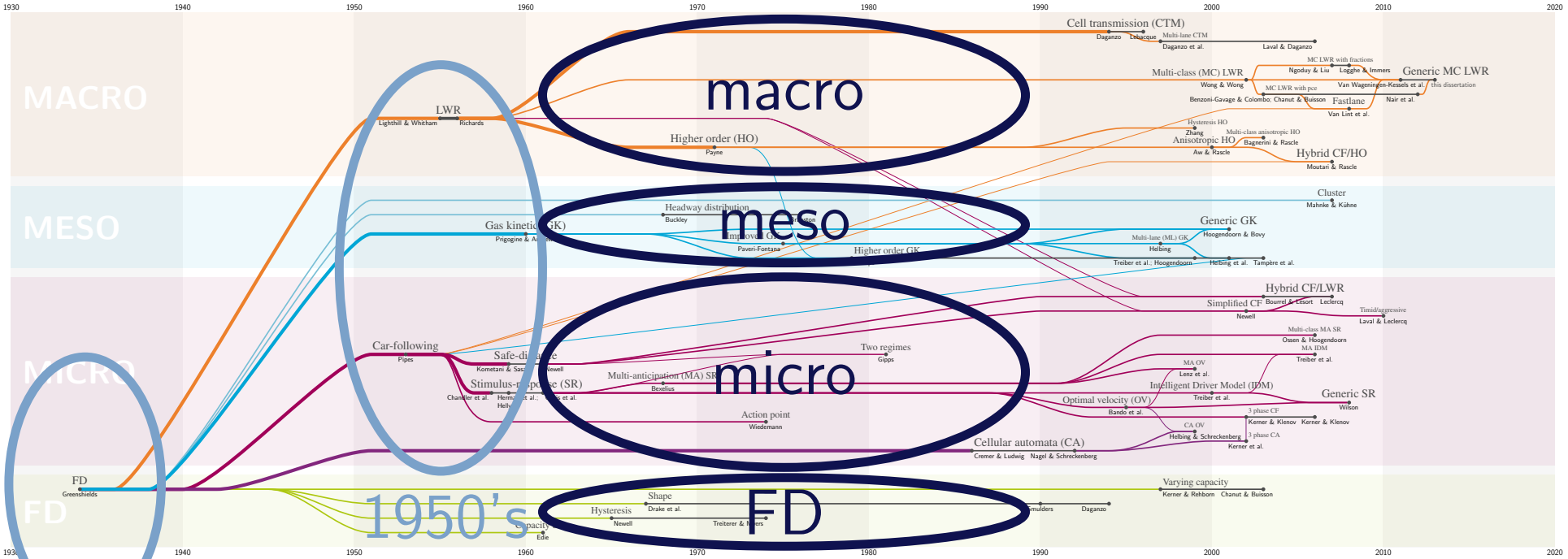
Models including dynamics

1934

Foundation of traffic flow modelling:
Fundamental diagram (FD)

Genealogy / Family tree / Model tree

1960 – 1980: 4 families



Models including dynamics

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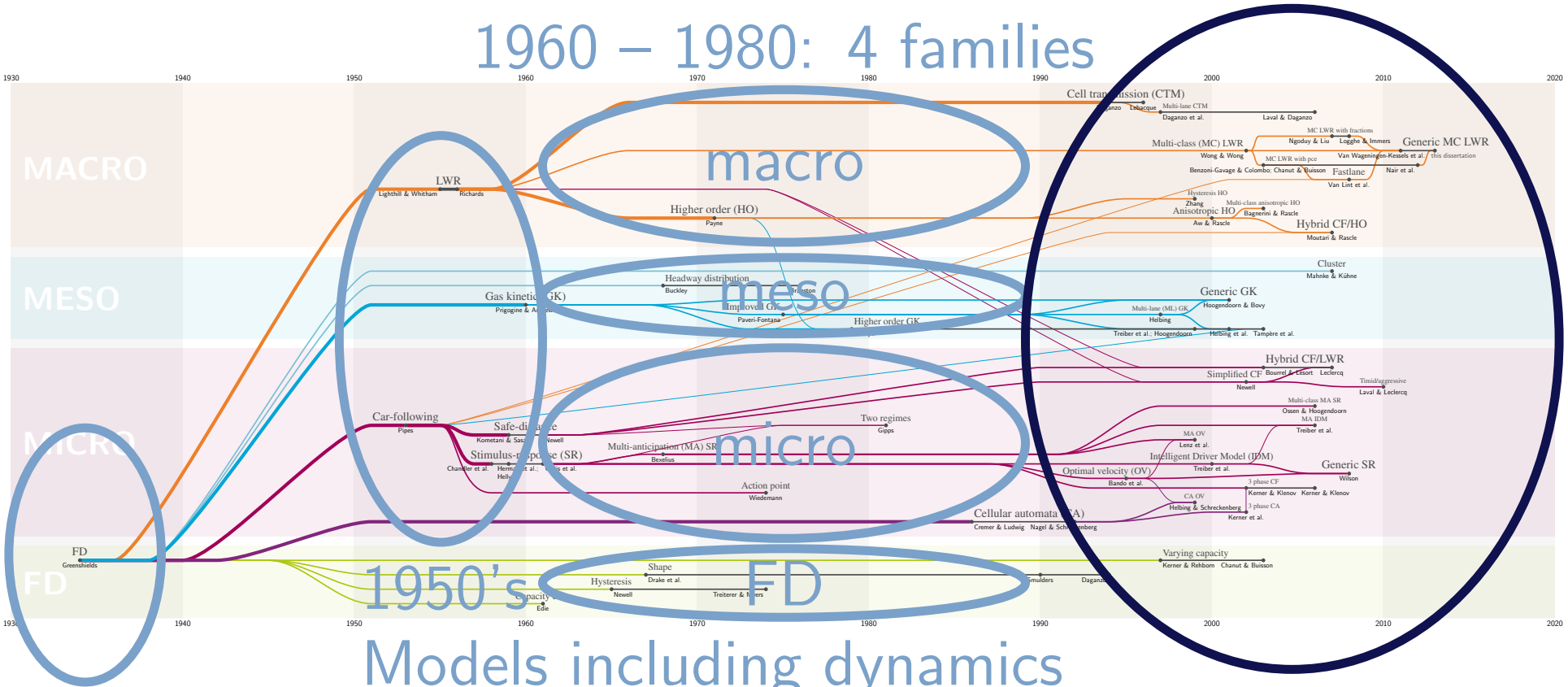


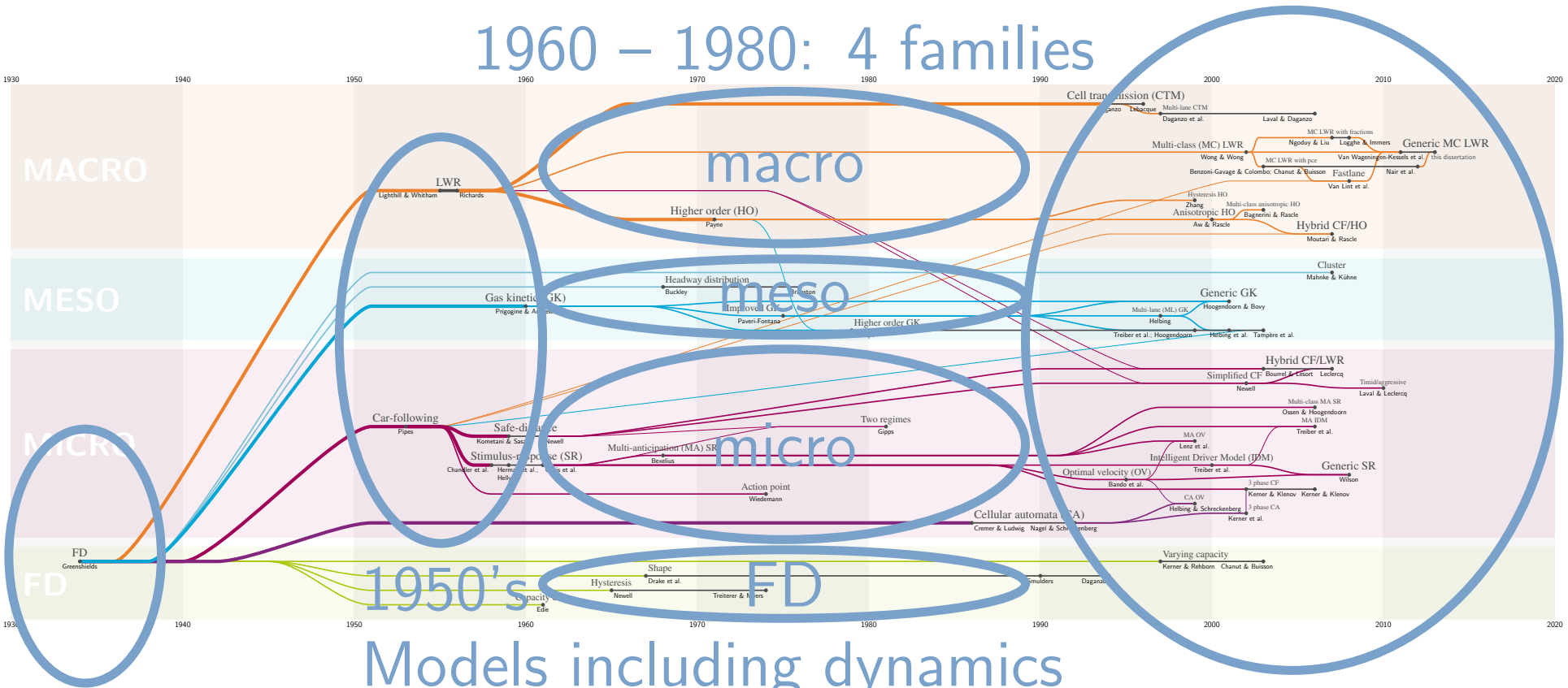
Models including dynamics

1934

Foundation of traffic flow modelling:
Fundamental diagram (FD)

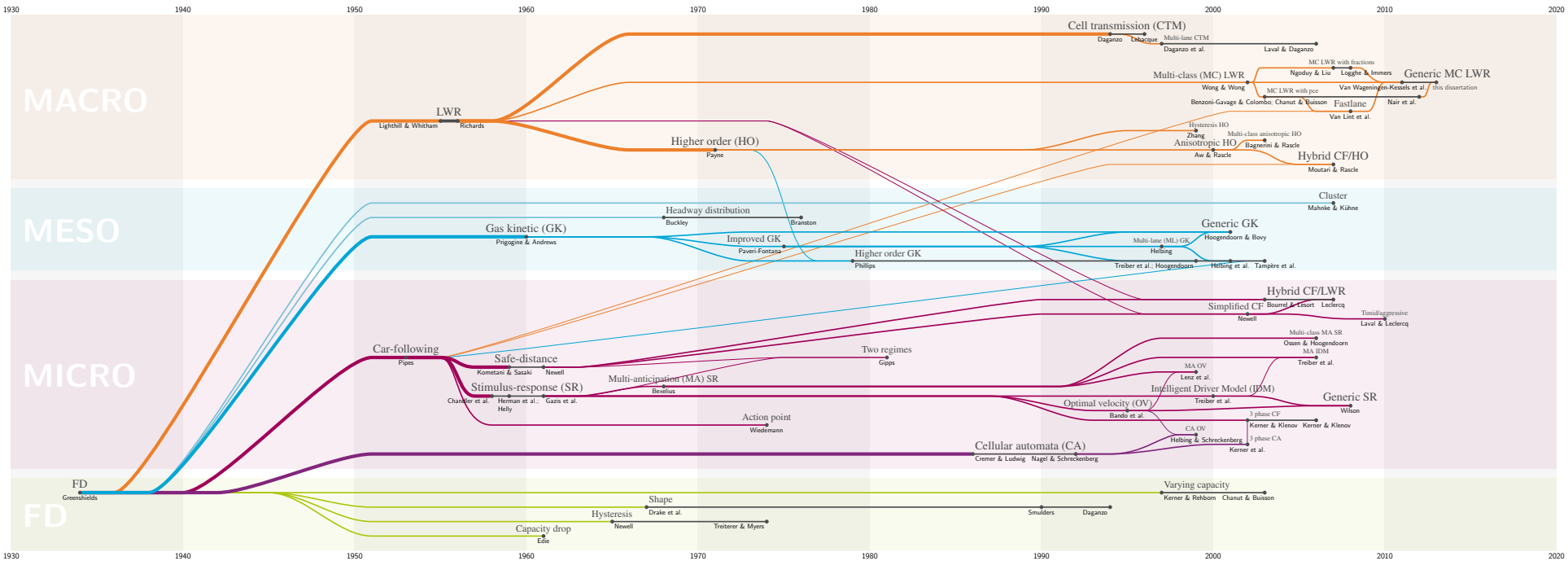
Since mid 1990's
Family extensions

Genealogy / Family tree / Model tree

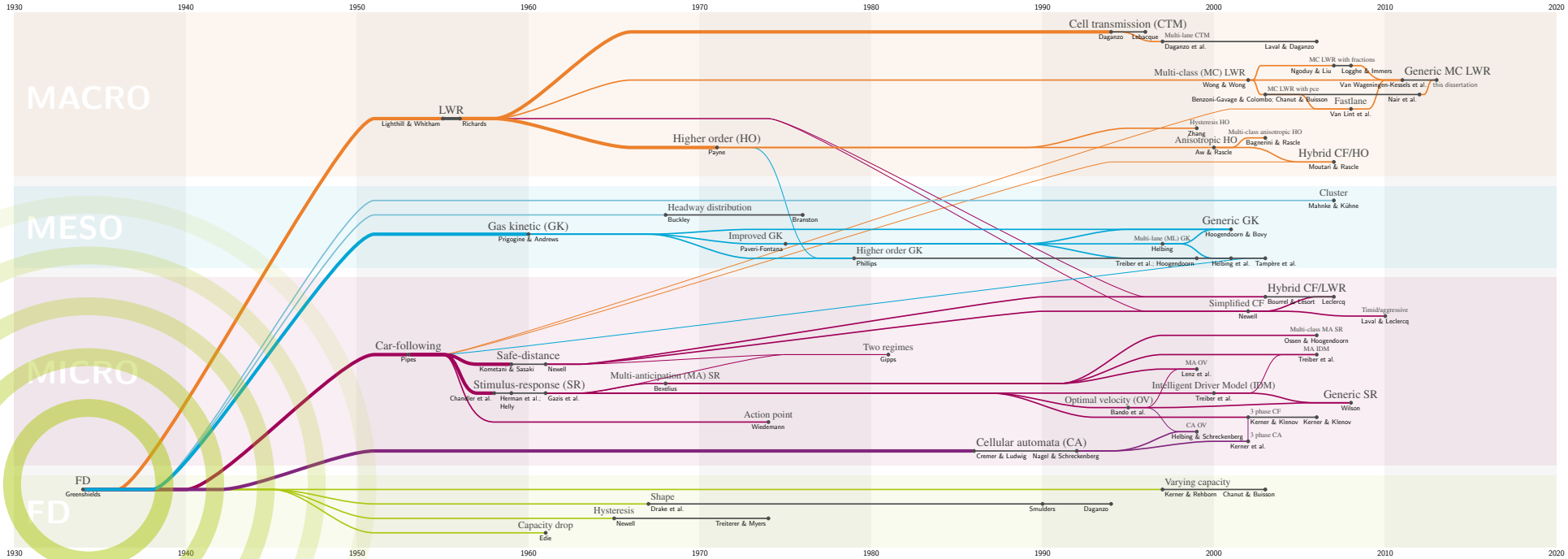


Outline

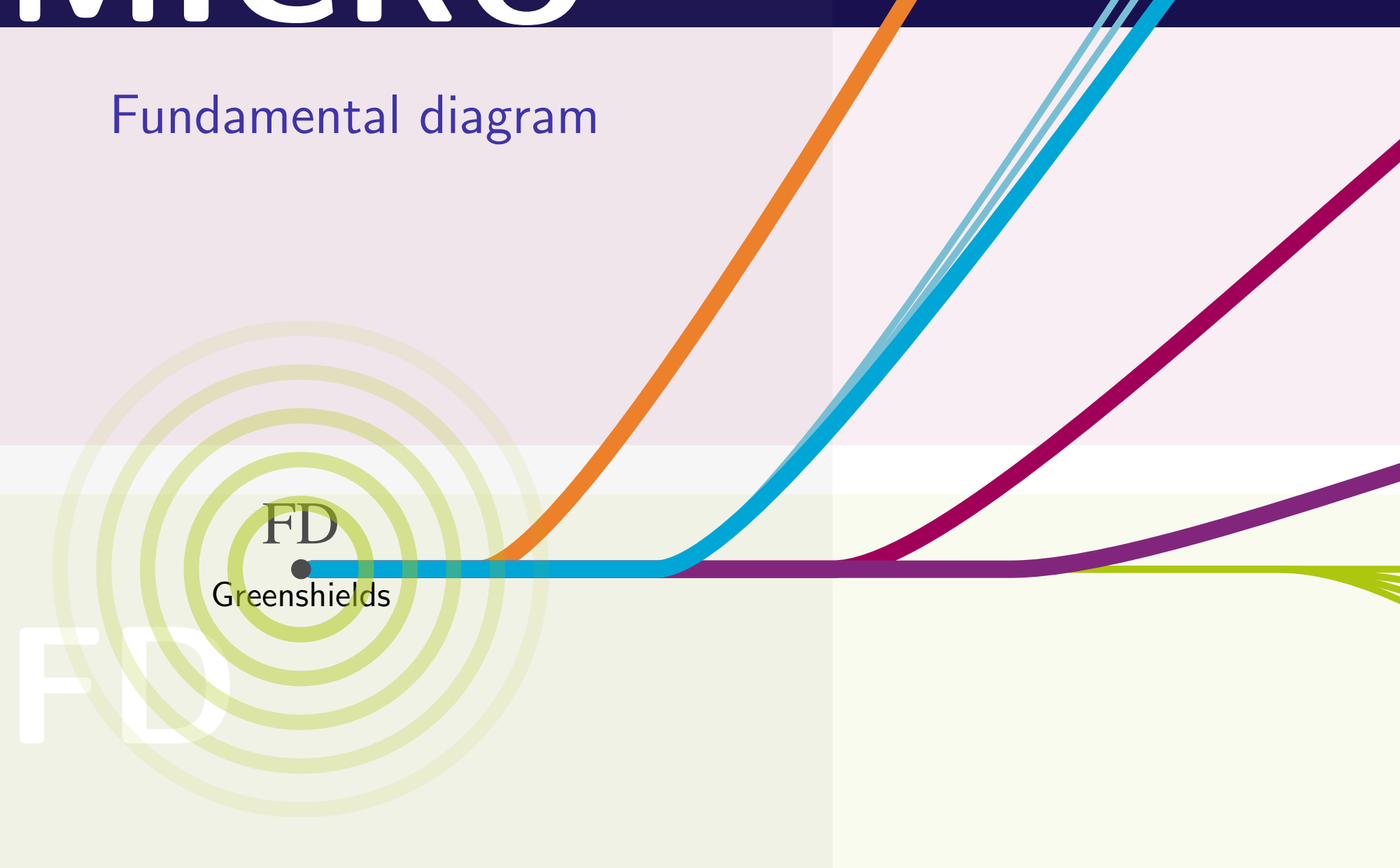
- Introduction families
- Trends
- Outlook



Fundamental diagram



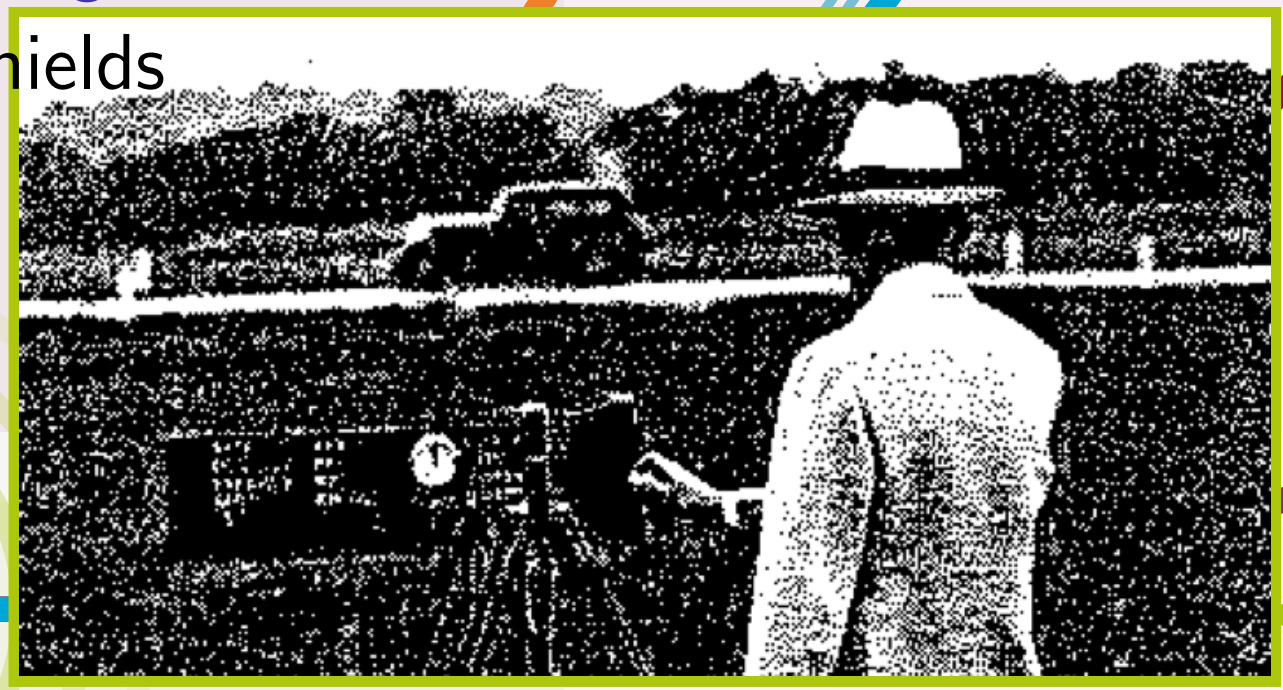
Fundamental diagram



1940

Fundamental diagram

Bruce Greenshields
1934 / 1935

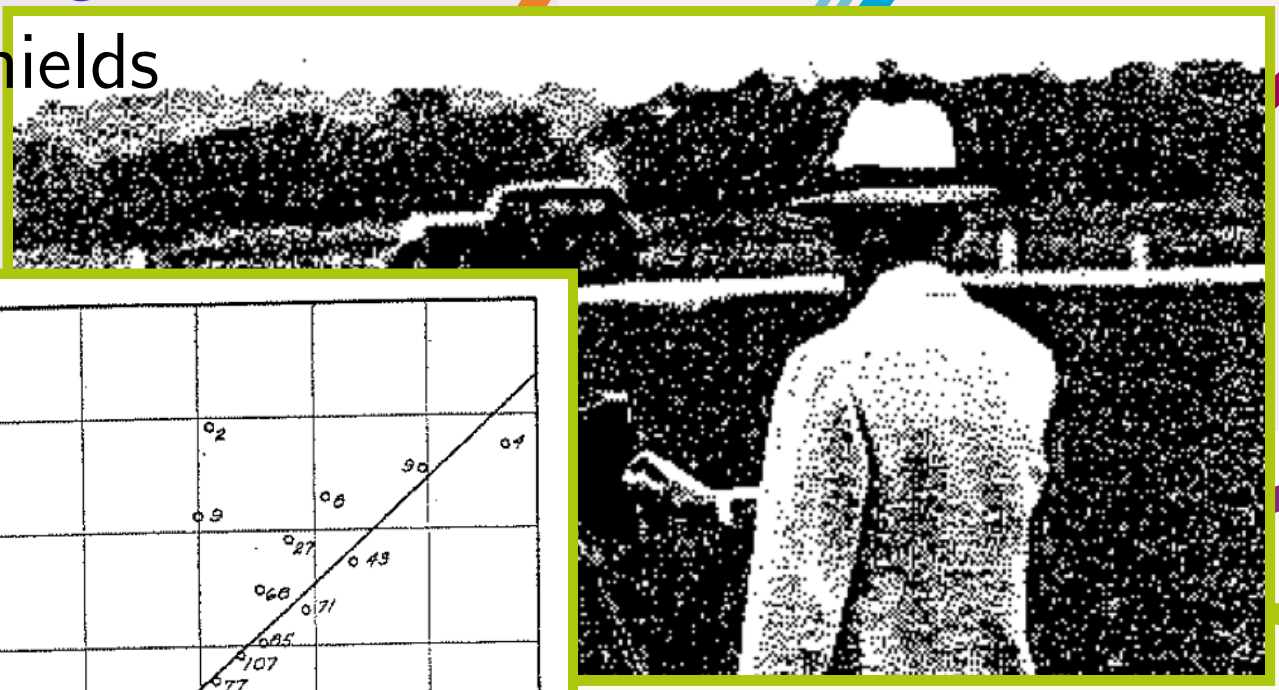


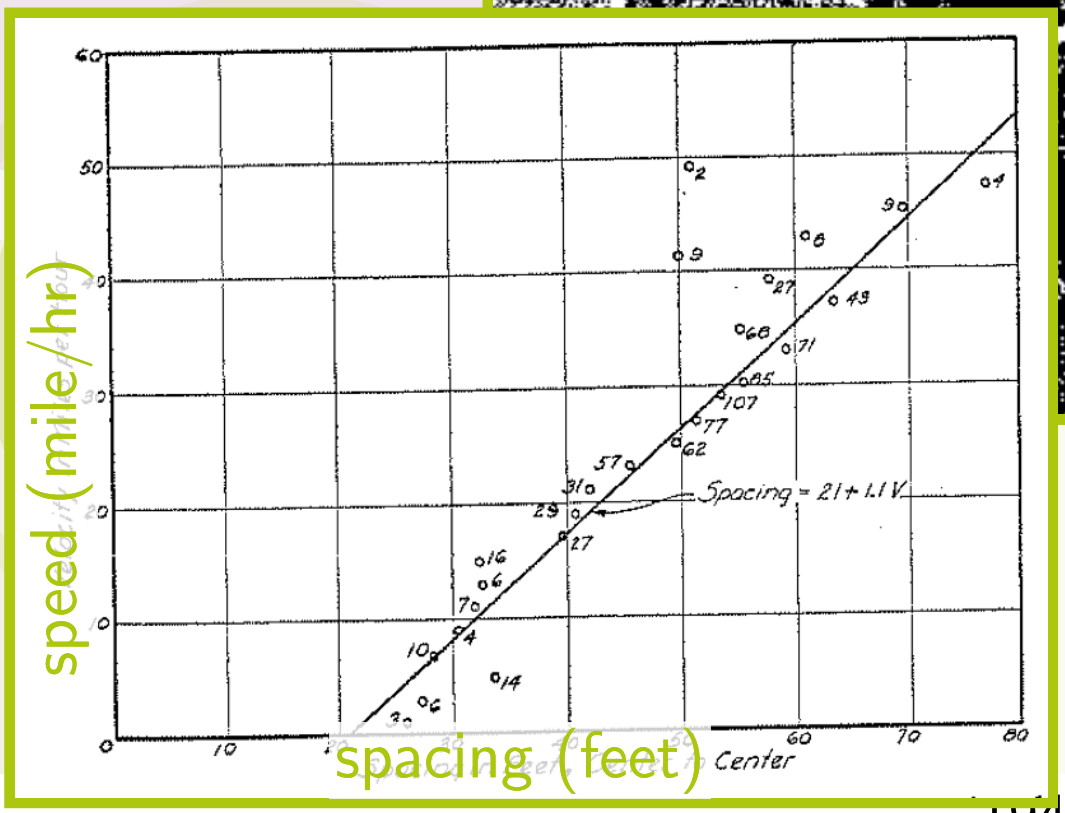
FD
Greenshields

1940

Fundamental diagram

Bruce Greenshields
1934 / 1935





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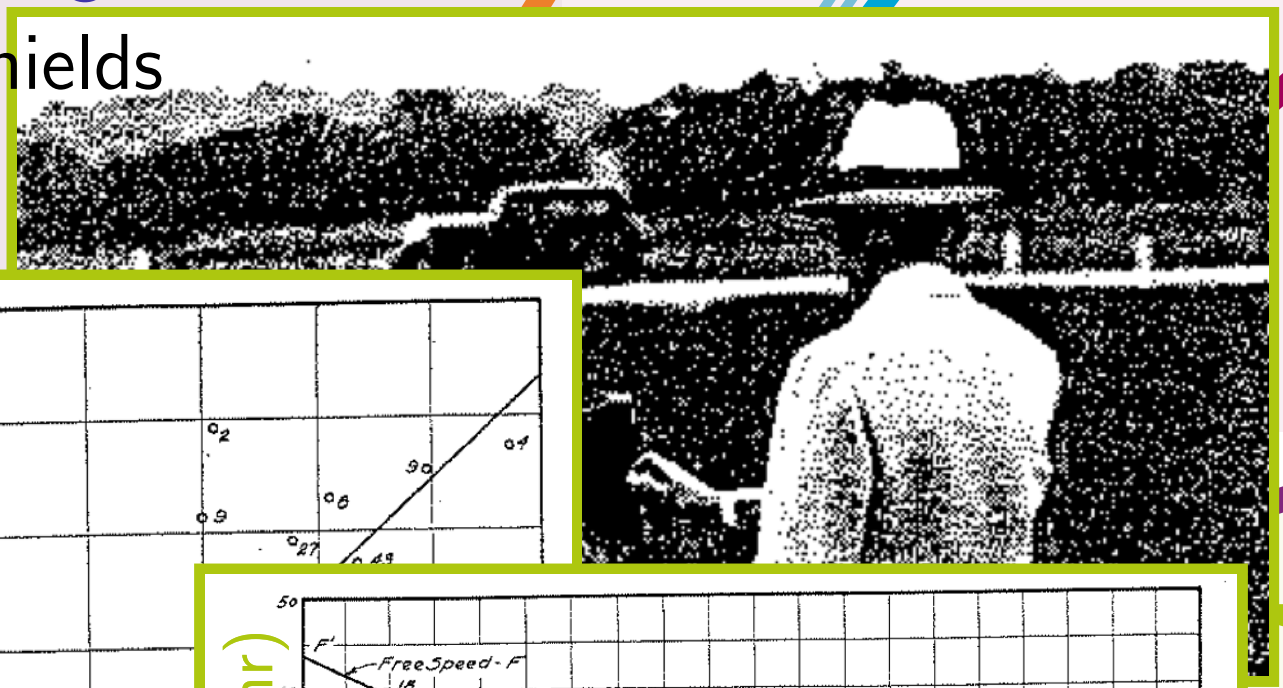
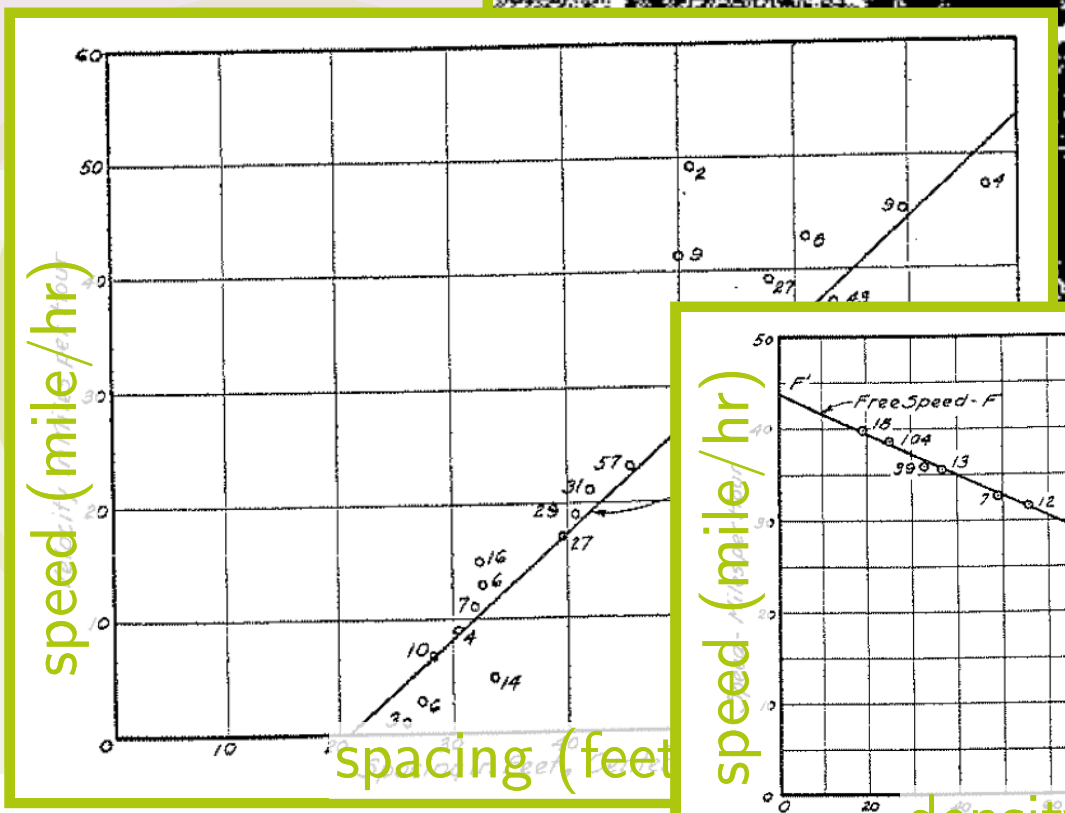
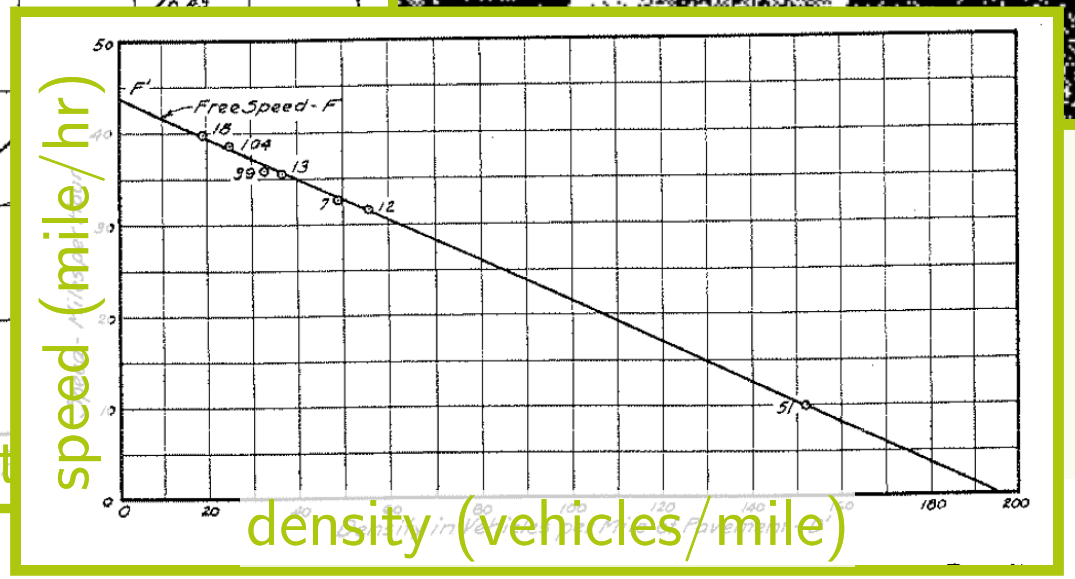
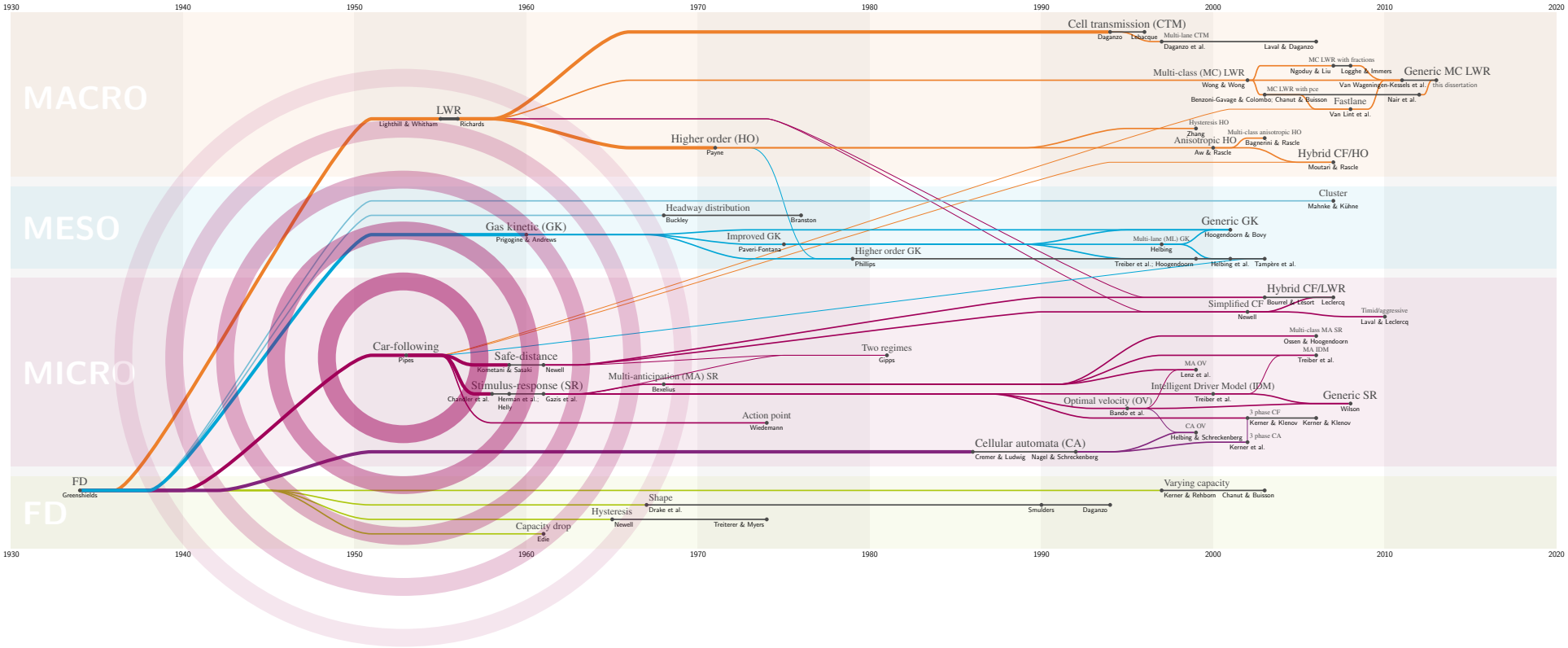


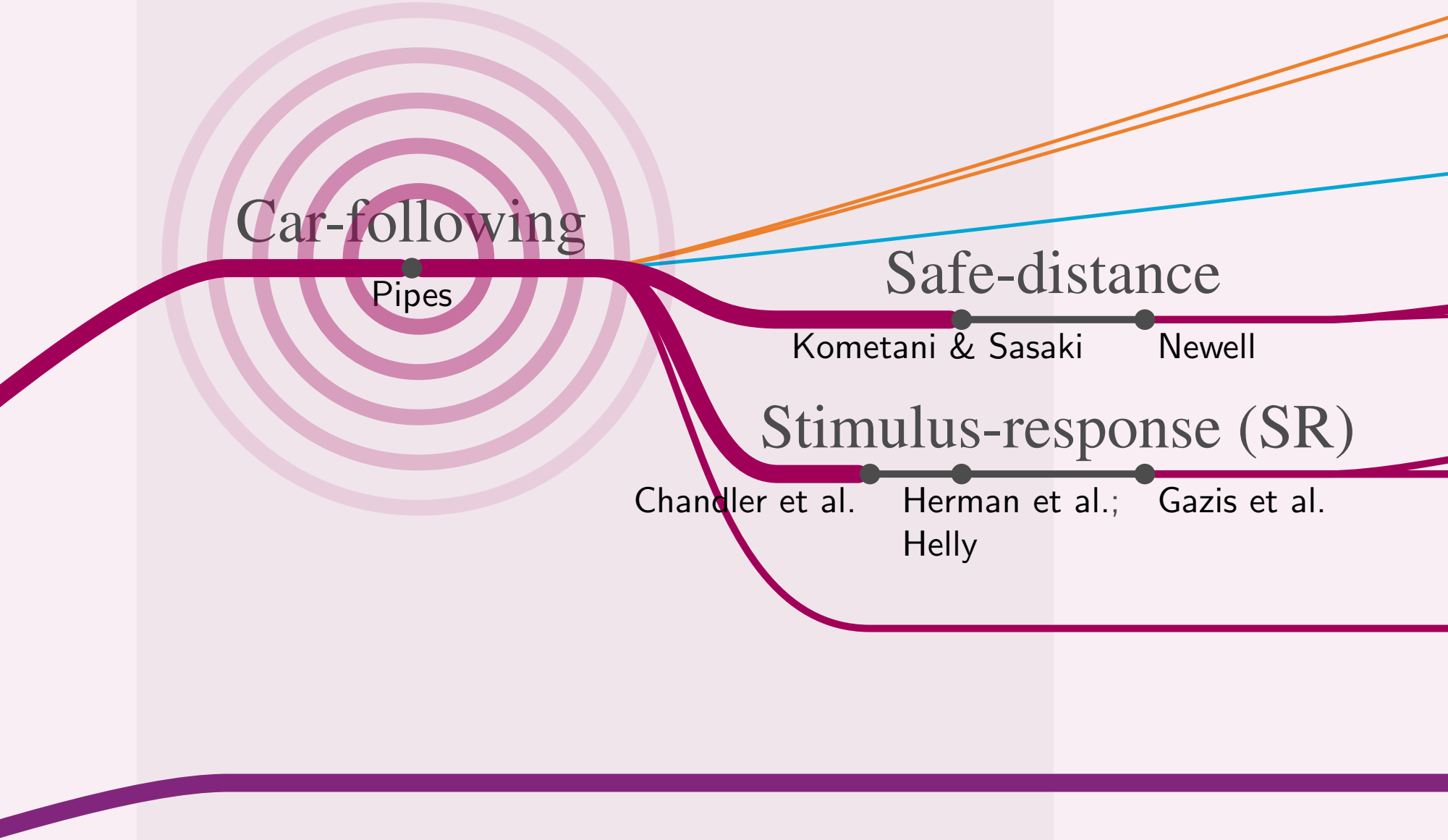




Microscopic models



Microscopic models

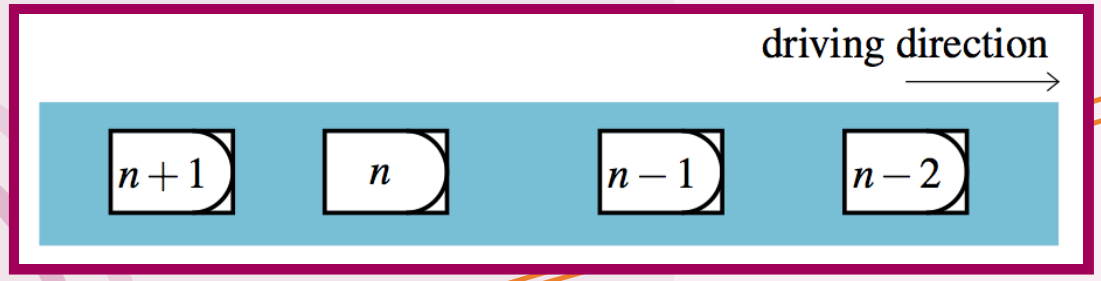


Microscopic models

Individual vehicles

Pipes, 1953

Car-following



Car-following

Pipes

Safe-distance

Kometani & Sasaki

Newell

Stimulus-response (SR)

Chandler et al.

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Microscopic models

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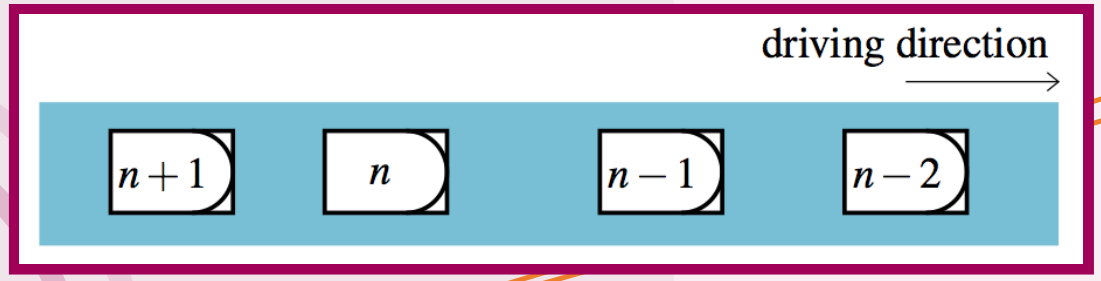

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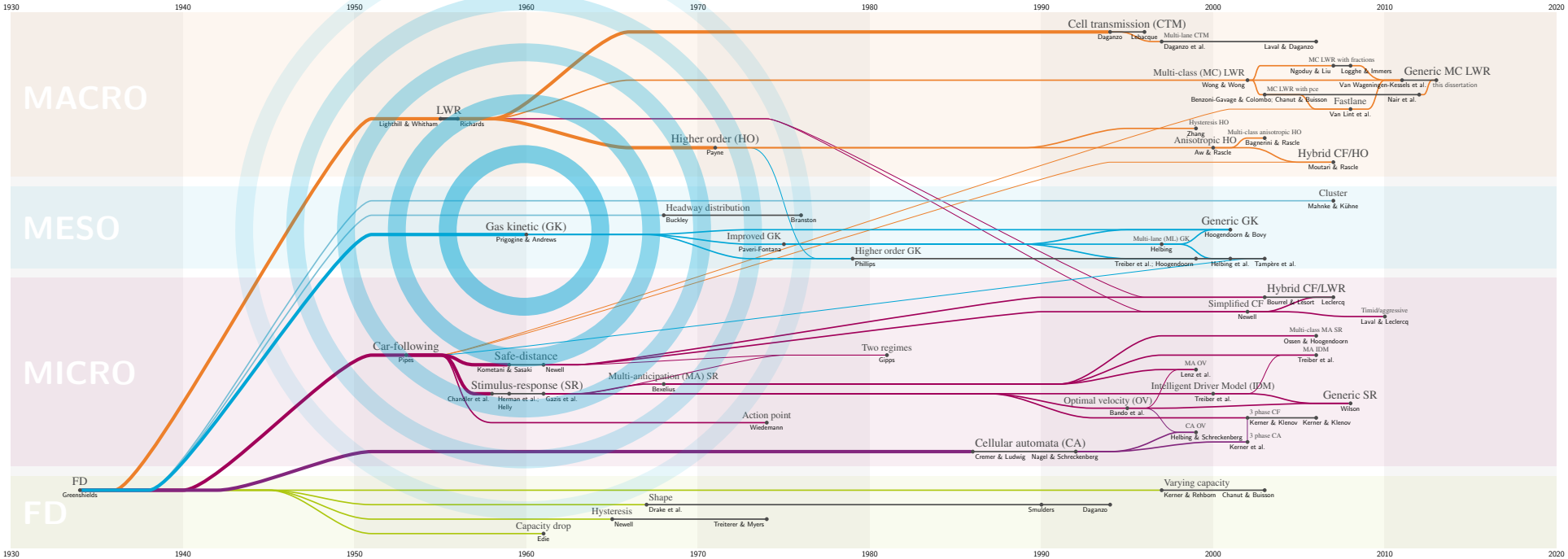
Drivers react on behavior of leaders

Mesoscopic models



Mesoscopic models

Mesoscopic models

Probability distributions

Prigogine & Andrews, 1960

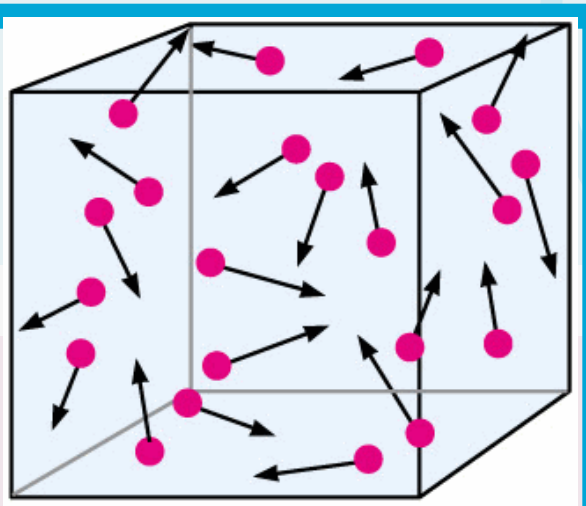
Gas-kinetic

Mesoscopic models

Probability distributions

Prigogine & Andrews, 1960

Gas-kinetic



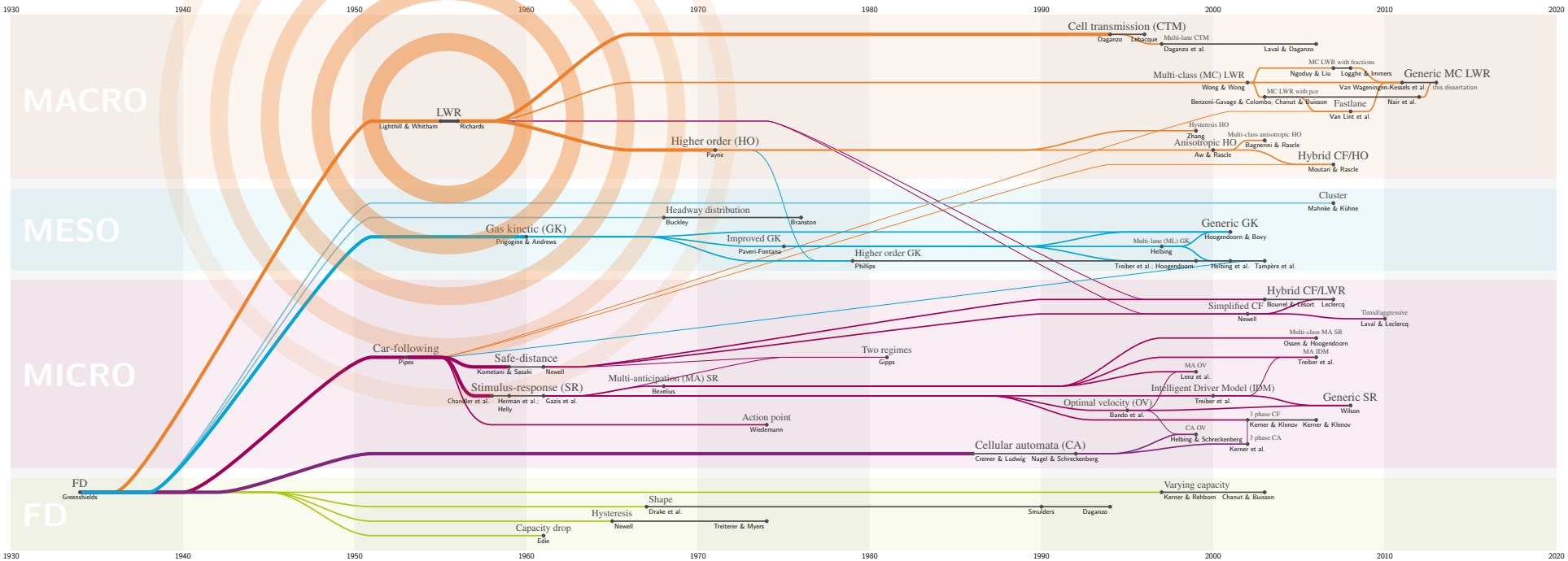
Picture souce: www.studfier.com, article: Boltzman Equation

Gas kinetic (GK)

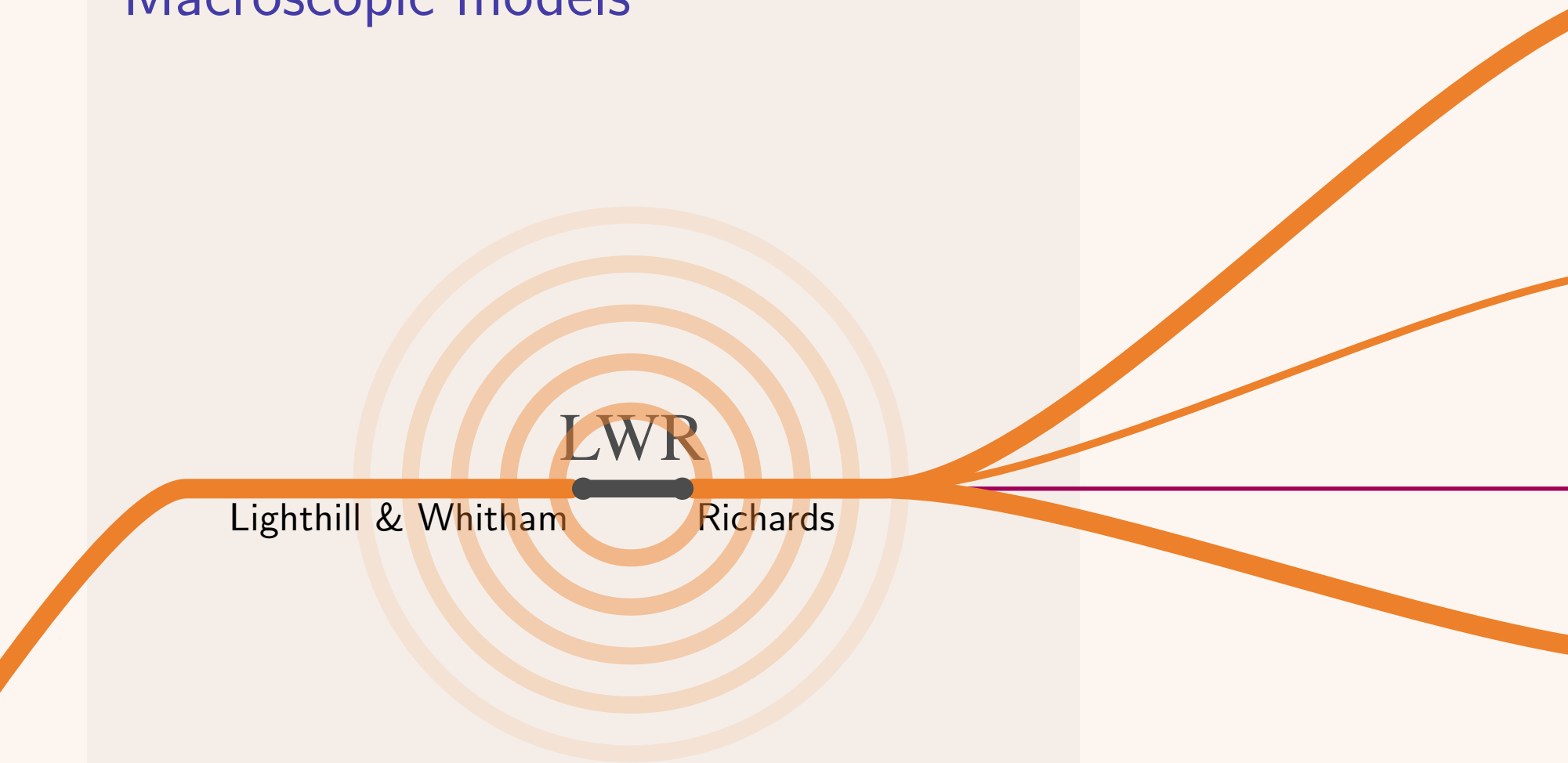
Prigogine & Andrews

Vehicles move similar to molecules in gas

Macroscopic models



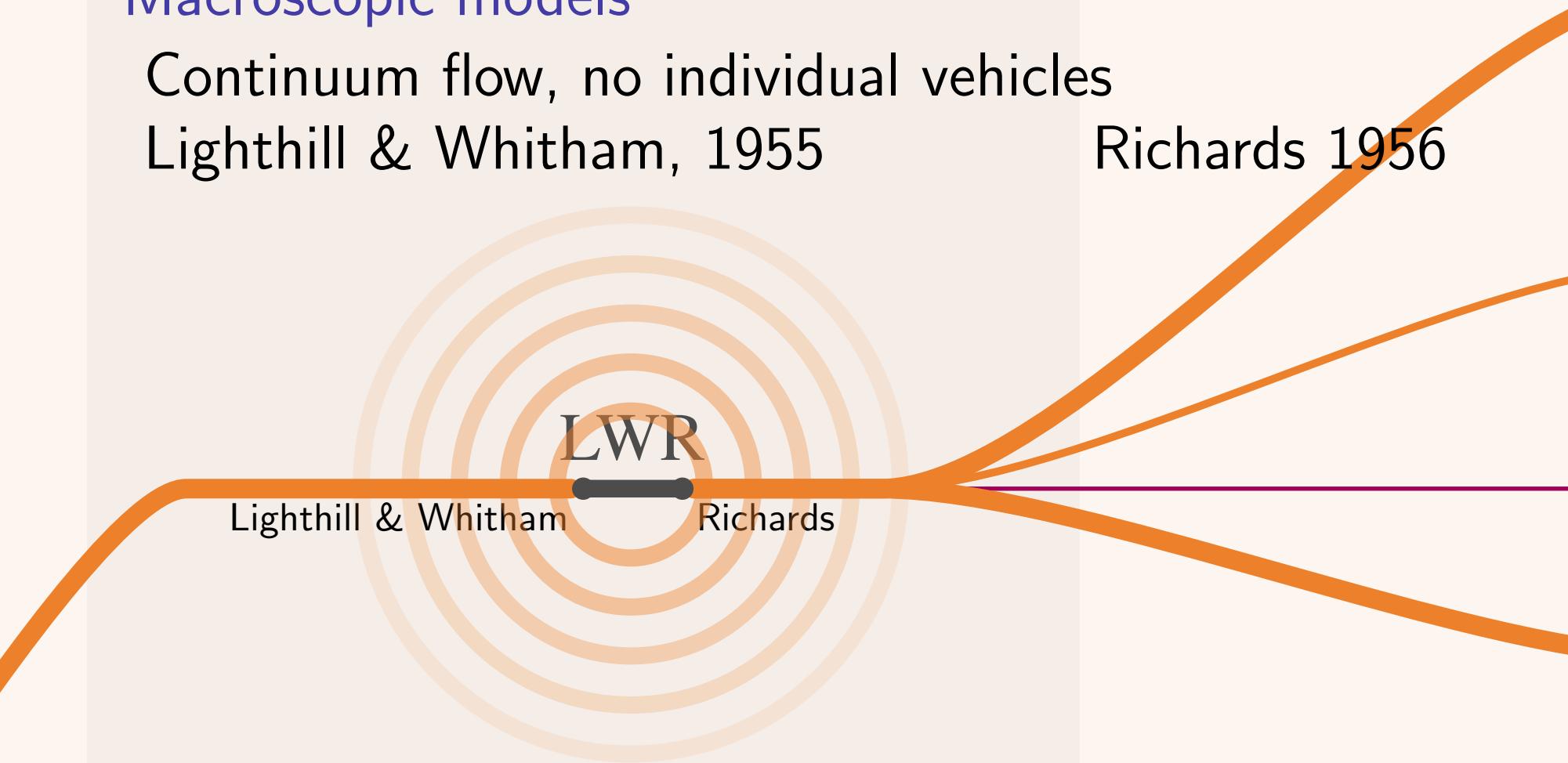
Macroscopic models



Macroscopic models

Continuum flow, no individual vehicles

Lighthill & Whitham, 1955 Richards 1956



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Continuum flow, no individual vehicles

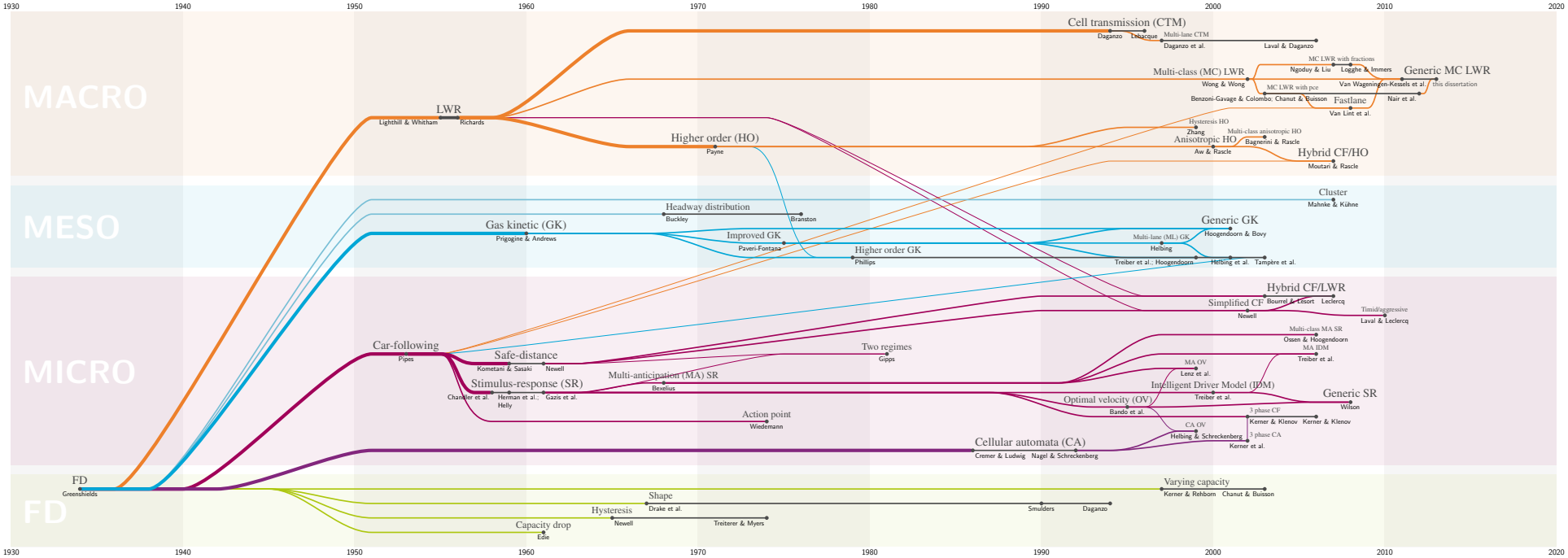
Lighthill & Whitham, 1955 Richards 1956

Part I: Flood Movement in Long Rivers

Part II: A Theory of Traffic Flow on Long Crowded Roads

LWR

Lighthill & Whitham Richards


1930
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MACRO
MESO
MICRO
FD
Cell transmission (CTM)
Daganzo
Lebacque
Multi-lane CTM
Daganzo et al.
Laval & Daganzo
Multi-class (MC) LWR
Wong & Wong
MC LWR with fractions
Ngoduy & Liu
Logghe & Immers
Generic MC LWR
Van Wageningen-Kessels et al.
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MC LWR with pce
Benzoni-Gavage & Colombo
Chanut & Buisson
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Van Lint et al.
LWR
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Richards
Higher order (HO)
Payne
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Mahnke & Kühne
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Gipps
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Ossen & Hoogendoorn
MA IDM
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Multi-anticipation (MA) SR
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Kerner et al.
Action point
Wiedemann
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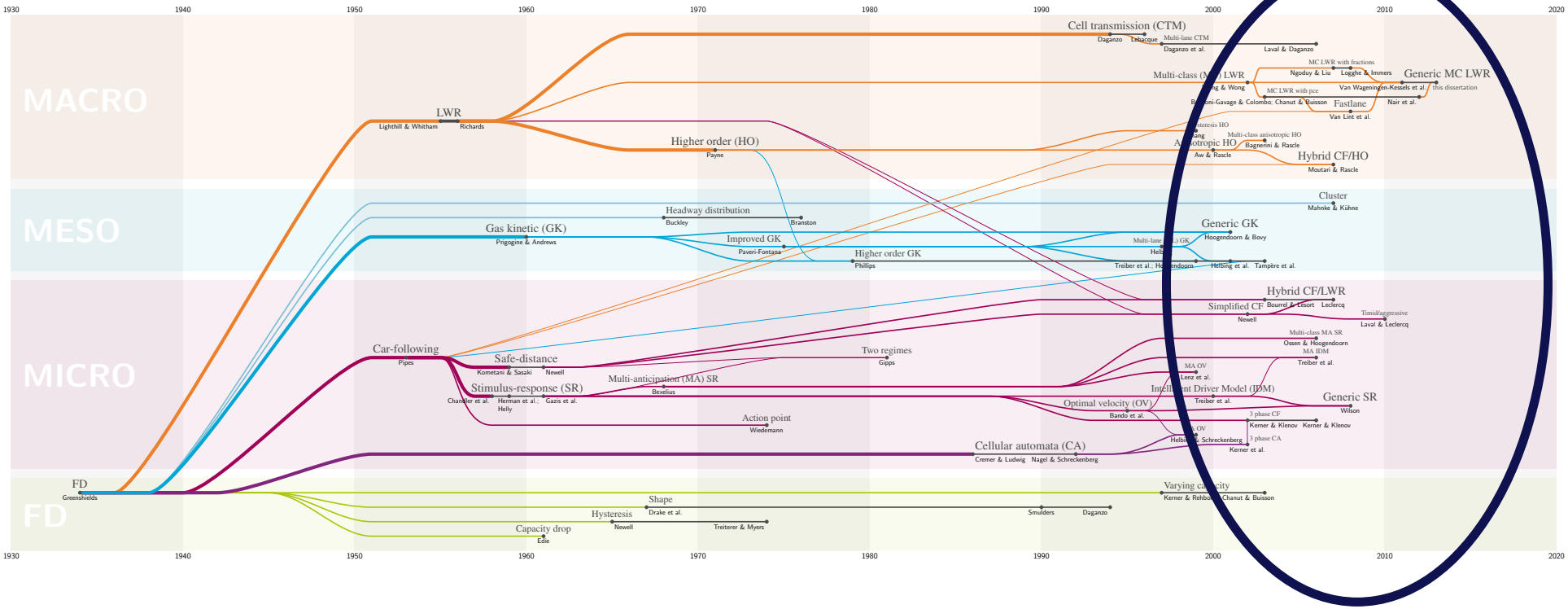
Varying capacity
Kerner & Rehborn
Chanut & Buisson
Shape
Drake et al.
Smulders
Daganzo
Hysteresis
Newell
Treiterer & Myers
Capacity drop
Edie

Trends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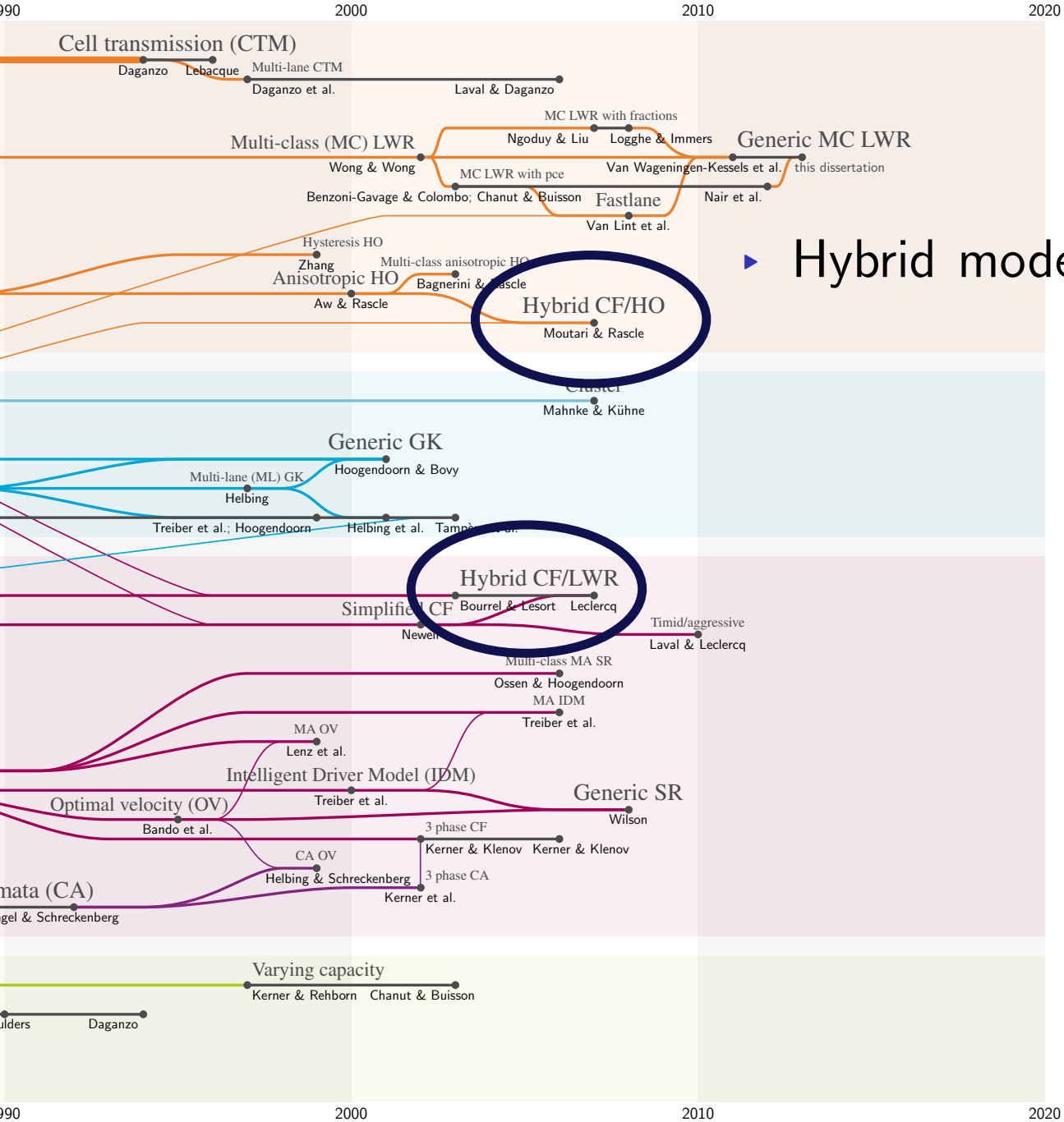
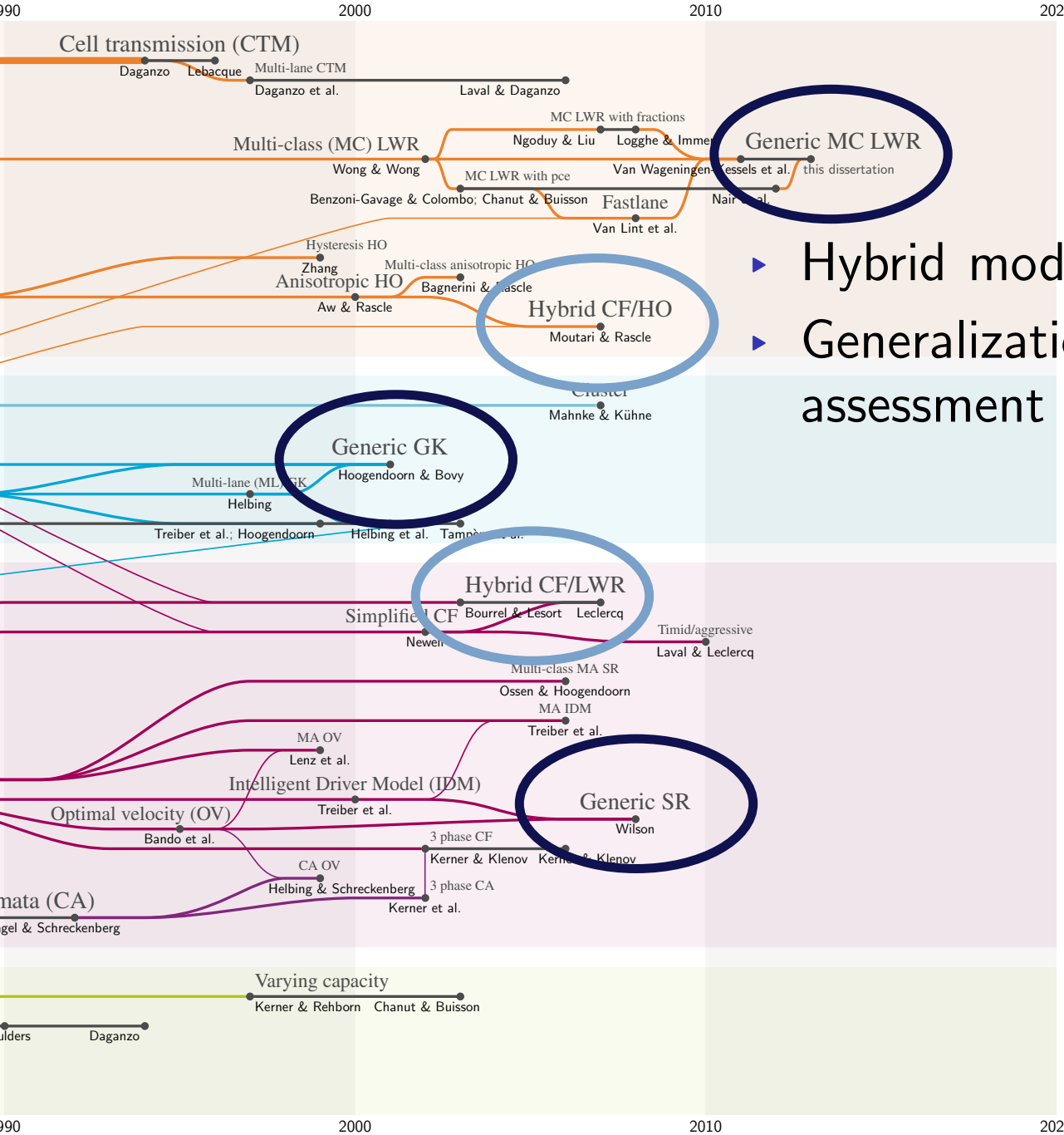


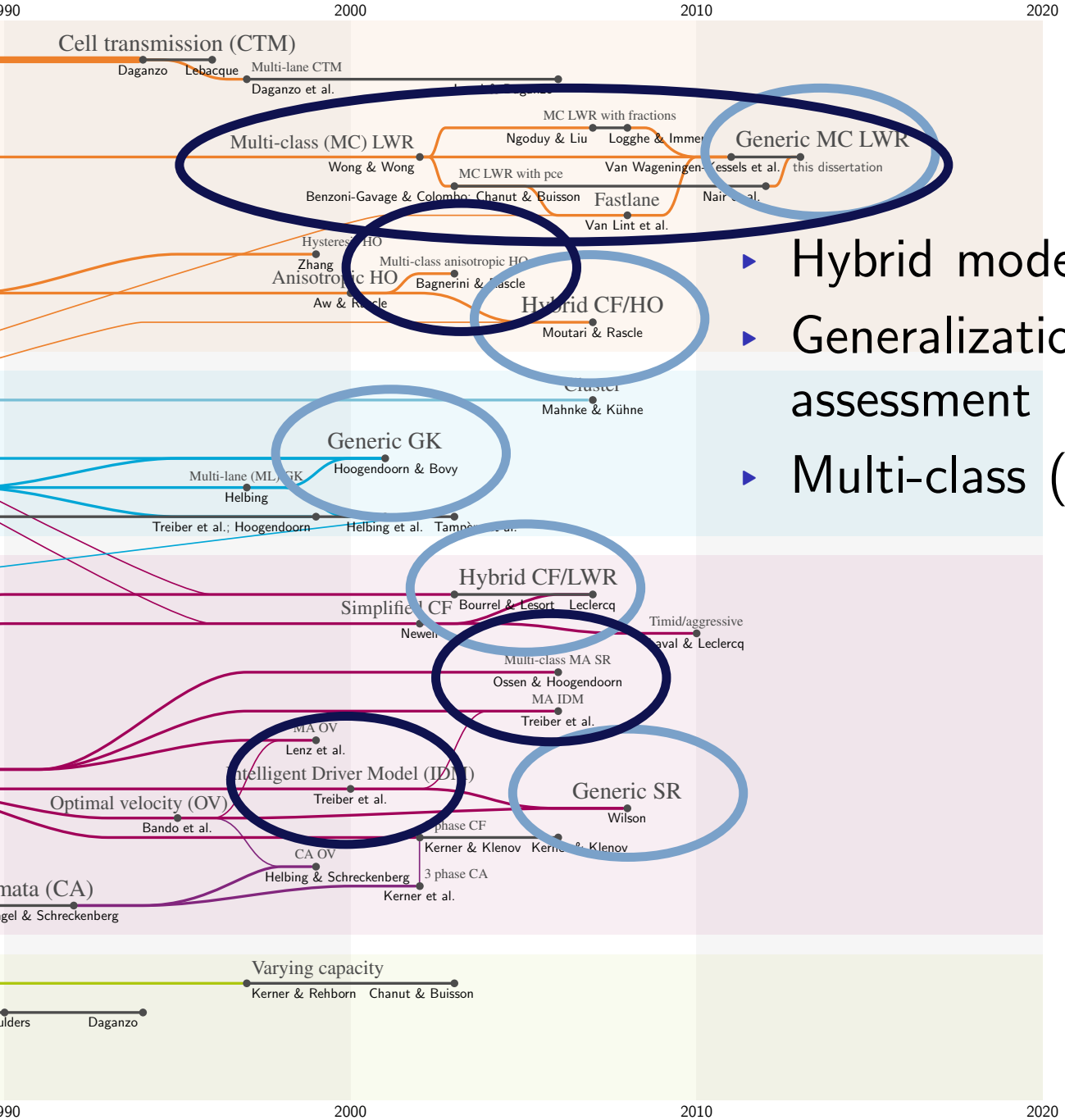
Trends

- Hybrid models (micro/macro)



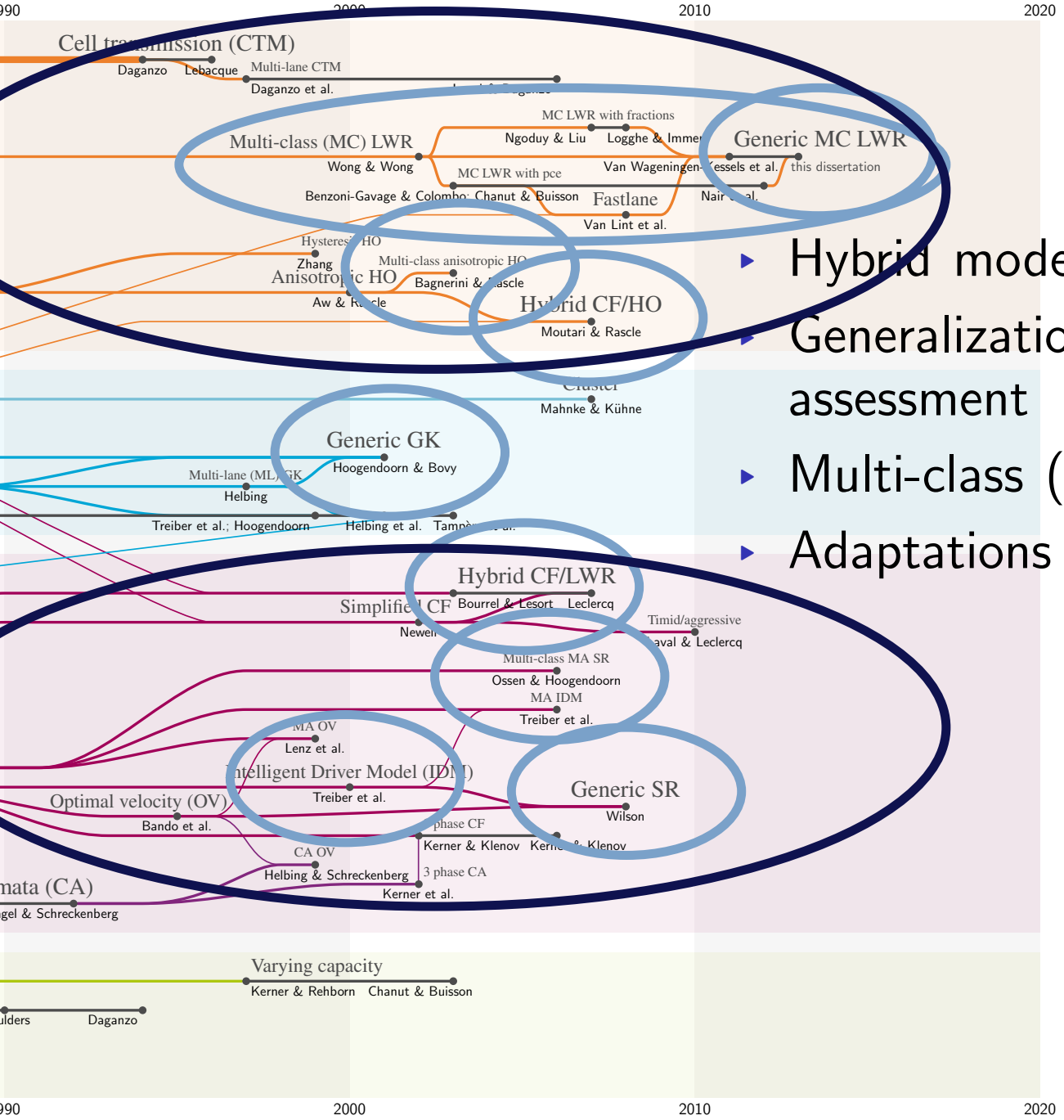
Trends

- Hybrid models (micro/macro)
- Generalizations, for qualitative assessment



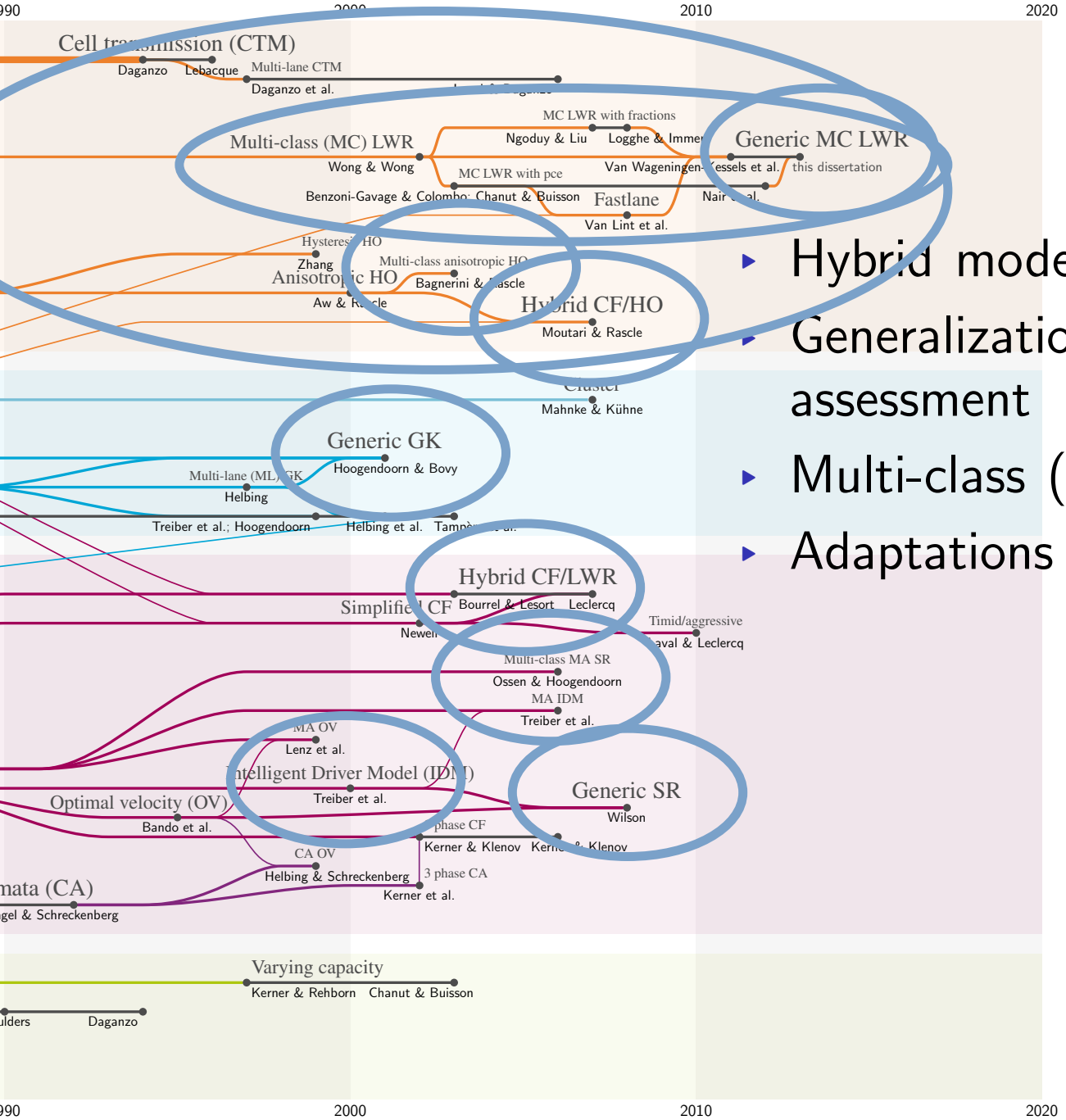
Trends

- Hybrid models (micro/macro)
- Generalizations, for qualitative assessment
- Multi-class (cars, trucks, ...)



Trends

- Hybrid models (micro/macro)
- Generalizations, for qualitative assessment
- Multi-class (cars, trucks, ...)
- Adaptations LWR & CF (realism)



Trends

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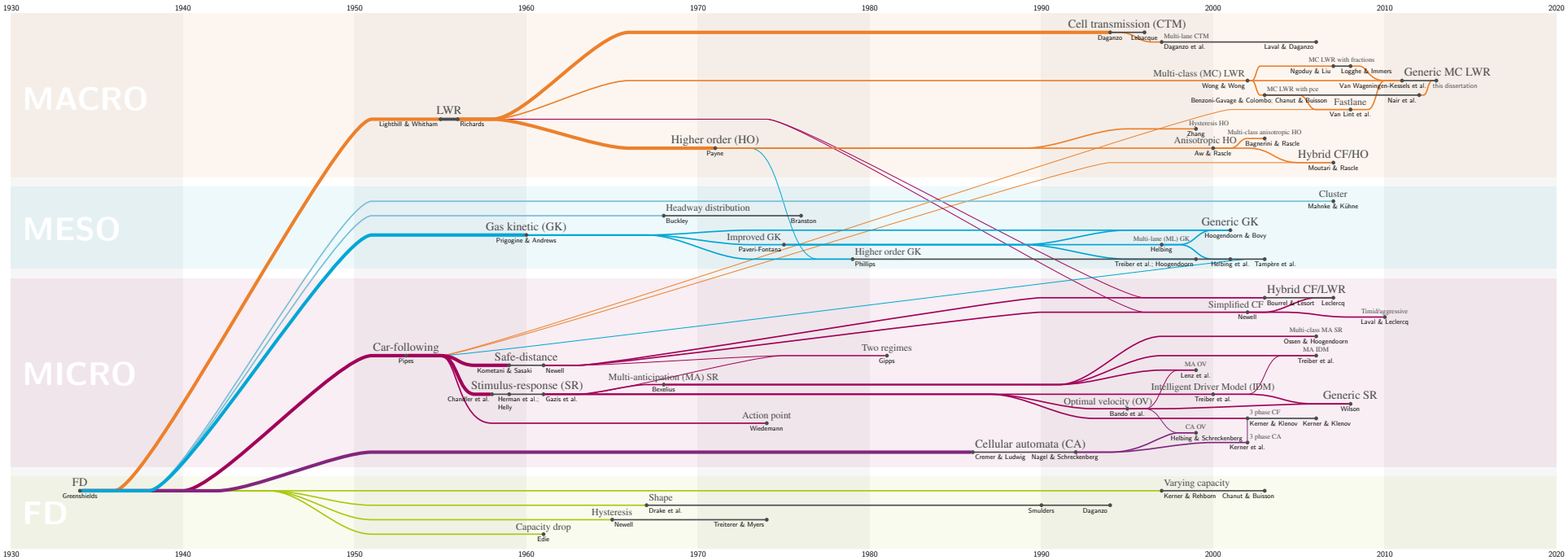
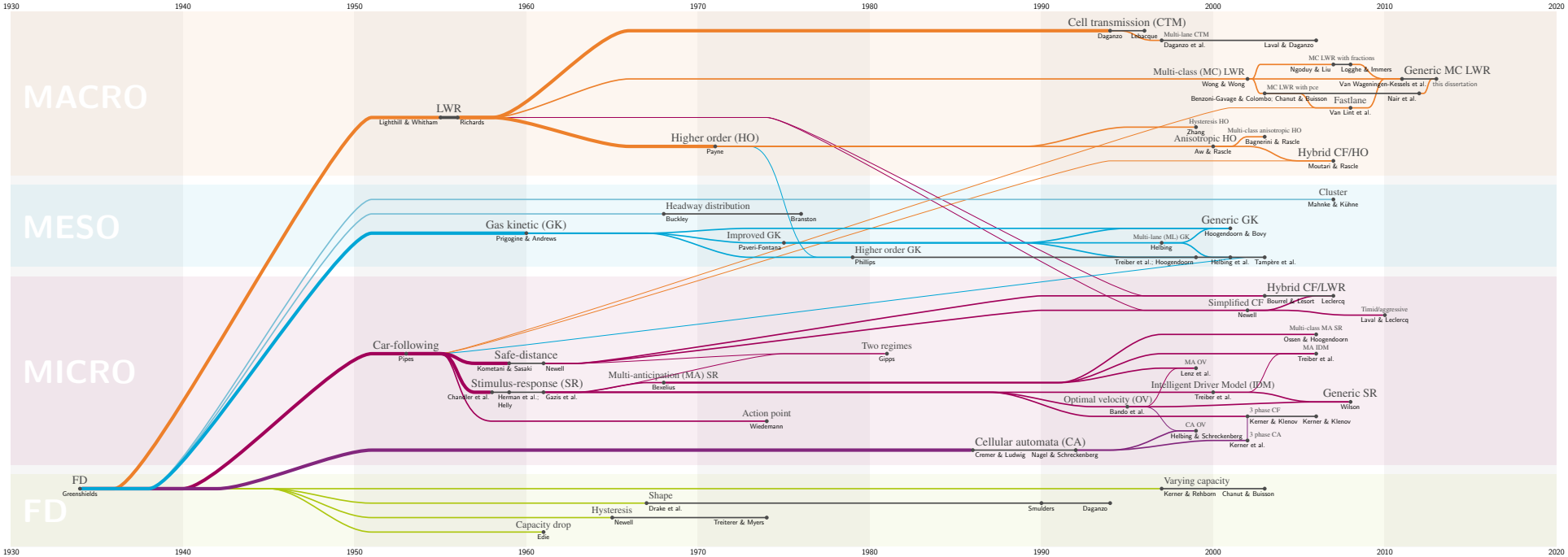
Outlook for simulations

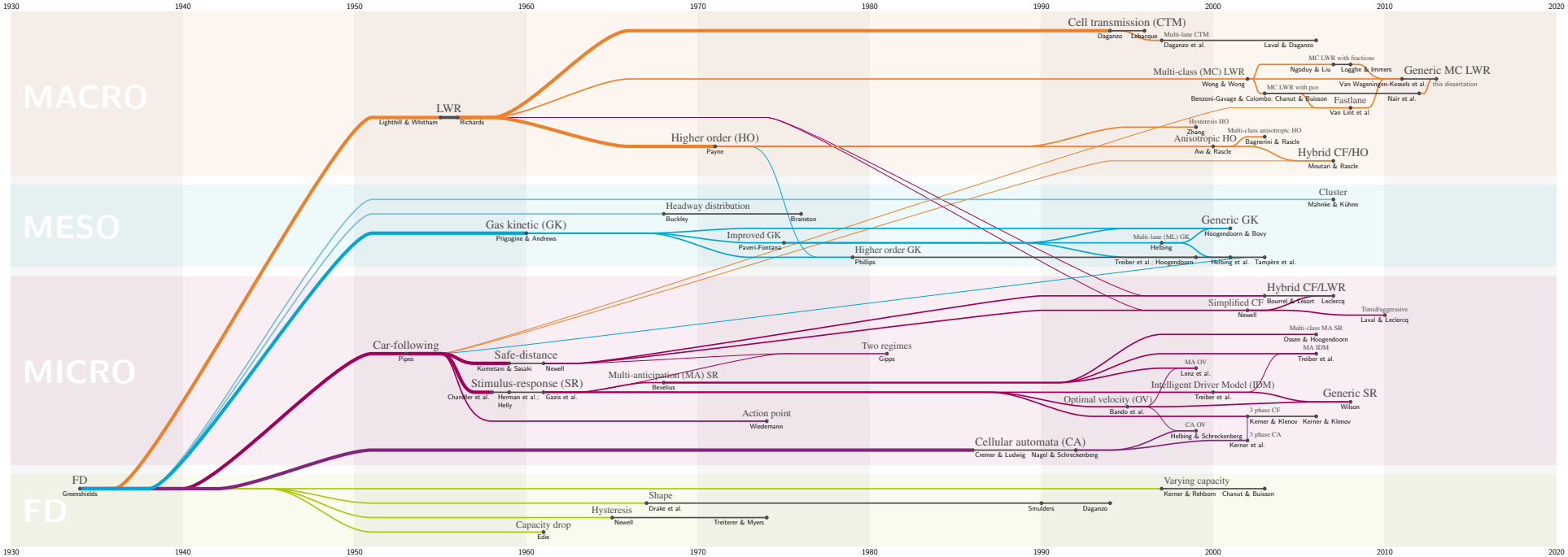


Outlook for simulations



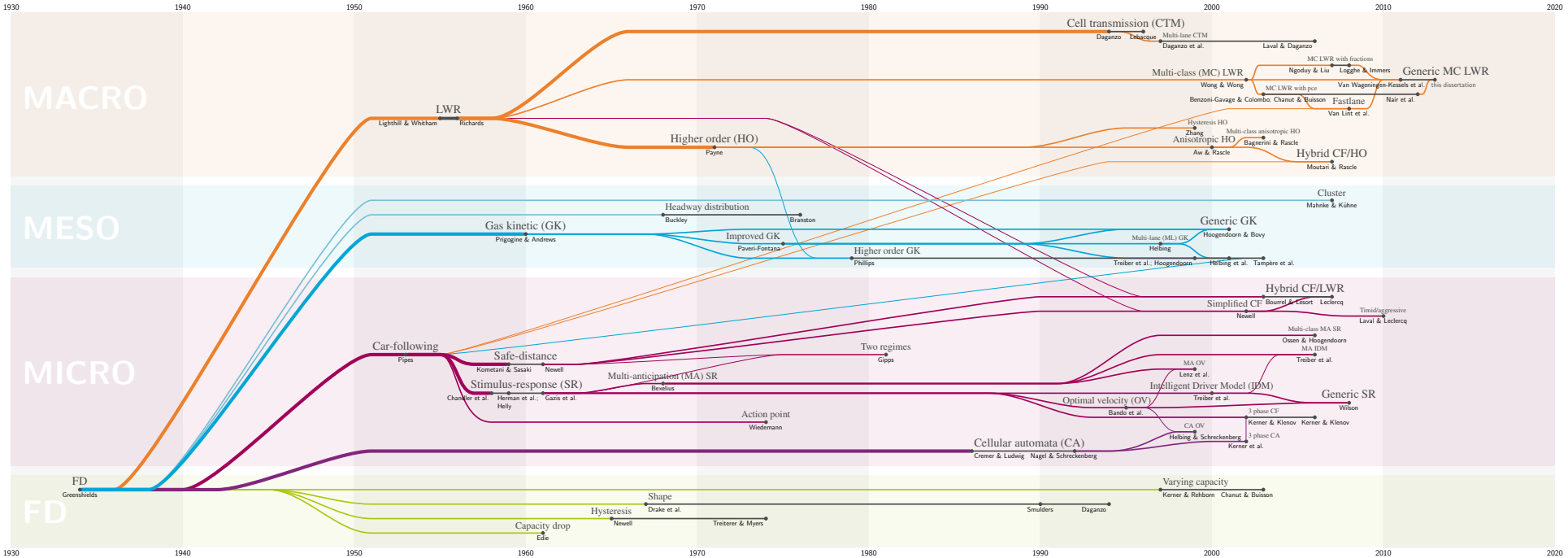
- Micro & macro & hybrid

Outlook for simulations



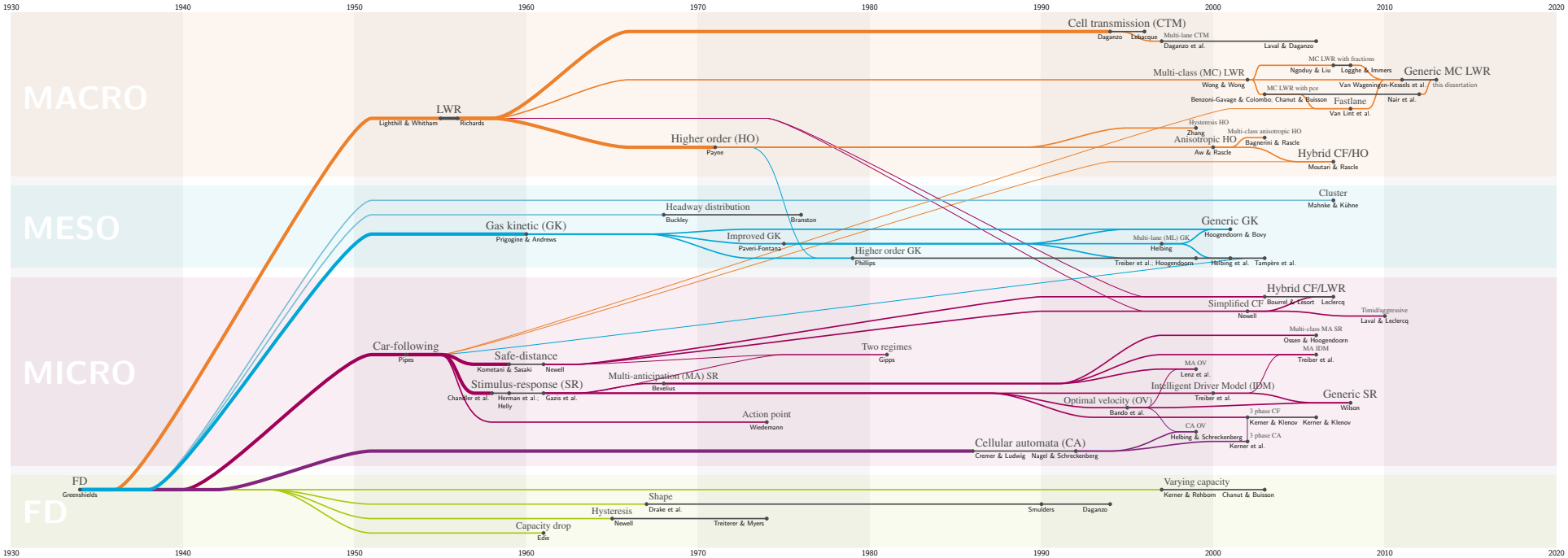
- Micro & macro & hybrid
- Micro when details are needed

Outlook for simulations



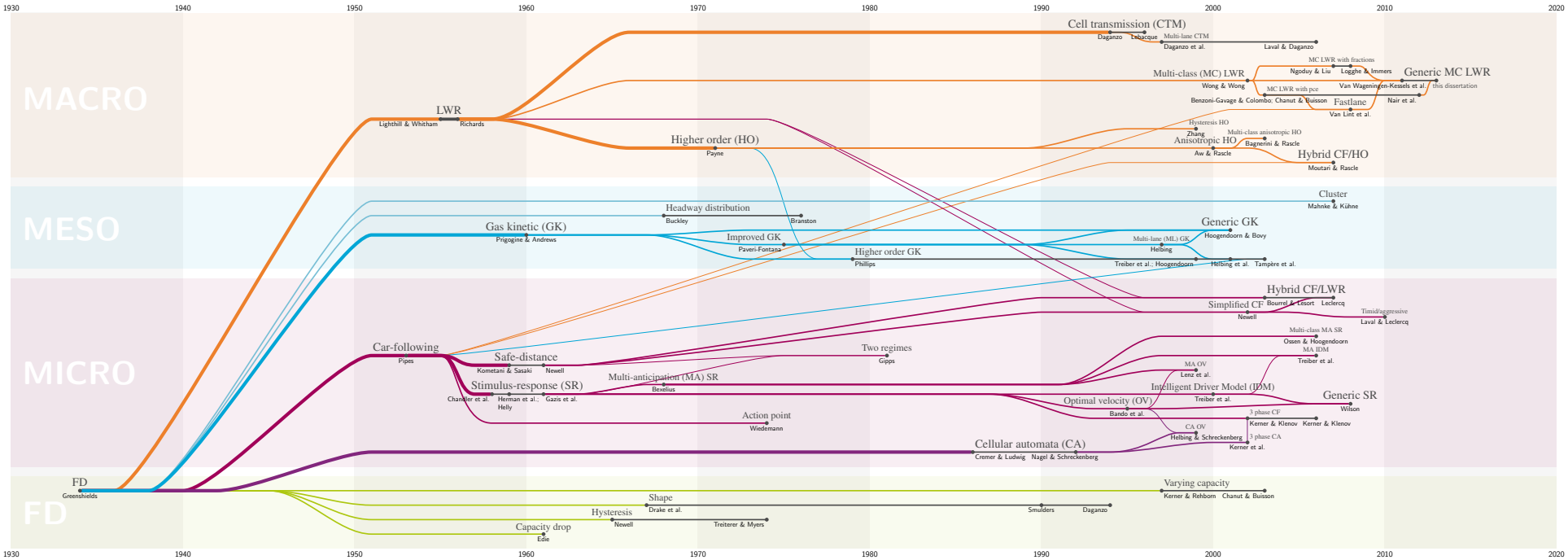
- Micro & macro & hybrid
- Micro when details are needed
- Macro when fast computations are needed

Outlook for simulations



- Micro & macro & hybrid
- Micro when details are needed
- Macro when fast computations are needed
- Use generalized models to analyse and select models with qualitatively good properties

Thanks!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1940
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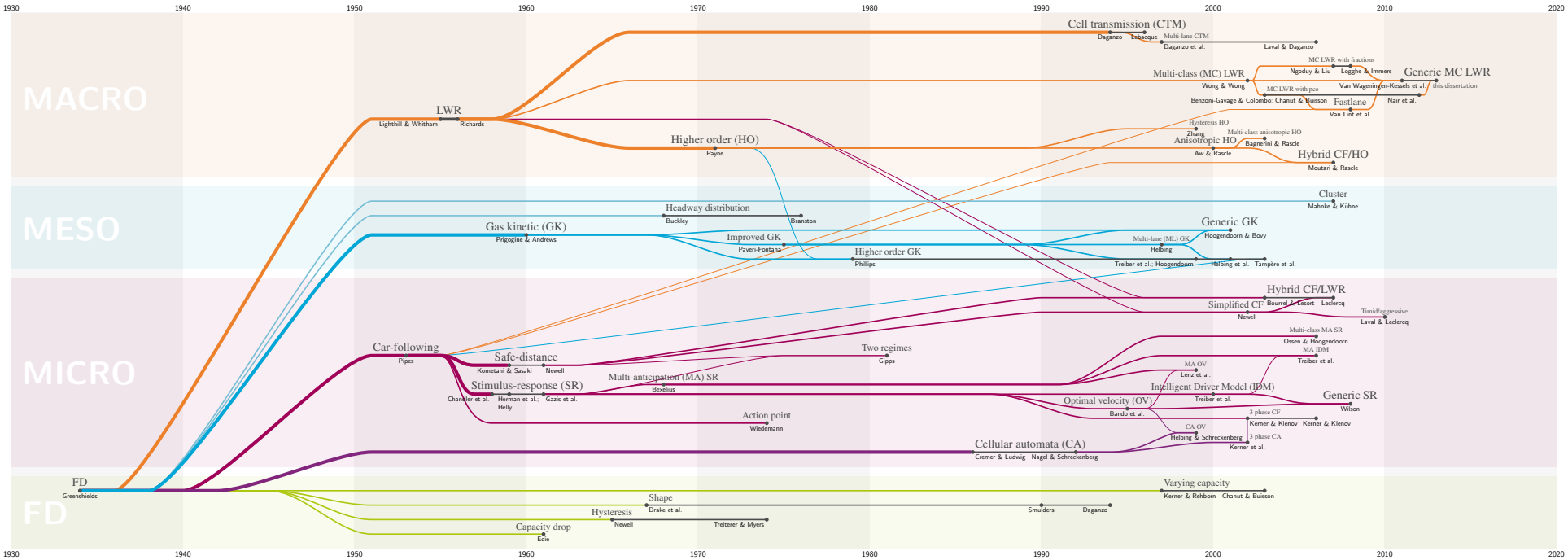
MACRO
MESO
MICRO
FD
Cell transmission (CTM)
Daganzo
Lebacque
Multi-lane CTM
Daganzo et al.
Laval & Daganzo
Multi-class (MC) LWR
Wong & Wong
MC LWR with fractions
Ngoduy & Liu
Logghe & Immers
Generic MC LWR
Van Wageningen-Kessels et al.
this dissertation
MC LWR with pce
Benzoni-Gavage & Colombo; Chanut & Buisson
Fastlane
Nair et al.
Van Lint et al.
LWR
Lighthill & Whitham
Richards
Higher order (HO)
Payne
Hysteresis HO
Zhang
Multi-class anisotropic HO
Anisotropic HO
Bagnerini & Rascle
Aw & Rascle
Hybrid CF/HO
Mourtan & Rascle
Cluster
Mahnke & Kühne
Headway distribution
Buckley
Branston
Gas kinetic (GK)
Prigogine & Andrews
Improved GK
Paveri-Fontana
Higher order GK
Phillips
Generic GK
Hoogendoorn & Bovy
Multi-lane (ML) GK
Helbing
Treiber et al.; Hoogendoorn
Helbing et al.; Tampère et al.
Hybrid CF/LWR
Simplified CF
Bourrel & Lesort
Leclercq
Newell
Timid/aggressive
Laval & Leclercq
Car-following
Pipes
Safe-distance
Kometani & Sasaki
Newell
Two regimes
Gipps
Multi-class MA SR
Ossen & Hoogendoorn
MA IDM
Treiber et al.
MA OV
Lenz et al.
Multi-anticipation (MA) SR
Bexelius
Stimulus-response (SR)
Chandler et al.
Herman et al.; Helly
Gazis et al.
Intelligent Driver Model (IDM)
Treiber et al.
Generic SR
Wilson
Optimal velocity (OV)
Bando et al.
3 phase CF
Kerner & Klenov
Kerner & Klenov
CA OV
Helbing & Schreckenberg
3 phase CA
Kerner et al.
Action point
Wiedemann
Cellular automata (CA)
Cremer & Ludwig
Nagel & Schreckenberg
FD
Greenshields
Varying capacity
Kerner & Rehborn
Chanut & Buisson
Shape
Drake et al.
Smulders
Daganzo
Hysteresis
Newell
Treiterer & Myers
Capacity drop
Edie

Thanks!



- Thesis: Multi-class continuum traffic flow models: Analysis and simulation methods
- Journal article under review
- f.l.m.vanwageningen-kessels@tudelft.nl

A Brief History of Traffic Simulation

Edward B. Lieberman, PE

KLD Engineering, PC

A Chronology of Traffic Simulation Development Organized by Decade

Thomas Watson, Senior, seated at the IBM 701 console, 1952

(19 made)

Computers Available in the 1950's

Model	Year	Memory Capacity
IBM 701	1952	2048 words – 16 bits
IBM 650	1953	4000 words – 10 digits
IBM 704	1954	4096 words – 36 bits
IBM 709 / 7090	1958 /1959	32,768 words – 36 bits

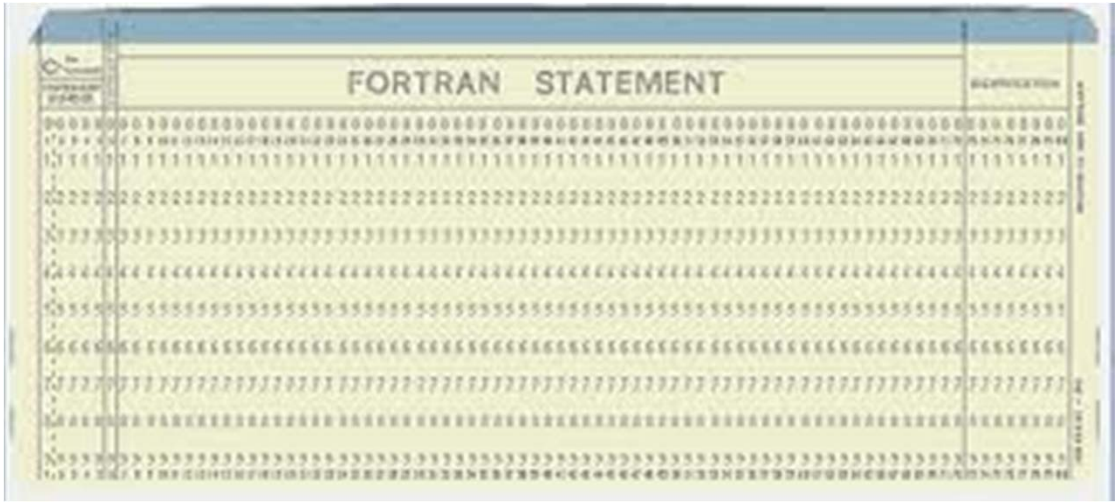
FORTRAN introduced in 1956

Pioneers in the 1950's

Name	Contribution
James H. Kell	Simulation of intersections controlled with two-way STOP signs: micro on IBM 701, 1954
Harry H. Goode	Simulation of signalized intersection, 1952
Daniel L. Gerlough	Simulation of Freeway Traffic: PhD dissertation, 1955
John G. Wardrop	User and Systems Network Equilibrium "Laws" (after Nash), 1952
Lighthill and Witham, Richards	Fluid Flow analogy – differential equations of motion: momentum, conservation, state; 1955, 1956

Researchers in traffic flow theory addressed the "car-following" problem and flow stability. First International Symposium on the Theory of Traffic Flow in 1959.

The Face of Computer Technology in the 1960's



Simulation an Emerging Analytical Tool: 1960's

Overview

- Main-frame computers were somewhat more plentiful
- All universities and large GOs acquired them
- But, they were costly; few engineering firms had them
- Practitioners were empiricists (see 1965 HCM)
- Researchers migrated from other disciplines

Simulation an Emerging Analytical Tool: 1960's

- DDOT acquired a small computer; what to do with it?
- Most engineers had little or no exposure to computers
- The result was a CA-oriented network simulation model designed by Dan Gerlough, with Fred Wagner
- NCHRP studies ➡ viability and value of network simulation
- FHWA sponsored the UTCS-1 micro network sim model
- TRANSYT employed a macro network simulation model

Additional Simulation Models of Network Flow for Evaluation: 1970's

- Important advances in traffic flow theory, computerized signal control and network modeling: LWR and UE/SE
- FHWA sponsored more simulation model development:
  - Extended UTCS-1 → NETSIM (micro surface street)
  - INTRAS (micro freeway)
  - TRAFLO "hybrid" (meso-macro) – integrated (freeway – surface street) with equilibrium TA
  - TEXAS (micro intersection)
- Initial research in DTA and path choice modeling

The PC Era Dawns: 1980's

IBM V.P.: "The PC cannot replace main-frame computers"

The Emergence of Integrated Simulation Models, Animation and of the PC: 1980's

- Most practitioners not interested in simulation at decade start
- The 1985 HCM index did not include "simulation"
- Nevertheless, the research community was active
- Simulation models of two-way, two-lane roads appeared
- Integrated, simulation-based planning models (CONTRAM, SATURN, INTEGRATION) appeared

The Emergence of Integrated Simulation Models, Animation and of the PC: 1980's

- The PC hard drive (1983), Intel 80386 (1985), MS Windows/ 386 (1988) and PC-based FORTRAN were transformative
- FHWA modernized and promoted simulation models:
  - > The FRESIM freeway model was developed
  - > The NETSIM model was expanded, ported to the PC
  - > Animation software for PC-NETSIM was developed
  - > The simulation source code was distributed
  - > Training courses were developed
- By decade end, many schools and some private firms were actively involved with simulation technology

The Development of Simulation-based Planning Models : 1990's

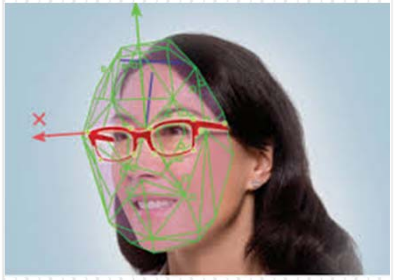
- FHWA integrated NETSIM and FRESIM to create CORSIM
- The growth of microprocessor-based systems supported development of large-scale simulation-based systems
- Research activities at universities formed the basis for products to be marketed by the private sector
- Initially these were mesoscopic simulation/DTA models
- Interest in macroscopic simulation was renewed by the development of the Cell Transmission Model (CTM)
- Focus on calibrating/validating simulation models

Simulation-based Models Come of Age: The New Millennium

- The large-scale network models came to market
- FHWA launched NGSIM: a public-private partnership
- Empirical database of vehicle trajectories lent credibility
- Practitioners widely accepted simulation-based products
- HCM (2010) included the role of simulation
- Link Transmission Models (LTM) developed
- Network software evolves: hybrid, multi-modal with APIs
- On-line deployment for real-time traffic management

What Now for Simulation??

- Bigger, better (valid, flexible) simulation-based models
- Extended on-line deployment for managing traffic flow
- Connected / Autonomous Vehicles
- Cloud computing
- Perceptual computing?



Evolution of the TEXAS Model for Intersection Traffic Simulation Animation and Traffic Flow Theory Milestones

By

Thomas W. "Tom" Rioux, Ph.D., P.E.
Rioux Engineering, Austin, Texas, President and Consultant to Harmonia Holdings Group, LLC., Blacksburg, Virginia
Tom.Rioux@att.net

Presented at the 93rd Annual Meeting of the Transportation Research Board
Workshop 172 – Simulation: Looking Back and Looking Ahead
Sunday, January 12, 2014, 1:30-4:30 PM in Washington, D.C.

TEXAS Model for Intersection Traffic

- Dr. Clyde E. Lee was the faculty member who conceived the idea of applying the University of Texas at Austin's (UT) new Control Data Corporation (CDC) 1604 mainframe digital computer for simulating traffic flow through an intersection in the late 1960s
- Tom Rioux developed an interactive graphics system (1) to display and manipulate a finite elements model mesh during the 1969-70 school year and (2) to display the theoretical and observed dynamic forces between the tires and pavement of a moving truck allowing the spring constants and damping coefficients to be modified during the 1970-71 school year at UT using the CDC 250 Display System

TEXAS Model for Intersection Traffic

- Tom Rioux was the graduate student leader of the team that developed the TEXAS Model from 1971 through its release in 1977
- Dr. Guido Radelat of FHWA suggested the name Traffic EXperimental and Analytical Simulation Model for Intersection Traffic (TEXAS Model)
- Source code released under the GNU General Public License in 2005 by UT
- The TEXAS Model is being enhanced to include Connected Vehicle messages by Harmonia Holdings Group and Dr. Rioux to be a test bed for Connected Vehicle applications

TEXAS Model 1970's Animation

- In 1973, Tom Rioux developed an animation that was used during initial development efforts
- CDC 250 Display System channel connected to a CDC 6600 mainframe Computer System
- Vector Refresh Monitor with a 4095-word display buffer, a 60-times-per-second refresh rate, a 1024x1024 coordinate system, and light pen and keyboard input devices
- Analog line from x,y to x,y and horizontal text
- Each driver-vehicle unit was individually characterized, had blinking left- and right-turn signals, and had brake lights on the rear bumper
- The animation code was inserted within the TEXAS Model simulation source code

TEXAS Model 1970's Animation

- To make the animation movie, a 16 mm single-frame movie camera was mounted on a tripod, a photocell was attached to the lower right corner of the screen, the animation was updated one time step increment, a flash of light was produced in the lower right corner of the screen to take one frame of movie film, and the process continued taking 3 hours to produce 3 minutes of film
- Used lines to draw vehicles and geometry
- Play, pause, and exit

TEXAS Model 1980's Animation

- In 1985, Mr. Robert F. "Bobby" Inman developed the Disk Operating System (DOS) version of the animation named DISPRO
- The simulation model produced a file with records for each driver-vehicle unit for each time step increment
- A preprocessor program DISPRE read this data and reformatted and processed the data to make it easier to animate
- The animation program DISPRO read the data from the preprocessor program DISPRE, took direct control of a display monitor turning on and off individual pixels on the color screen, and took input from the keyboard and function keys

TEXAS Model 1980's Animation

- The animation could be paused and go backward and forward in single step, slow, or fast mode
- Vehicles appeared as a series of dots making up the edge of the vehicles and again had blinking left- and right-turn signals and brake lights on the rear bumper
- The lane edges and stop lines were drawn as lines and traffic signal indications were displayed near the stop line
- For development purposes, the traffic signal controller timers and states as well as detector actuations were displayed

TEXAS Model 1990's Animation

- In 1992, Mr. Scott Carter and Dr. Rioux developed the X Windows version of the animation named DISPRO on an Intergraph Corporation RISC-processor-based Unix workstation
- The animation program DISPRO read the data from the preprocessor program DISPRE, opened one control X Window, opened 1-4 intersection X Windows so the user could compare two or more different runs, and took input from the keyboard and mouse
- Each X Window could be separately panned, zoomed, sized, and moved around the screen

TEXAS Model 1990's Animation

- The animation could be paused and go backward and forward in single step, slow, or fast mode
- Vehicles appeared as lines making up the edge of the vehicles and again had blinking left- and right-turn signals and brake lights on the rear bumper
- The lane edges and stop lines were drawn as lines and traffic signal indications were displayed beyond the stop line as green, yellow, or red arrows or squares

TEXAS Model 2000’s Animation

- In 2000, Mr. Moboluwaji "Bolu" Sanu and Dr. Rioux developed the proof of concept version of the Java animation
- In 2005, Dr. Sanu and Dr. Rioux developed the Java version of the animation
- The animation program runs on any computer with the Java Runtime Environment (JRE)
- The animation program texasdis.jar reads the data from the preprocessor program DISPRE, opens one control window, opens 1-2 intersection windows so the user can compare two different runs, and takes input from the keyboard and mouse

TEXAS Model 2000's Animation

- Each window can be separately panned, zoomed, sized, and moved around the screen
- The animation can be paused, restarted, and go forward or backward in single step, slow, or variable-speed fast mode
- The user can enter the start time for the animation
- Optionally, the user can enable Presentation Mode so that it would restart at the end rather than stopping at the end
- Vehicles appear as filled shapes with angled front ends, a blue windshield, blinking left- and right-turn signals, and brake lights on the rear bumper

TEXAS Model 2000's Animation

- The TEXAS Model had been upgraded to have articulated vehicles and these are drawn to scale
- The lane edges and stop lines are drawn as lines and traffic signal indications are displayed beyond the stop line as green, yellow, or red arrows or squares
- The user can optionally:

  (1) display the driver-vehicle unit number,

  (2) change the vehicle color by vehicle class,

  (3) view turn signals,

  (4) view brake lights,

TEXAS Model 2000's Animation

- The user can optionally: (continued)

  (5) identify vehicles blocked by a major collision,

  (6) identify vehicles involved in a major collision,

  (7) identify emergency vehicles running calls,

  (8) view vehicles reacting to emergency vehicles running calls,

  (9) view vehicles reacting to VMS messages,

TEXAS Model 2000's Animation

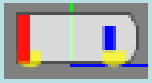
- The user can optionally: (continued)

(10) view an attached image file,

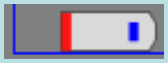
(11)

view pedestrian activity if there is a NEMA traffic signal controller with pedestrians,

(12) view vehicle detector activity –

 vehicle front bumper crossing the front edge

vehicle rear bumper crossing the rear edge

 vehicle within or spanning the detector

(13) view sight distance restriction locations,

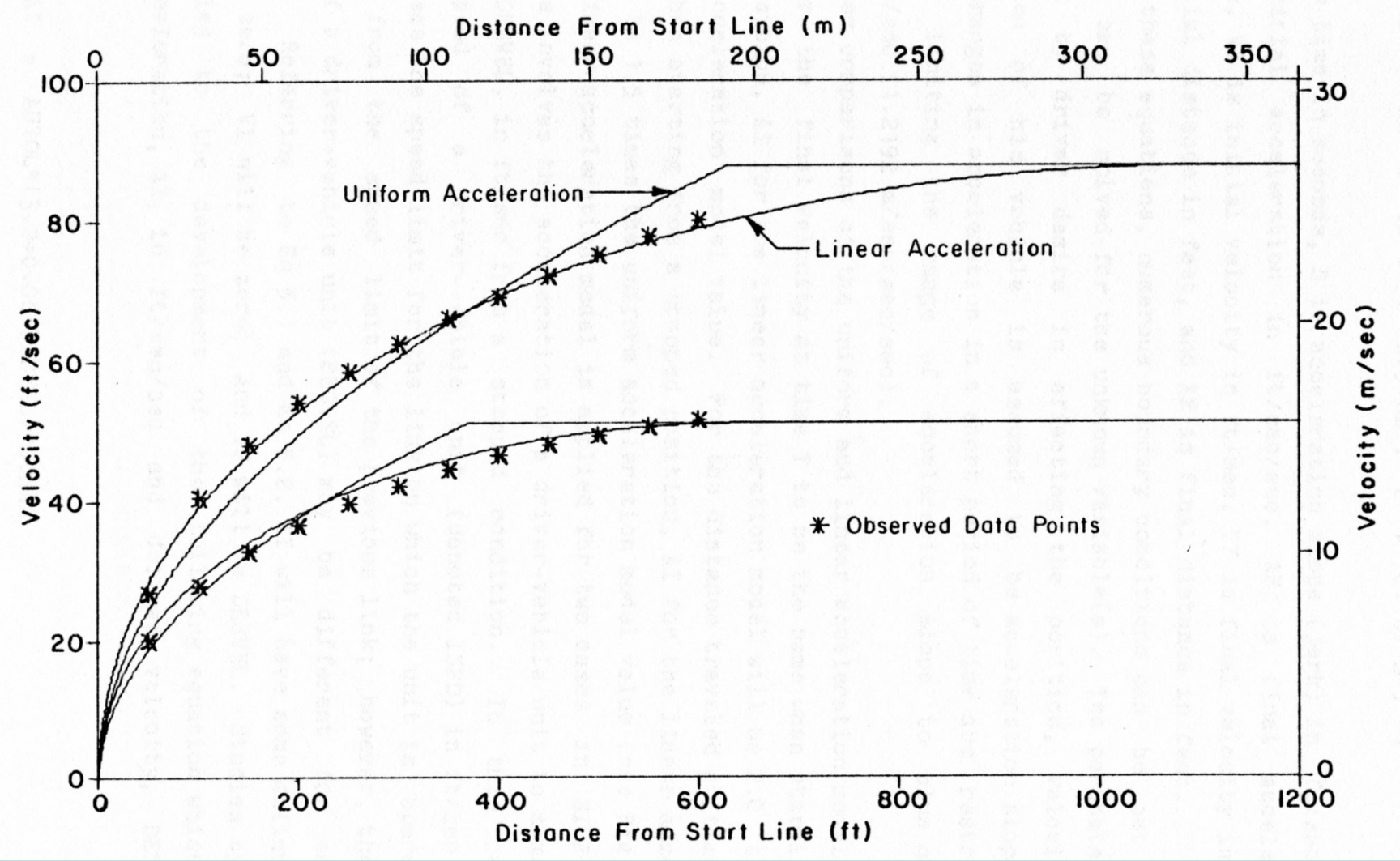
(14) view user-defined arcs of circles, and

(15) view user-defined lines

Triangular Acceleration

- The uniform acceleration model did not match observed behavior accurately when considered on a microscopic scale
- A linear acceleration model was investigated
- Comparisons of this model with observed data indicate excellent agreement
- Starting from a stopped condition, a driver-vehicle unit will use a maximum positive jerk rate until it reaches the maximum acceleration then the driver-vehicle unit will use a negative jerk rate until the acceleration is zero at the driver-vehicle unit's desired speed
- The maximum acceleration is defined by the driver's desired speed and vehicle capabilities

Triangular Acceleration



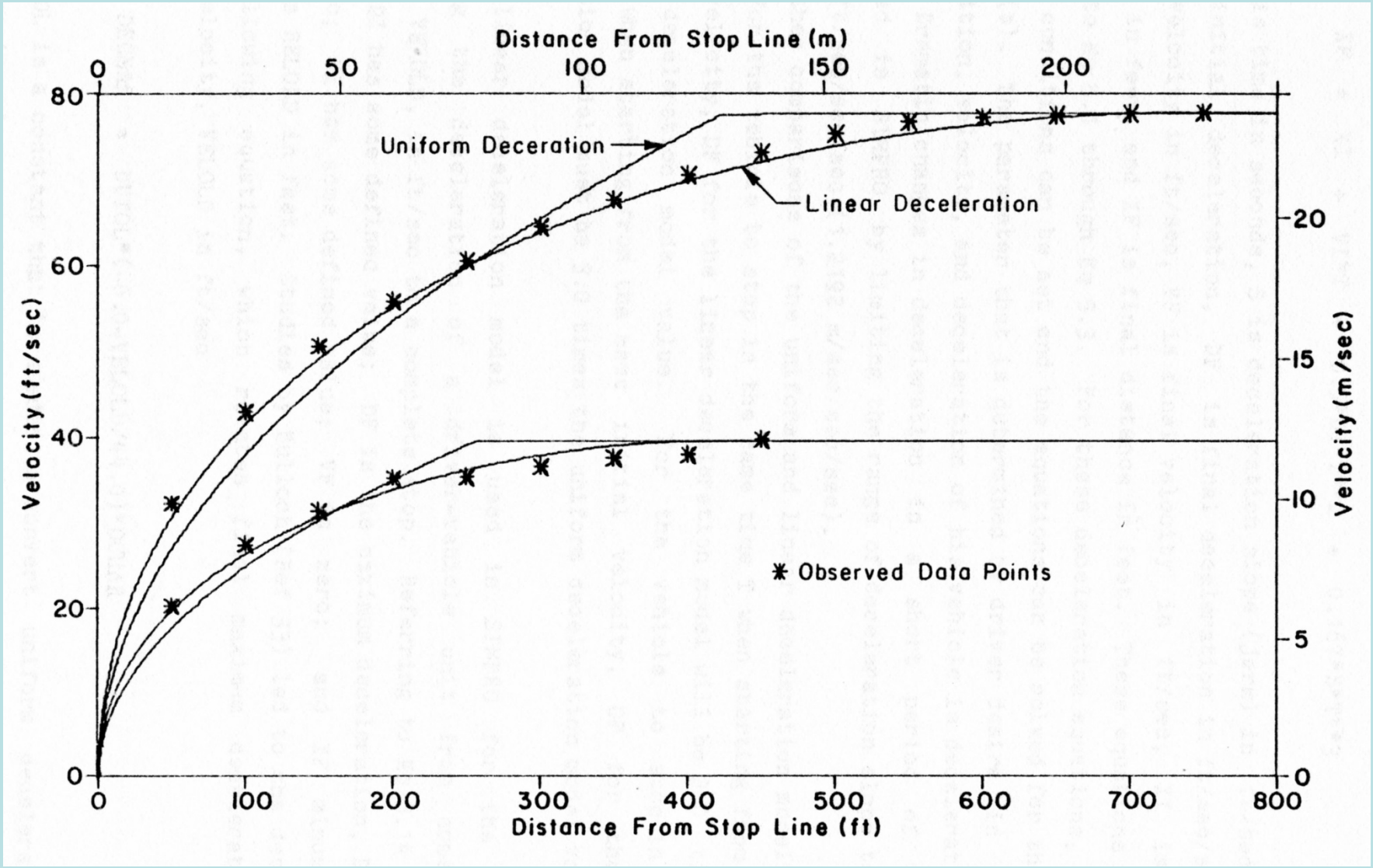
Triangular Deceleration

- The uniform deceleration model did not match observed behavior accurately when considered on a microscopic scale
- A linear deceleration model was investigated
- Comparisons of this model with observed data indicate excellent agreement
- Starting from a moving condition, a driver-vehicle unit will use a maximum negative jerk rate until it reaches the maximum deceleration when the driver-vehicle unit stops
- The maximum deceleration is defined by the driver-vehicle unit’s current speed and vehicle capabilities

Triangular Deceleration

- If a driver-vehicle unit is to decelerate to a stop, the time to stop and then the distance to stop is calculated each time step increment using current speed, current acceleration/deceleration, and current maximum deceleration
- A deceleration to a stop is initiated when the driver-vehicle unit’s distance to the location for a stop becomes less than or equal to the distance to stop

Triangular Deceleration



Equations of Motion

With the development of the triangular acceleration and triangular deceleration models, it was clear that the equations of motion had to include jerk rate as follows:

$AN = AO + J * DT$

$VN = VO + AO * DT + 1/2 * J * DT^2$

$PN = PO + VO * DT + 1/2 * AO * DT^2 + 1/6 * J * DT^3$

where:

AN = acceleration/deceleration new in ft/sec/sec
AO = acceleration/deceleration old in ft/sec/sec
DT = time step increment in seconds
J = jerk rate in ft/sec/sec/sec
PN = front bumper position new in feet
PO = front bumper position old in feet
VN = velocity new in ft/sec
VO = velocity old in ft/sec

Car Following

The non-integer, microscopic, generalized Gazis-Herman-Rothery (GHR) car-following model was selected as follows:

$$RelPos = PVPos - PO$$

$$RelVel = PVVel - VO$$

$$AN = CarEqA * VO^{CarEqM} / RelPos^{CarEqL} * RelVel$$

where:

AN = current driver-vehicle unit acceleration/deceleration new in ft/sec/sec
CarEqA = user-specified GHR Model Alpha parameter (min=1, def=4000, mx=10000)
CarEqL = user-specified GHR Model Lambda parameter (min=2.3, def=2.8, max=4.0)
CarEqM = user-specified GHR Model Mu parameter (min=0.6, def=0.8, max=1.0)
PO = current driver-vehicle unit front bumper current position old in feet
PVPos = previous driver-vehicle unit rear bumper position in feet
PVVel = previous driver-vehicle unit velocity in ft/sec
RelPos = relative position in feet
RelVel = relative velocity in ft/sec
VO = current driver-vehicle unit velocity old in ft/sec

Car Following

A conservative car-following distance is defined as follows:

RelVel = PVVel - VO

CarDis = (1.7 * PVVel + 4 * $RelVel^2$) / DrivChar

where:

CarDis = car-following distance in feet

DrivChar = user-specified driver characteristic
(<1=slow, 1=average, >1=aggressive)
(min=0.5, max=1.0)

PVVel = previous driver-vehicle unit velocity in ft/sec

RelVel = relative velocity in ft/sec

VO = current driver-vehicle unit velocity old in ft/sec

Car Following

- If the relative velocity RelVel is greater than or equal to zero (the previous driver-vehicle unit is going faster than the current driver-vehicle unit) and the relative position RelPos is greater than some minimum value then the driver-vehicle unit is allowed to accelerate to its desired speed
- If the relative position of the vehicle RelPos is less than or equal to zero then emergency braking is applied.
- If the relative position of the vehicle RelPos is greater than the 1.2 times the car-following distance CarDis then the driver-vehicle unit is allowed to accelerate to its desired speed
- If the previous driver-vehicle unit is decelerating then calculate where it will stop and calculate the deceleration to stop behind the driver-vehicle unit ahead when it stops and if this deceleration is less than the car following deceleration then use it
- If the traffic signal changed from green to yellow and the current driver-vehicle unit decides to stop on yellow then calculate a deceleration to a stop at the stop line
- If the traffic signal is yellow and the driver-vehicle unit previously decided to stop on yellow then continue a deceleration to a stop at the stop line

Intersection Conflict Checking

- Intersection Conflict Checking (ICC) is the algorithm that determines whether a driver-vehicle unit, seeking the right to enter the intersection, has a predicted time-space trajectory through the intersection that does not conflict with the predicted time-space trajectory through the intersection of all other driver-vehicle units that have the right to enter the intersection
- If this vehicle’s rear can safely go in front of the other vehicle or this vehicle’s front can safely go behind the other vehicle then there is no conflict

Intersection Conflict Avoidance

- Intersection Conflict Avoidance (ICA) is the algorithm used to simulate the behavior of driver-vehicle units that have the right to enter the intersection and try to maintain a non-conflict time-space trajectory through the intersection with the predicted time-space trajectory through the intersection of other driver-vehicle units that have the right to enter the intersection
- Adjusts the vehicle’s speed to maintain the previously detected gaps through the intersection

Sight Distance Restriction Checking

- The user defines the coordinates of all critical points needed to locate sight obstructions in the intersection area
- The TEXAS Model Geometry Processor calculates the distance that is visible between pairs of inbound approaches for every 25-foot increment along each inbound approach
- The time required for a fictitious driver-vehicle unit, traveling at the speed limit of the approach, to travel from a position that is just visible on the inbound approach to the point of intersection conflict is predicted

Sight Distance Restriction Checking

- The time required for the driver-vehicle unit being examined to travel to the point of intersection conflict is predicted
- If the unit being checked may not safely pass through the point of intersection conflict ahead of the fictitious driver-vehicle unit then it may not clear its sight distance restrictions and continues on a deceleration to a stop at the stop line

Lane Changing

- In the early 1970s, Mr. Ivar Fett collected and analyzed the field data, developed the original lead and lag gap-acceptance decision models, and used a cosine curve for the lateral position for a lane change
- Dr. Rioux developed the concept of distinguishing between two types of lane changes: (1) the forced lane change wherein the currently occupied lane does not provide an intersection path to the driver-vehicle unit's desired outbound approach and (2) the optional lane change wherein less delay can be expected by changing to an adjacent lane which also connects to the driver-vehicle unit's desired outbound approach
- Later, Dr. Rioux added cooperative lane changing and a lane change to get from behind a slower vehicle

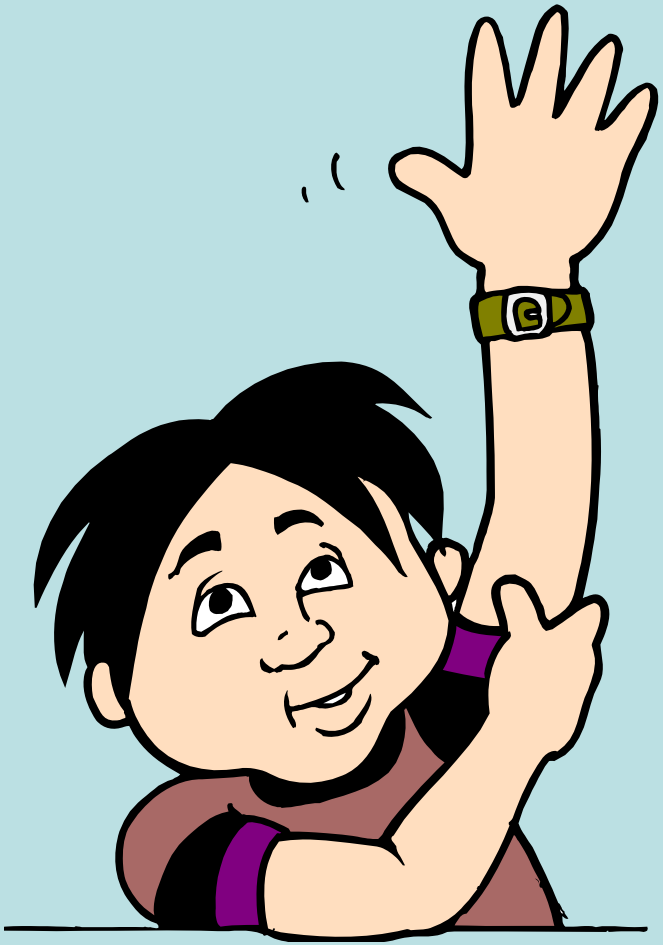
Crashes

- If the front bumper position of the driver-vehicle unit (lag driver-vehicle unit) is greater than the rear bumper position of the driver-vehicle unit ahead (lead driver-vehicle unit) then there is a crash; originally, only lead-lag crashes were detected and were called “clear zone intrusions”
- The lag driver-vehicle unit defied physics by placing itself 3 feet behind the lead driver-vehicle unit traveling at the speed of the lead driver-vehicle unit and with zero acceleration/ deceleration and jerk rate and the traffic simulation continued normally

Crashes

- In 2008, Dr. Rioux added the option to stop a driver-vehicle unit involved in a “major” crash using crash deceleration and remain stopped for the remainder of the simulation
- Additionally, a crash between driver-vehicle units on different intersection paths was detected
- Logic was added to cause other driver-vehicle units to react to driver-vehicle units involved in a “major” crash by slowing down as they passed the crash or to take evasive actions after they had been delayed for some response time

Questions ???



Transportation Research Board Annual Meeting

Sunday, January 12, 2014

Workshop 172 - Simulation: Looking Back and Looking Ahead

Future Directions for Managing Uncertainty in Stochastic Traffic Models

Vincenzo Punzo

University of Naples Federico II, Italy

When models are used for policy analysis…

"Post-Normal Science" (Funtowicz and Ravetz, 1992)

"[…] *When models are used for policy analysis, one must acknowledge that today's role of scientists in society is not that of revealing truth, but rather of providing evidence, be it "crisp" or circumstantial, based on incomplete knowledge, sometimes in the form of probability, before and within systems of conflicting stakes and beliefs*" (Funtowicz and Ravetz, 1992 as quoted in Saltelli et al., 2006)

Vast critique of models: the making of a model is not scientifically prescribed → indeterminacy, equifinality (Young et al., 1996; Beven and Freer, 2001), impossibility to validate (Konikov and Bredehoeft's, 1992, and Oreskes et al., 1994), complexity, over-parameterization…

…in one concept: uncertainty

Some 'symptoms' or effects

- (Un)repeatability of experiments
- (Un)reliability of predictions
- Vulnerability to instrumental or otherwise unethical use
  - Stakeholders will tend to expect or suspect instrumental use of models. They will "believe everything was possible and that nothing was true"
- Lack of effectiveness, credibility, transparency

" *[…] Uncertainty is not an accident of the scientific method but its substance"* (Saltelli et al., 2008)

'Management of modelling uncertainty', intended as the process of identification, quantification and reduction of model uncertainty.

When applying mathematical models in support of policy decision making, this can be considered as a step of a broader process also referred as 'sensitivity auditing': "*a practice of organised scepticism toward the inference provided by mathematical models*" (Saltelli et al. 2013).

Traffic modelling is 'not only' matter of good maths

Many sources of uncertainty:

- At **disaggregate level**:
  - ✓ modelling uncertainty (of sub-models)
  - ✓ system variability:
    - ✓ heterogeneity of drivers → each agent is a different model!!
    - ✓ Stochastic behaviours/sub-models
- At **aggregate level** (traffic stream)
  - ✓ Different (stochastic) sub-models that interact (CF, LC, LA, RC, etc.)
  - ✓ Different drivers/models interacting

So far…

- Most of the efforts to improve modelling assumptions and structures
- The management of the uncertainty limited to calibration/ validation
  - ✓ All the uncertainties incorporated within the parametric inputs (calibration)
- Advanced methods for Global Sensitivity Analysis (GSA) and Uncertainty Quantification (UQ) almost unknown
- Stochasticity as an accident of the modelling process

Common Misconceptions in Traffic Simulation:

1) Asymmetry in the uncertainty between model and reality

Dealing with stocasticity: uncertainty propagation and model replications

Input

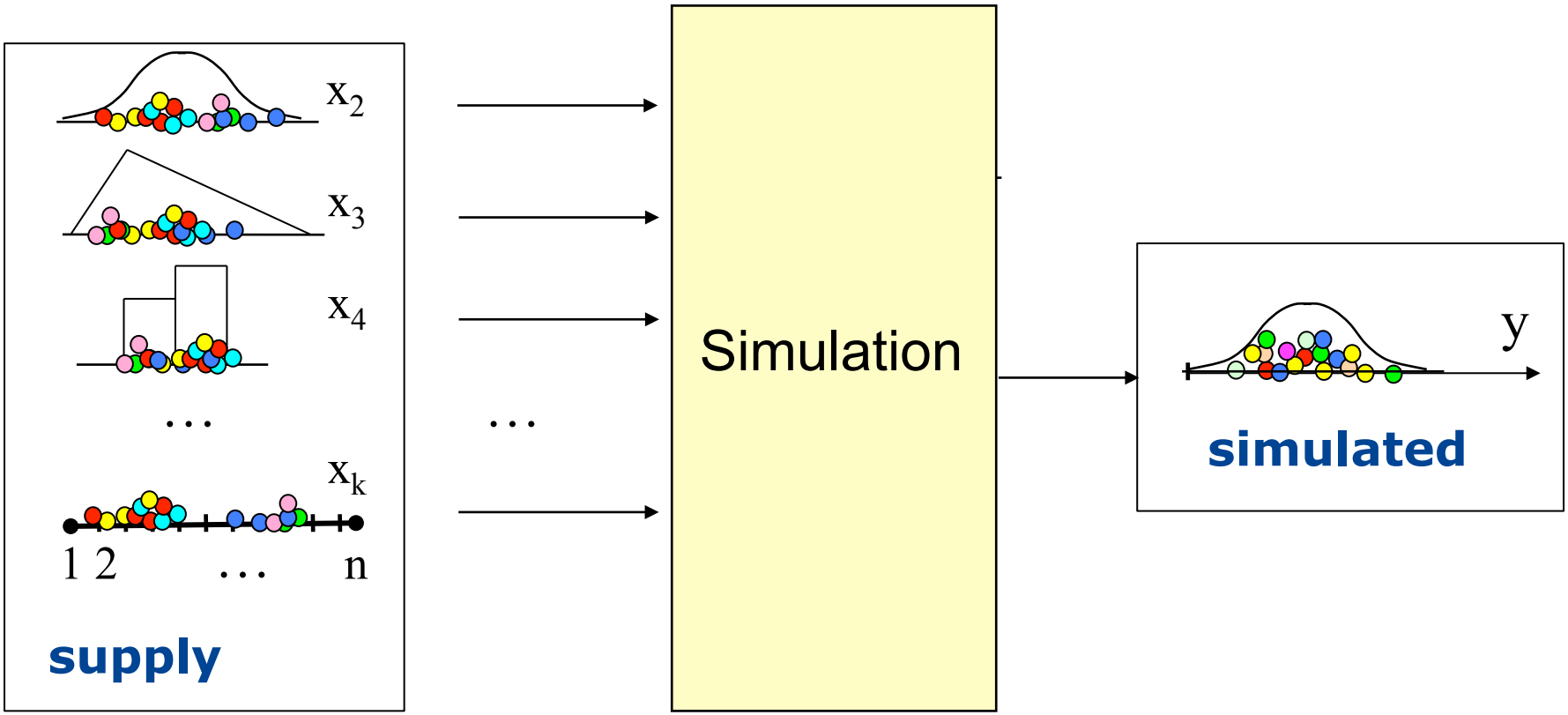
$$p(\vec{x})$$

Model/reality

$$Y = f(\vec{x})$$

Output

$$p(Y)$$



Acknowledged principles in stochastic modelling

Provided that:

- Models are stochastic → probabilistic measures of outputs e.g. averages, percentiles, pdf
- Uncertainty in the output has to be as close as possible to the uncertainty in the real world

The following question arises:

- Are the outputs from the model replications (usually performed in traffic simulation practice) able to tell the uncertainty in the real system?

Asymmetry in the uncertainty between model and reality

Input

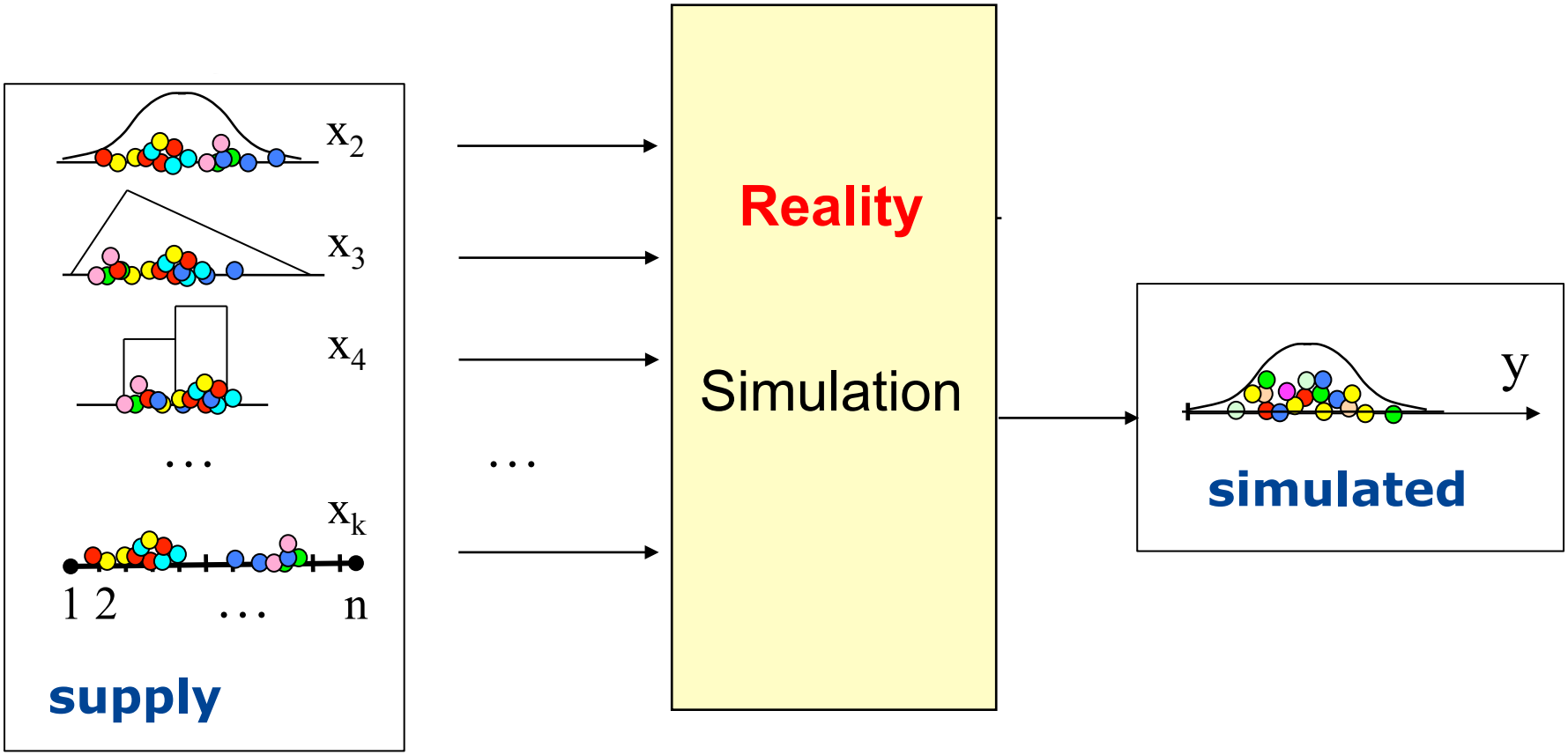
$$p(\vec{x})$$

Model/reality

$$Y = f(\vec{x})$$

Output

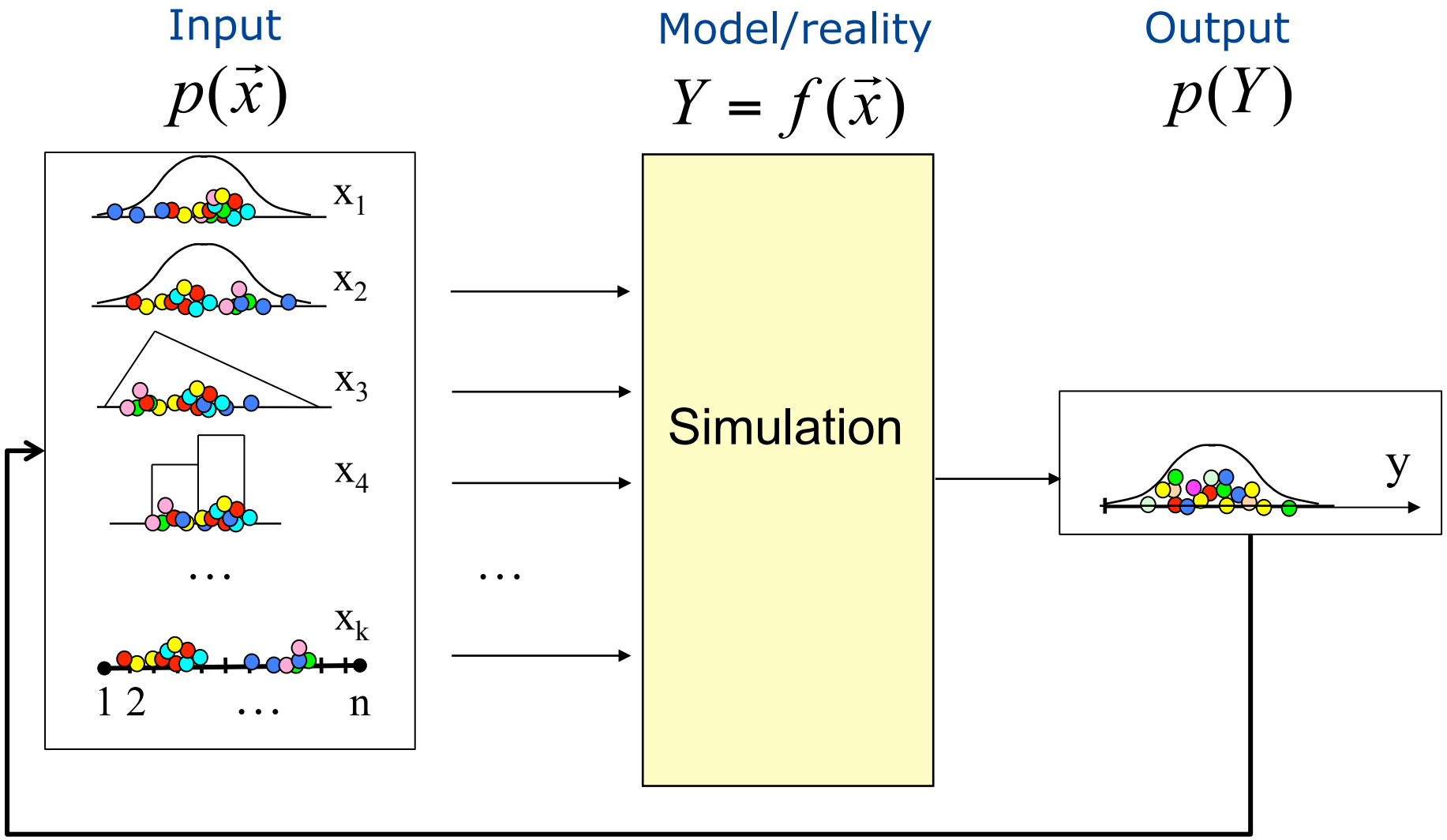
$$p(Y)$$



Common Misconceptions in Traffic Simulation:

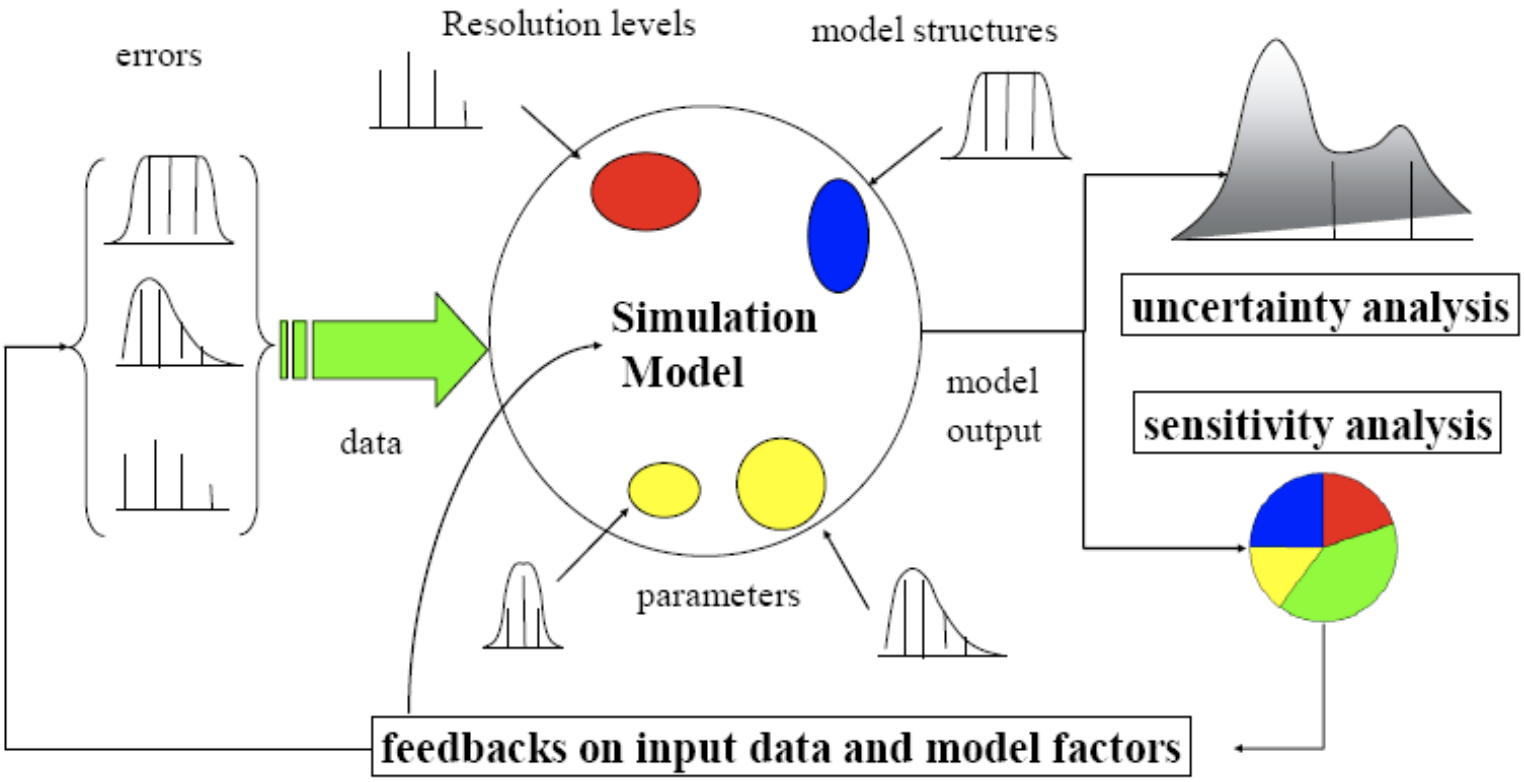
2) Sensitivity Analysis

Sensitivity analysis as a feedback process...



Sensitivity analysis

…to investigate the sources of the output uncertainty…



"SA is the study of how uncertainty in the output of a model can be apportioned to different sources of uncertainty in the model input." (*Saltelli et al., 2004*)

...to many aims

- Identify and rank influential inputs;
- Simplify models and defend against falsifications of the analysis;
- Identify critical regions in the space of inputs;
- Uncover technical errors;
- Establish priorities for research.

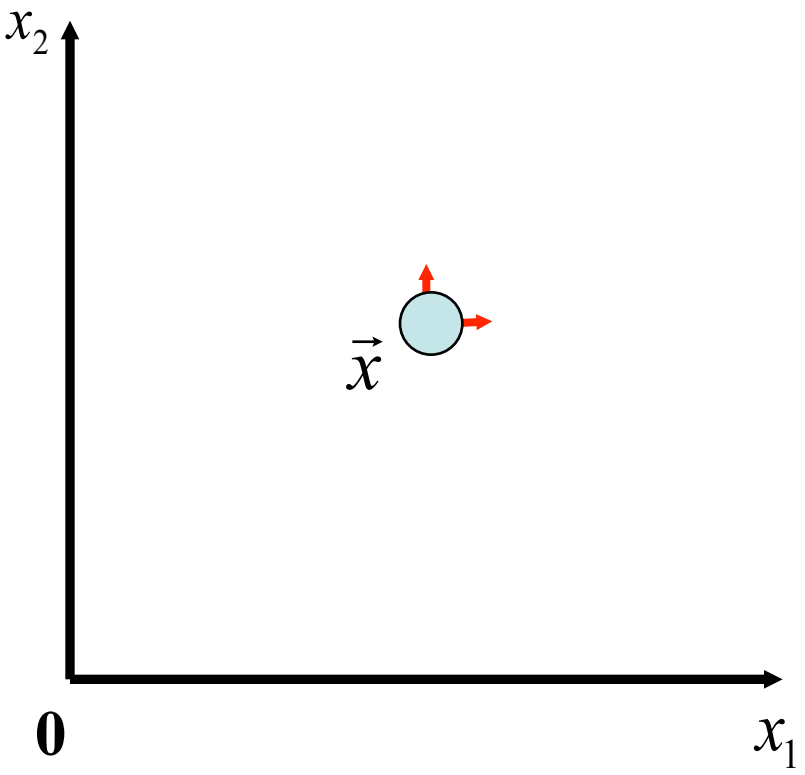
A basic list of SA techniques

- ✓ Input/output scatterplots
- ✓ Sigma-normalized derivatives
- ✓ Standardized regression coefficient
- ✓ Elementary effects
- ✓ Variance-based
  - ✓ FAST (Fourier Amplitude Sensitivity Test)
  - ✓ Uncertainty Importance
  - ✓ Importance Measure (based on Sobol's variance decomposition)
  - ✓ First order sensitivity indices
  - ✓ Interactions effects
- ✓ Monte Carlo filtering
- ✓ …

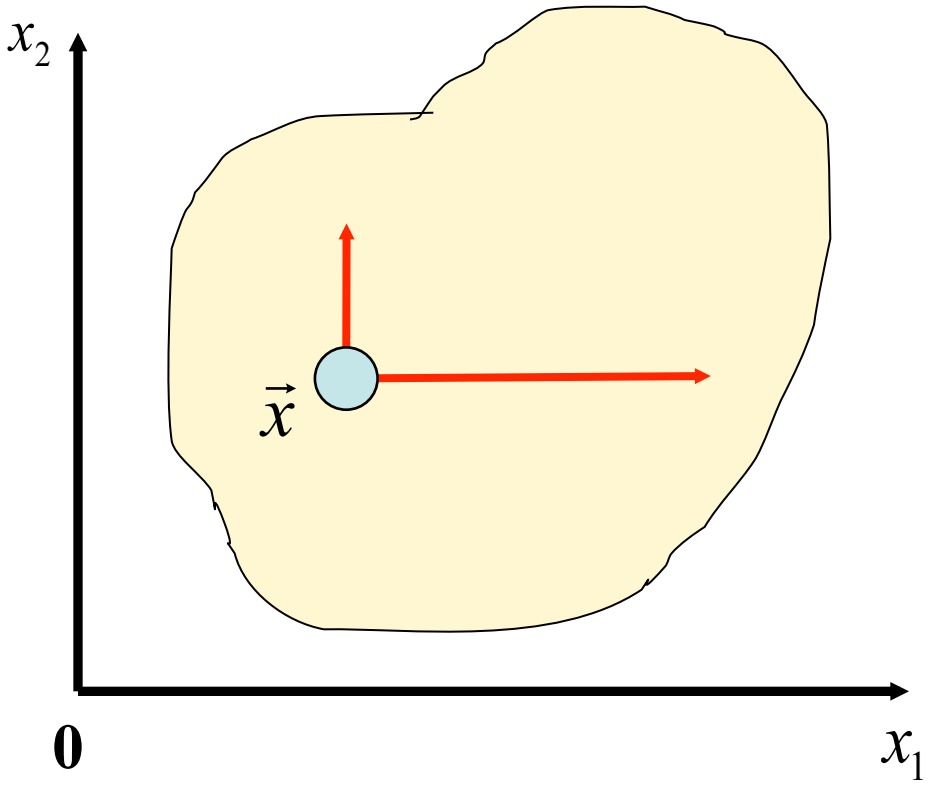
Sensitivity analysis in current traffic simulation

- Simulation practice:
  - ✓ Uncertainty propagation with one-factor-at-a-time (OAT) experimental design
  - ✓ None or little statistical analysis
- Scientific literature:
  - ✓ The most advanced methods are vastly unknown

Local SA

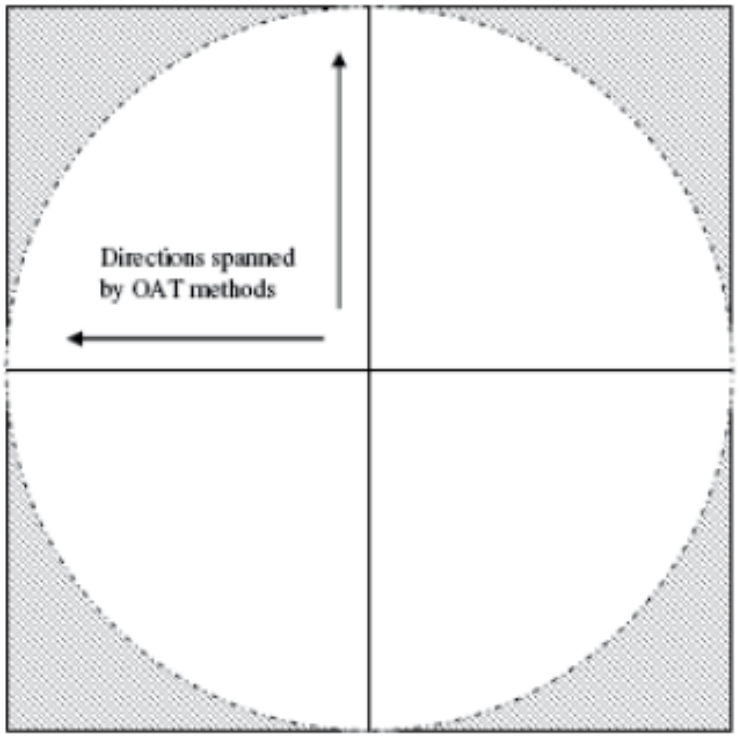


One at a time SA



(x_1, x_2) = space of input $\vec{x}$ = nominal value

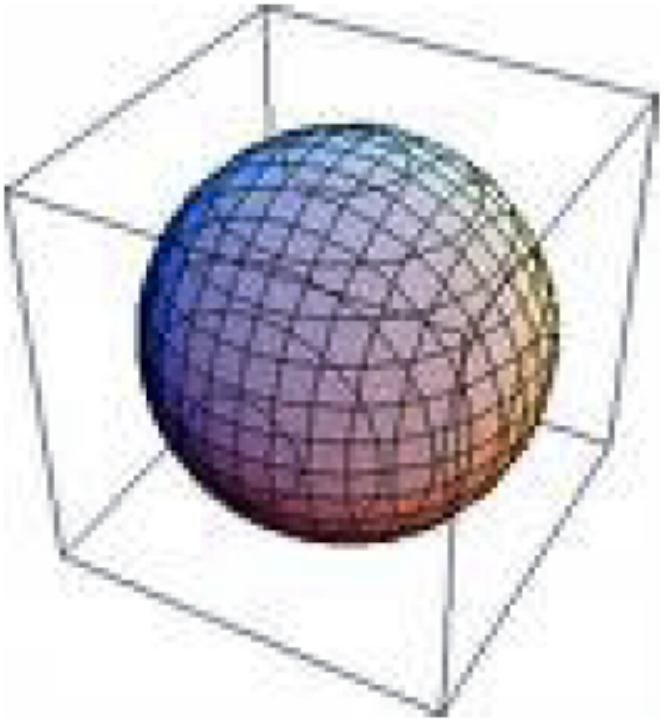
OAT in 2 dimensions



Area circle / area square =?

~ 3/4

OAT in 3 dimensions



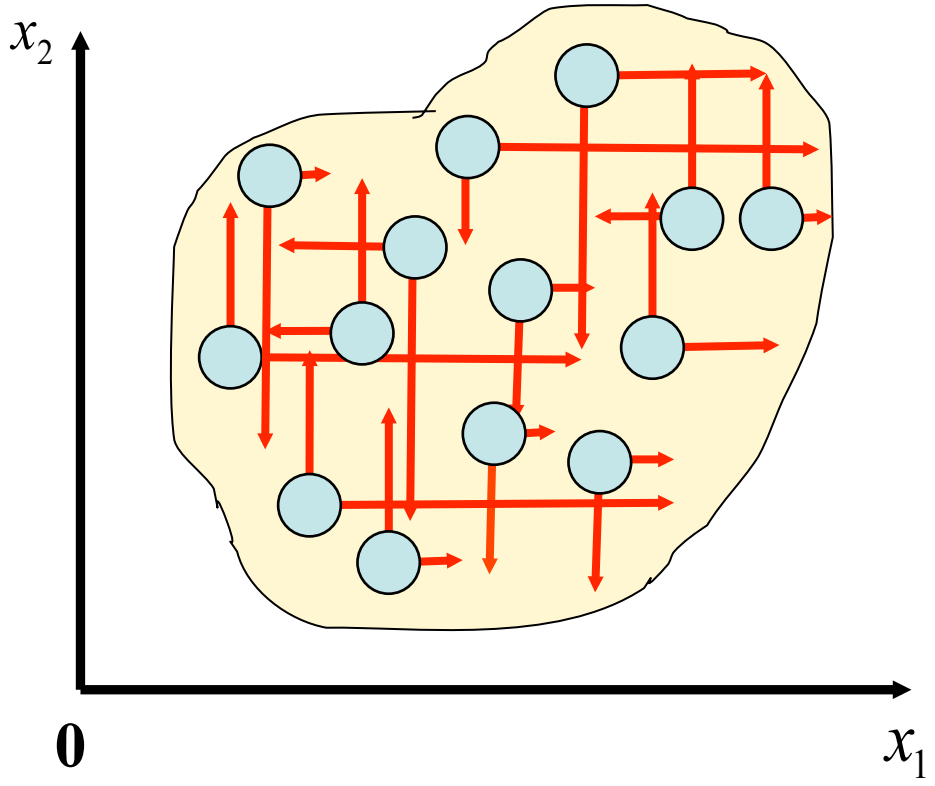
Volume sphere /
volume cube =?

~ 1/2

OAT in 10 dimensions

Volume hypersphere / volume
ten dimensional hypercube ~ 0.0025

Global SA



(x_1, x_2) = space of input

Common Misconceptions in Traffic Simulation:

3) Misuse of the term 'Sensitivity Analysis'

Misuse of the term 'sensitivity analysis'

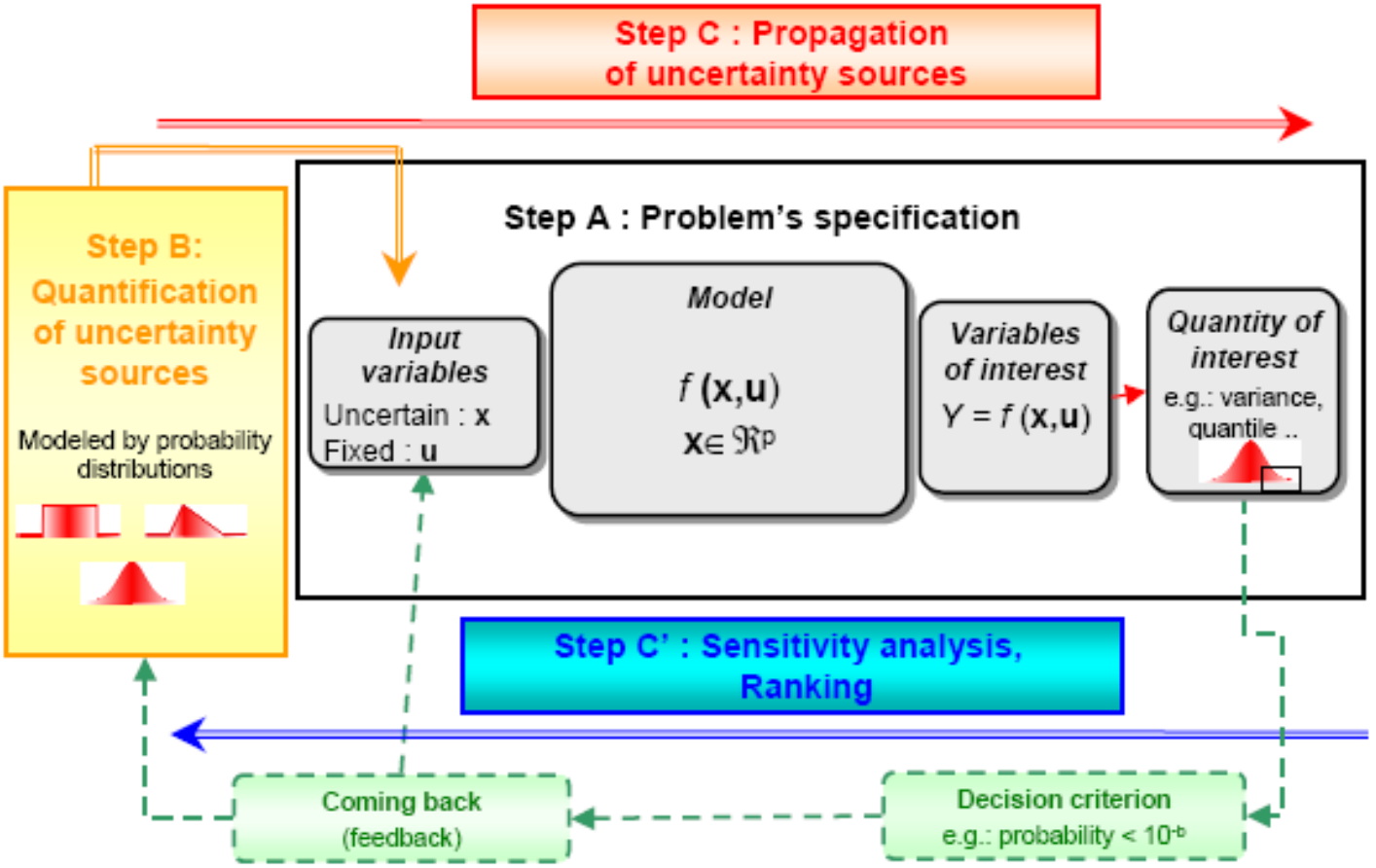
- Applied instead of 'uncertainty analysis' (or uncertainty quantification)

  For instance, quoting the Traffic Analysis Toolbox Vol. III (FHWA, 2003): "[…] *A sensitivity analysis is a targeted assessment of the reliability of the microsimulation results, given the uncertainty in the input or assumptions. The analyst identifies certain input or assumptions about which there is some uncertainty and varies them to see what their impact might be on the microsimulation results*".

- Stability analyses of the objective function in parameter estimation problems or, reliability analyses of traffic assignment solutions, have been also referred as sensitivity analyses.

Future Directions

A general framework to manage uncertainty in traffic modelling (Punzo et al. 2014)



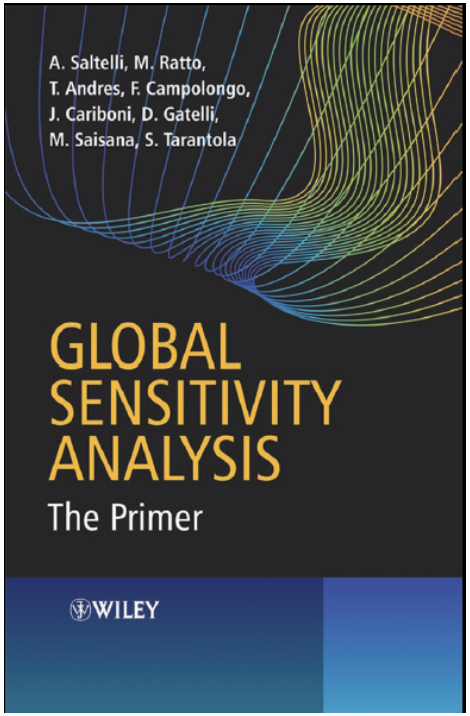
Future directions and hot topics (1)

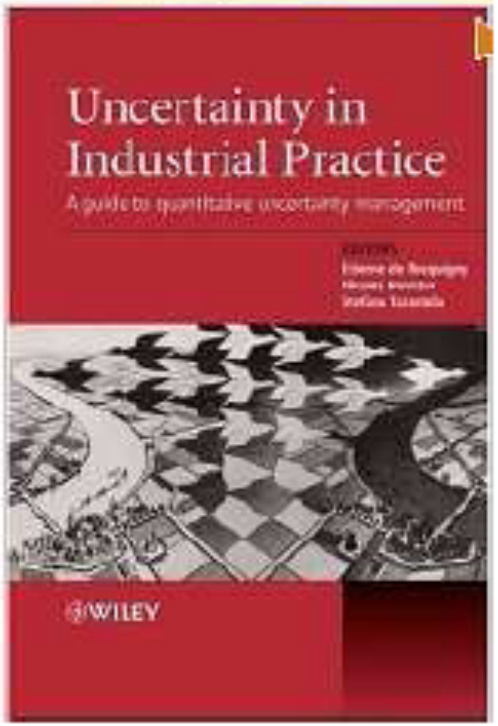
- Move to Global Sensitivity Analysis (GSA) and uncertainty management techniques (where calibration is only one of the steps)
- Coping with computational complexity in GSA
  - ✓ Screening methods on full models
  - ✓ Variance-based methods on meta-models (Ciuffo et al. 2013)
  - ✓ Mixed strategies (Qiao et al. 2014, **session 783**)
- Model simplification (Punzo et al. 2014 **session 783**)
- Investigating the impact of input correlation structure and sampling strategies on simulation results
- Dealing with correlated inputs in GSA

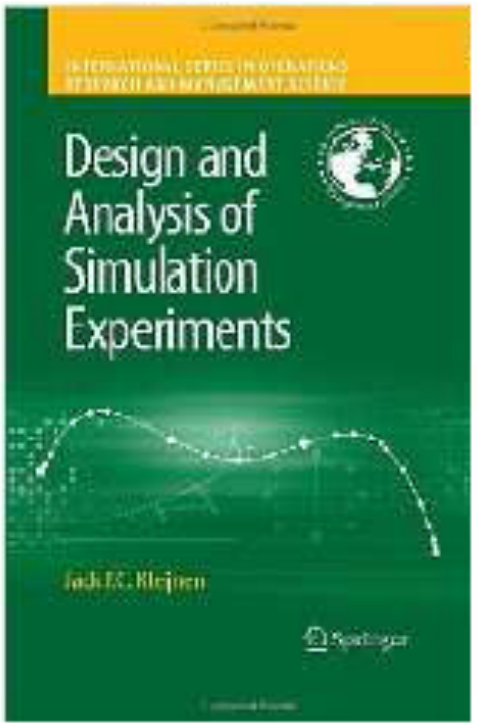
Future directions and hot topics (2)

- Investigating the impacts of uncertainty in traffic data on model calibration and simulation
- Encompassing both supply and demand in design of experiments (model replications)
- Moving to methods for robust scenario analysis
- GSA on both disaggregate and full models: from uncertainty in sub-models to the emerging traffic flow behaviour
- …
- One step further: Sensitivity Auditing

Some useful books







CONTACTS:

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Request reconstructed NGSIM dataset
(I80 4.00-4.15 p.m.)
www.multitude-project.eu

NEW YORK UNIVERSITY

URBAN MITS Lab@NYU

Big Data & the Calibration and Validation of Traffic Simulation Models

Kaan Ozbay, Sandeep Mudigonda, Ender F. Morgul, Hong Yang, Bekir Bartin

January 13, 2014

Introduction

- Three main steps in building accurate simulation models:
  - Model verification,
  - Calibration,
  - Validation.

  } All require **DATA**!

- Availability, accuracy and relevance of real-world data can seriously affect the reliability of the models' predictions.

Introduction

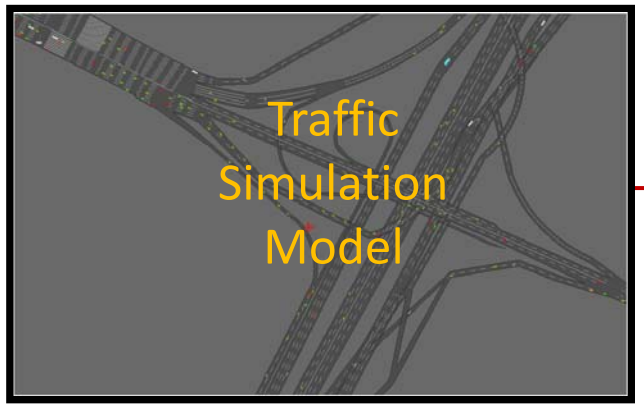
- Big Data's large spatial and temporal extent can help calibrate and validate traffic simulation models.
  - Smart phones,
  - GPS-equipped devices,
  - Traffic sensors and cameras,
  - Computers in cars.

Process of Calibration

Calibration Parameters:
User-, traffic-related parameters

C_s

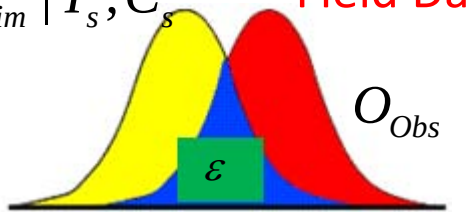
I_S



Simulated Outputs: given inputs and parameters

$O_{Sim} \mid I_s, C_s$

Observed Field Data



Error

Inputs:
Travel Demand
Geometry
Operational rules

Calibration

$$\min_{C_S} \{\varepsilon : U(O_{obs}, O_{sim}(I_s, C_s))\}$$

NYU

CUSP

Data Needs for Calibration

Model Inputs:

- Driver Characteristics Data
- Vehicle Composition Data
- Travel Demand Data
- Ped./Bike Data

Model Parameters:

- Link (capacity, speed limit,…)
- Path (route choice, tolls,…)
- Infrastructure (signal timings, VMS, work zones,…)
- Weather
- Driver behavior data
- Activity data

Observed Outputs:

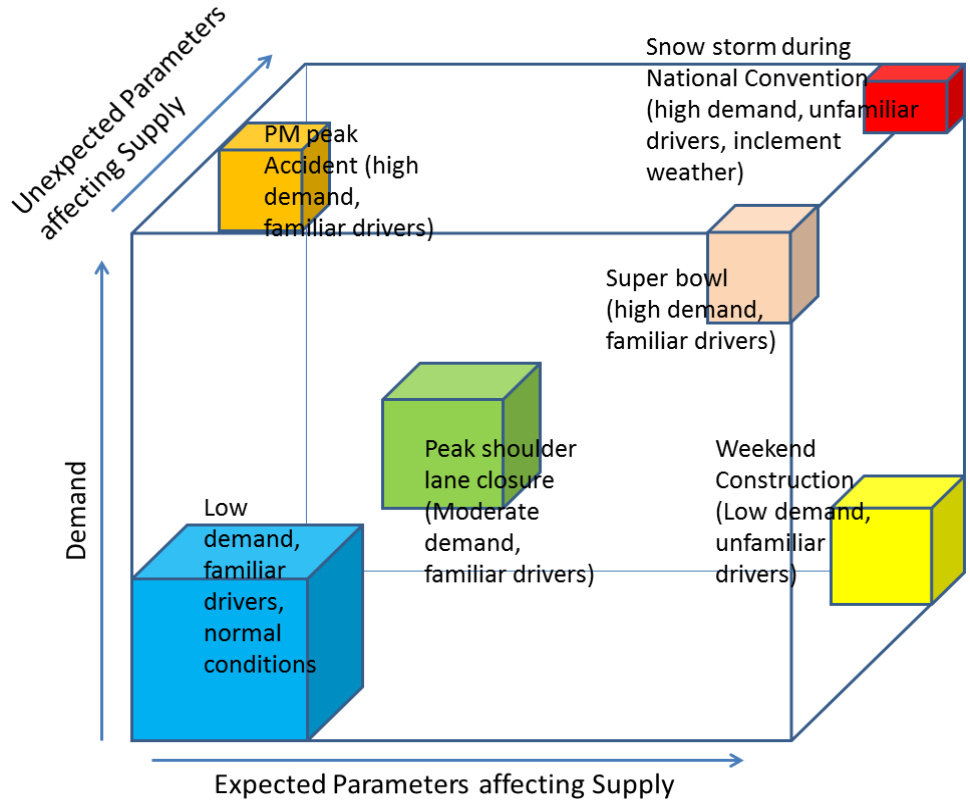
- Flows & Speeds
- Queue data
- Trajectories
- Accidents (?)
- Emissions
- Other

NYU

CUSP

Current Practice of Calibration

- In most studies data used for calibration is limited to AM and PM peak periods no more than a few days.
- Thus, the data captures only a few specific conditions, or is a dilute sample of different conditions.



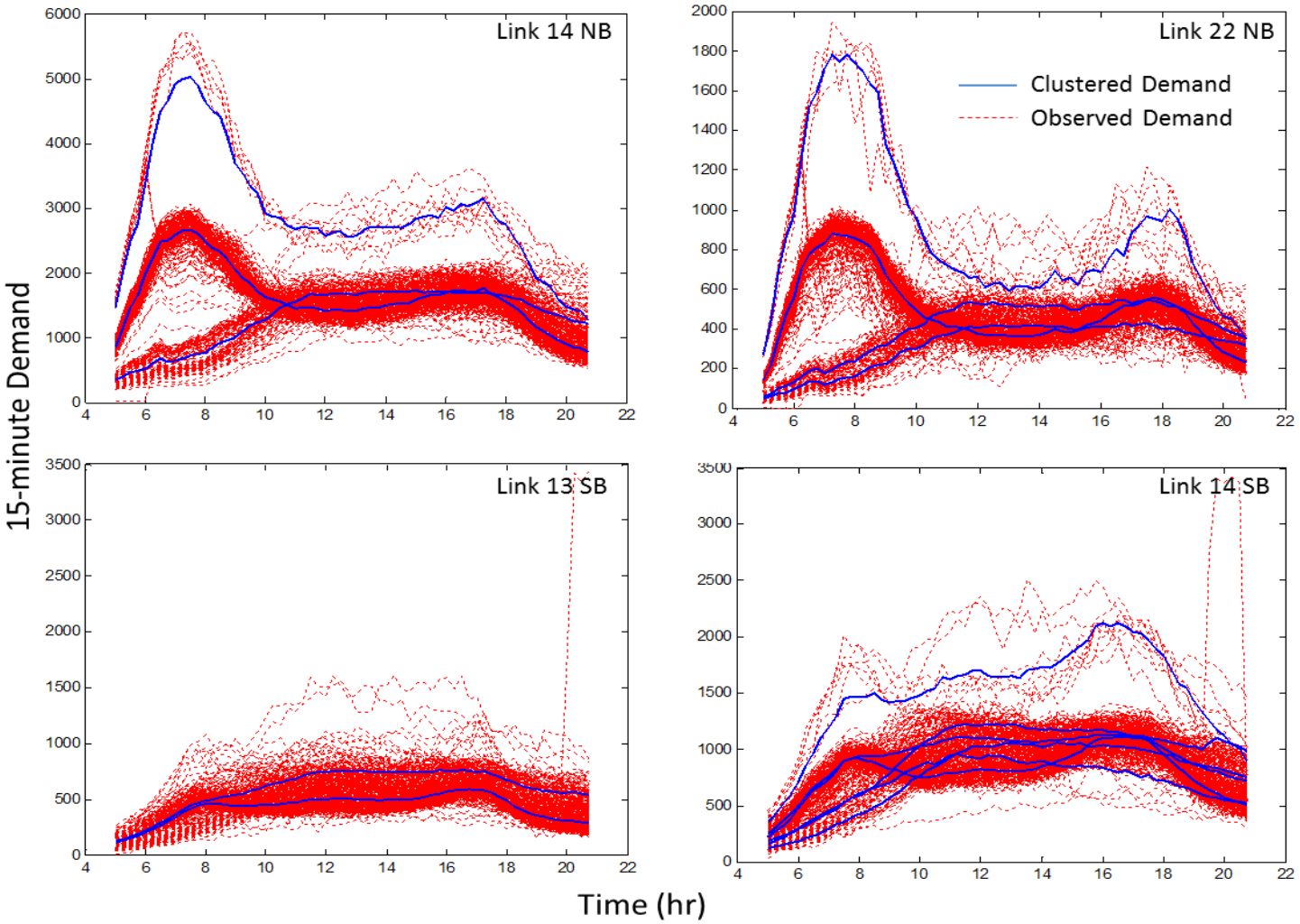
Distribution of traffic data: Typical day?

- Traffic Simulation Model:
  - The demand from various clusters,
  - The variation of demand about each cluster.
- Traffic Flow Variation:
  - Incidents,
  - Work zones,
  - Driver/vehicular variability and,
  - Other unobserved phenomena.

- Big Data from GPS, cellular phones, RFIDs, etc. provide vast amounts of demand, vehicle, speed, flow, event data

Distribution of traffic data: Typical day?

- Illustration of clusters



Examples of Typical "Big Data" Sources

- ETC Data
  - Vehicle-by-vehicle entry and exit time, lane, transaction type, vehicle type, number of axles.
  - Available in NJ for 150 miles of NJTPK and 170 miles of GSP.
- Traffic data providers

  - INRIX: flows and speeds on 260,000 miles of highways using 800,000 equipped vehicles.
  - Receives information from road sensors, taxi cabs, delivery vans, long-haul trucks, and mobile devices.
  - Reports accident and other local data.

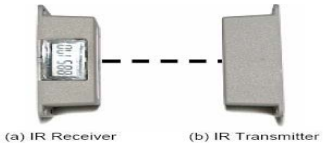
Examples of Typical Big Data Sources

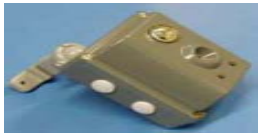
- GPS Data from Large Vehicle Fleets
  - Trucks, taxis.
  - New York City Taxi and Limousine Commission (TLC) data: 40 million records per year integrated to a single database.
  - GPS recordings from more than 13,000 taxis covering all time periods and almost all regions in New York City.
- Cellular Network Data
  - Good proxy for the user location.
  - Travel demand, travel time, trip distribution from various studies world over using millions of data points.

Examples of Typical Big Data Sources

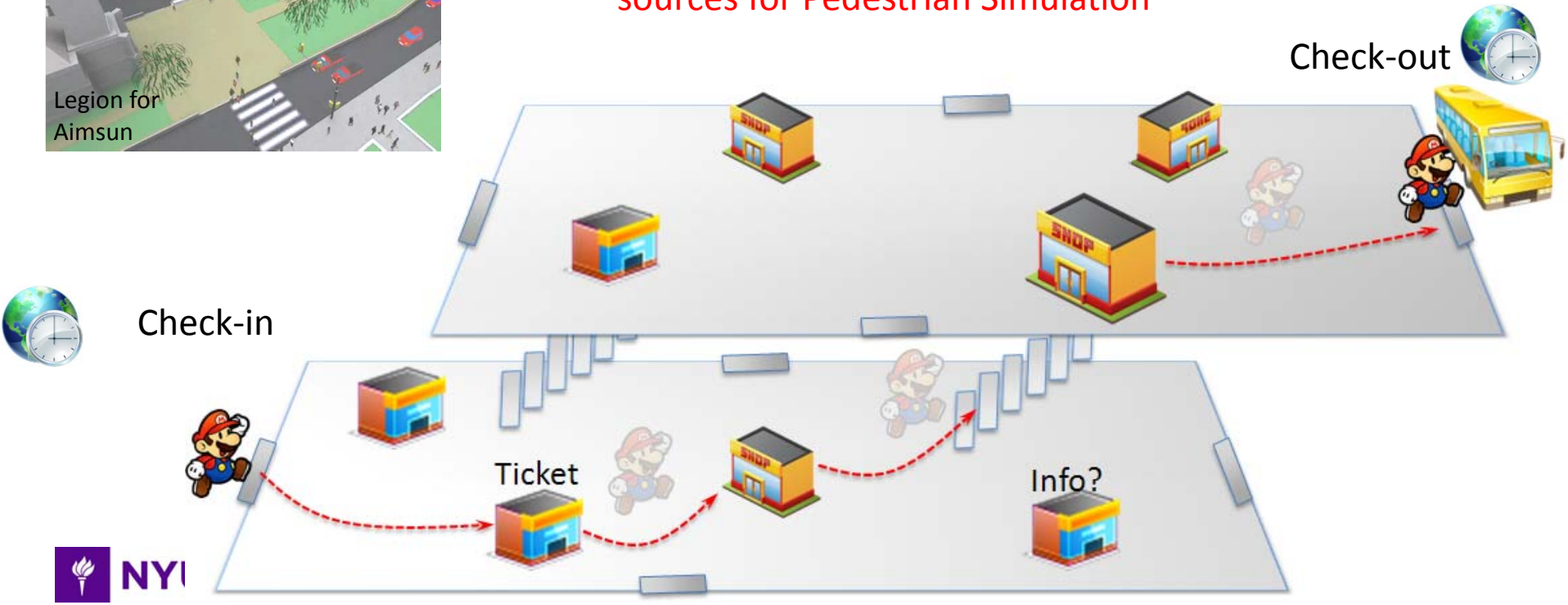
- Crowdsourcing Data (Virtual Sensors)
  - From online services that provide real-time or historical traffic data.
  - Google Maps™, Bing Maps™ and MapQuest™ APIs help in collecting real-time travel times and speed data.
- Event data
  - Several agencies collect incidents, crashes as well as other road related events.
  - TRANSCOM collects traffic data in the NY-NJ area, especially, during events such as, workzones, accidents, hurricanes, sporting events, conventions.

Examples of Typical Big Data Sources



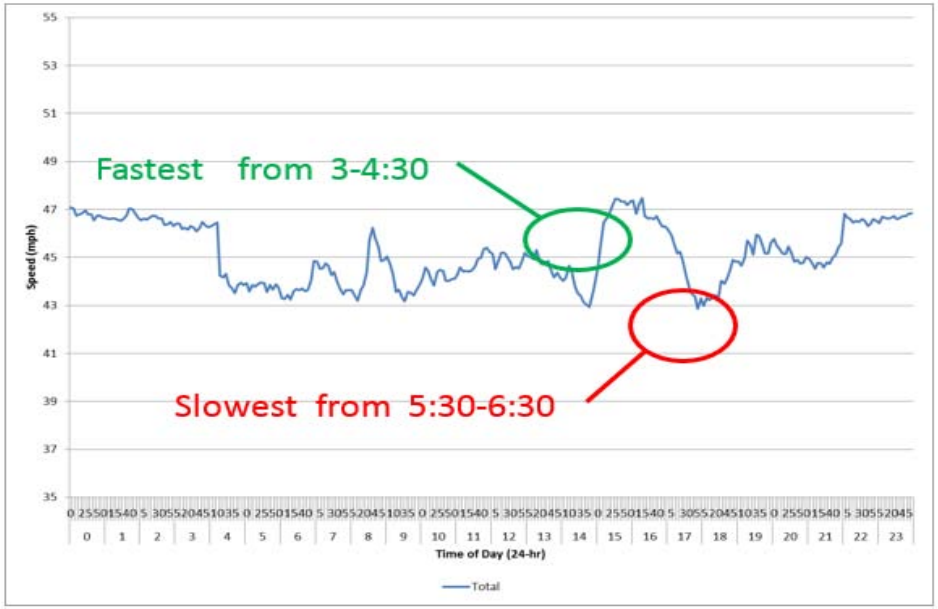


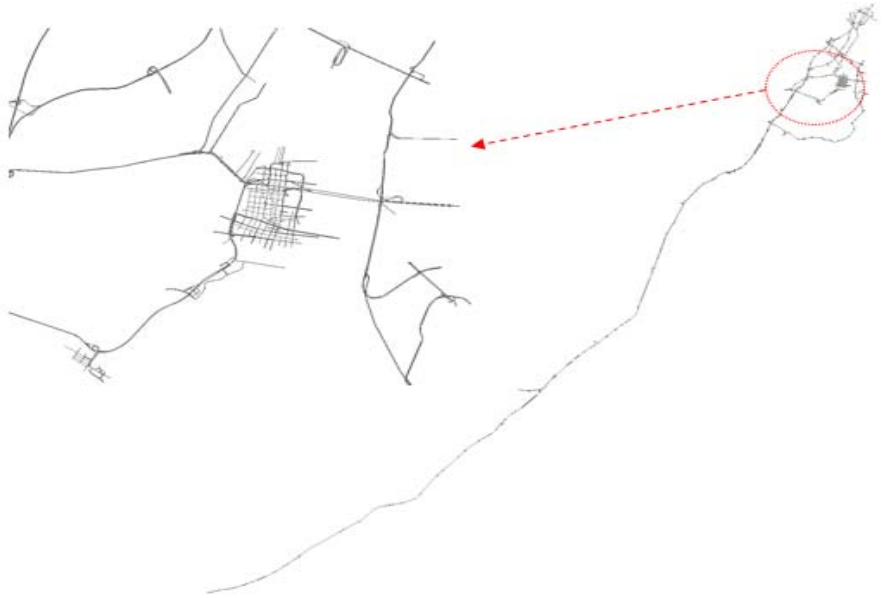
Various Pedestrian Sensors provide rich data sources for Pedestrian Simulation



Case Studies: ETC Data

- Newark Bay-Hudson County Extension (NB-HCE) PARAMICS simulation model (Ozbay et al., 2011).
- Big Data sources such as ETC data (200,000 transactions), INRIX data (300 million points for 2010) and TRANSCOM event data were combined with traditional traffic count data.





Case Studies: ETC Data

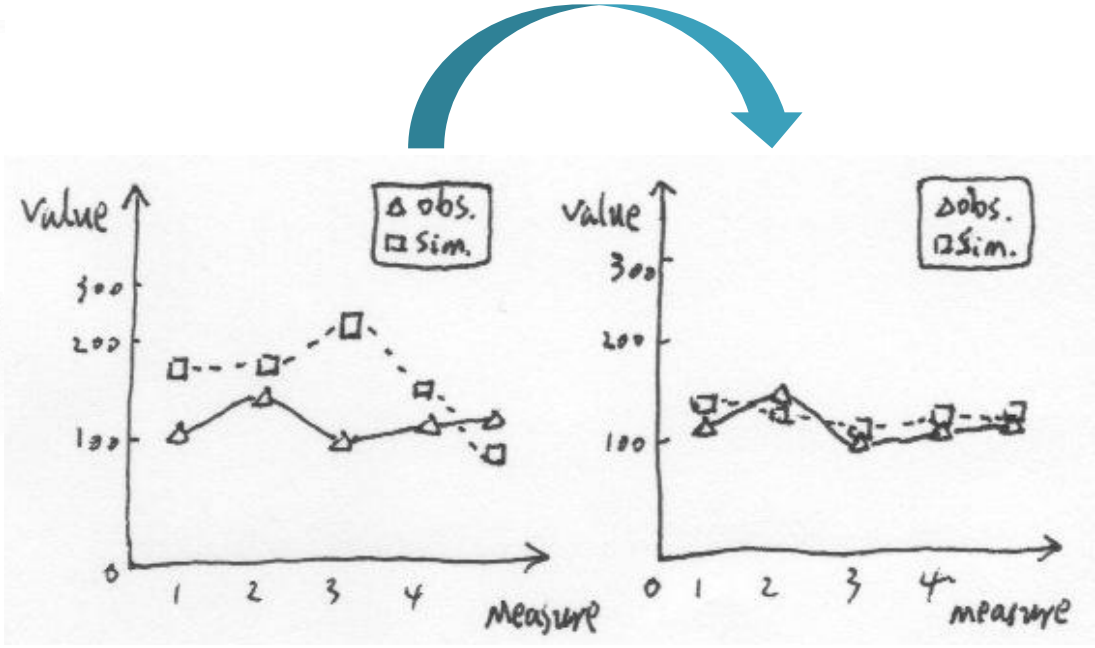
- Calibration of NJTPK network with Toll Plazas (Ozbay et al., 2006)
  - Peak and peak shoulder ETC data during AM and PM periods in 2003 with 100,000 vehicle transactions per hour.
- Calibration of specific toll plaza algorithms (Mudigonda et al., 2009, Ozbay et al., 2010)
  - 7,000 vehicle transactions and lane choices.
- Calibration of freeway merge for operations and safety (Ozbay et al., 2006)
  - 38,000 vehicle transactions.

Case Studies: Trajectory Data for Safety Simulation

High resolution trajectory data sets like the NGSIM data are expected to be available in large scale.

So many parameters may affect safety indicators

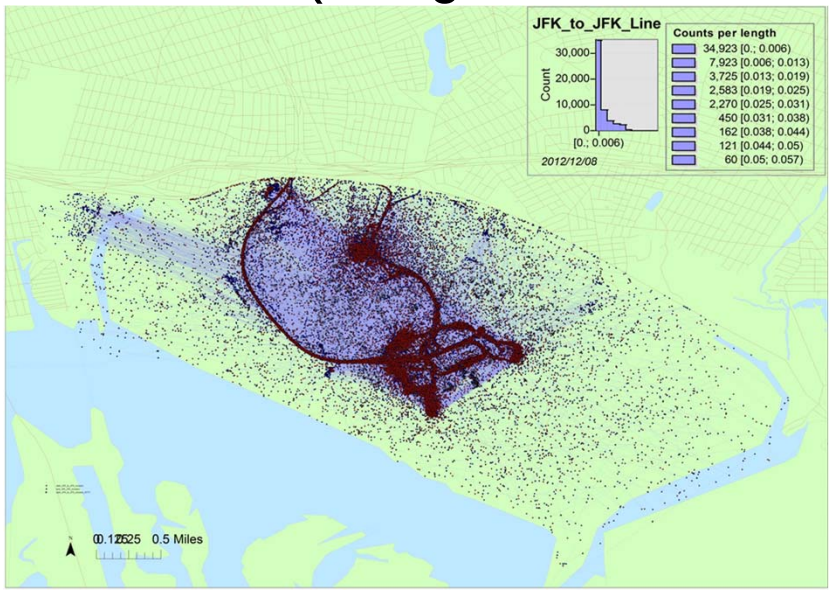
Are traditional input data enough for safety simulation?



Large-scale trajectory data provide more detailed information to capture surrogate safety measures

Case Studies: Taxi GPS Data

- Calibration of NYBPM Travel Demand Model (Morgul et al., 2012)
  - New York City Bridge and Tunnel Counts
  - NY/NJ Weigh-in-motion data
  - NJTPK truck ETC data
  - 80 million taxi trips for speed data

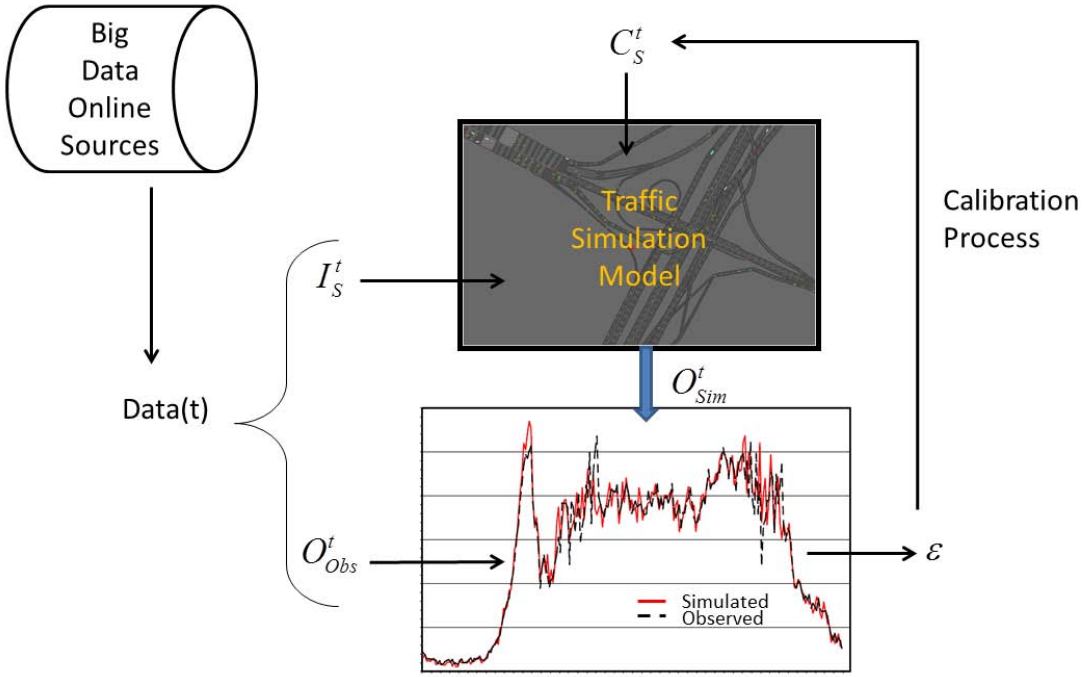


NYC JFK Airport Trips

- Calibration of traffic safety model (Xie et al., 2013)
  - 40,000 GPS equipped taxis in Shanghai
  - Combined with volume data from loop detectors to predict accident probability on various links in the city

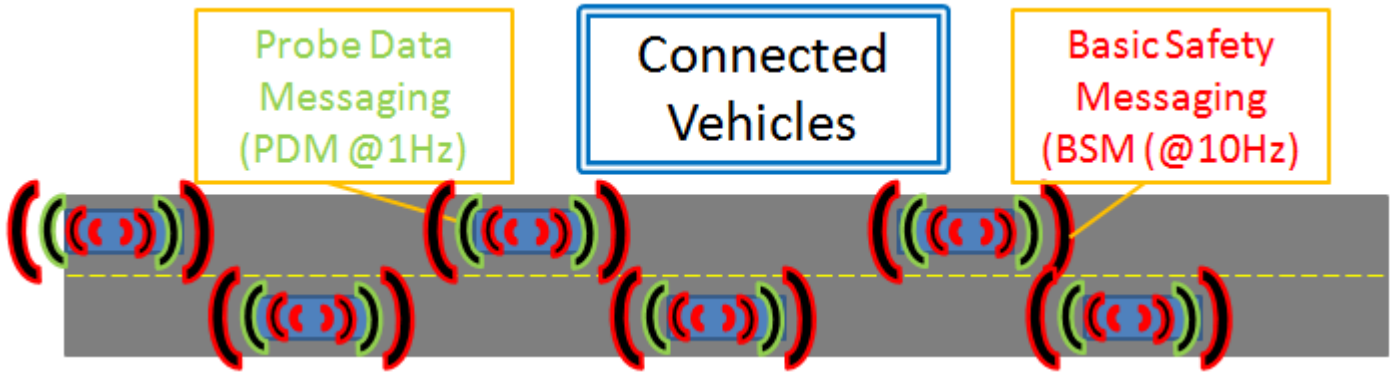
Future of Big Data in Calibration

- ETC (demand), Cell phone (traveler behavior), GPS/INRIX (speed, travel time), TRANSCOM (event) can be combined into a unified framework using AI and other data mining techniques.
- Methodology for online calibration with Big Data.



Future of Big Data in Calibration

- PDM ⟶ travel time, speed data.
- BSM - - → trajectory data ~ NGSIM, MULTITUDE.
- E.g., 74 sensors (sonar, cameras, radar, accelerometers, temperature and rain sensors) installed by Ford Energi hybrid cars ⟶over 25 gigabytes/hour.
- Very useful in calibrating even core traffic simulation algorithms such as car-following, gap acceptance, etc.



Future of Big Data in Calibration

- Location-sensitive data using geo-social networks such as

- Helps models to be more sensitive.
- Several software applications for both in-vehicles and on the drivers' smartphones connected to vehicles are being developed using initiatives such as Ford OpenXC, Google Open Automotive Alliance.

Future of Big Data in Calibration

- A correlation of such extensive Big Data over various dimensions time, space and events, is useful in providing information regarding behavior of drivers' under different temporal, spatial and environmental conditions.
- Such data helps in improving the accuracy of not only the operational modeling of traffic simulation models but also safety modeling.

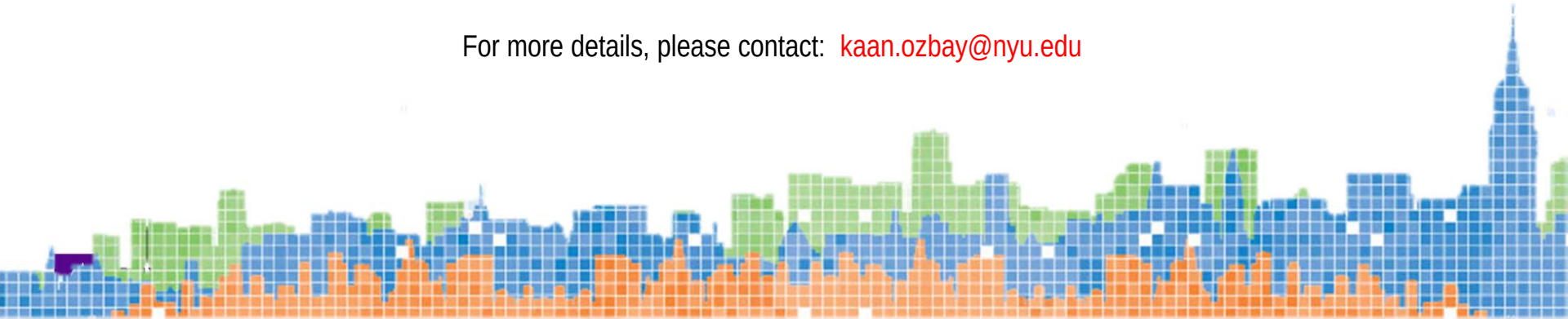
"…Big Data…
•will enable us to know more about the world we travel through,
•help city and transportation planners design next generation systems,
•move more people with greater efficiency and personal mobility."

CENTER FOR URBAN SCIENCE+PROGRESS

Thank You!

Urban Mobility & Intelligent Transportation Systems Laboratory
(urbanMITS) @ NYU

For more details, please contact: kaan.ozbay@nyu.edu



MONASH University
Engineering

Looking forward, looking back on computer simulation models of safety

William Young

Co Authors:

Amir Sobhani

Kayvan Aghabayk

Majid Sarvi

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- **Introduction**
- **Looking back**
- **Looking forward**
- **Concluding remarks**

Introduction

- **Simulation approaches have been used to model road traffic safety, vehicle movement, crash dynamics, and driver injury.**
- **Conflict measures for the basic measures in existing road safety simulation models.**
- **The next step in road safety simulation model development is the detailed investigation of the crash.**

The role of simulation models

- **Road Safety Simulation Models**
  - Visualisation of transport system
  - Design
  - Virtual environment for driver simulators
- **Understanding safety**
  - Not a primary aim

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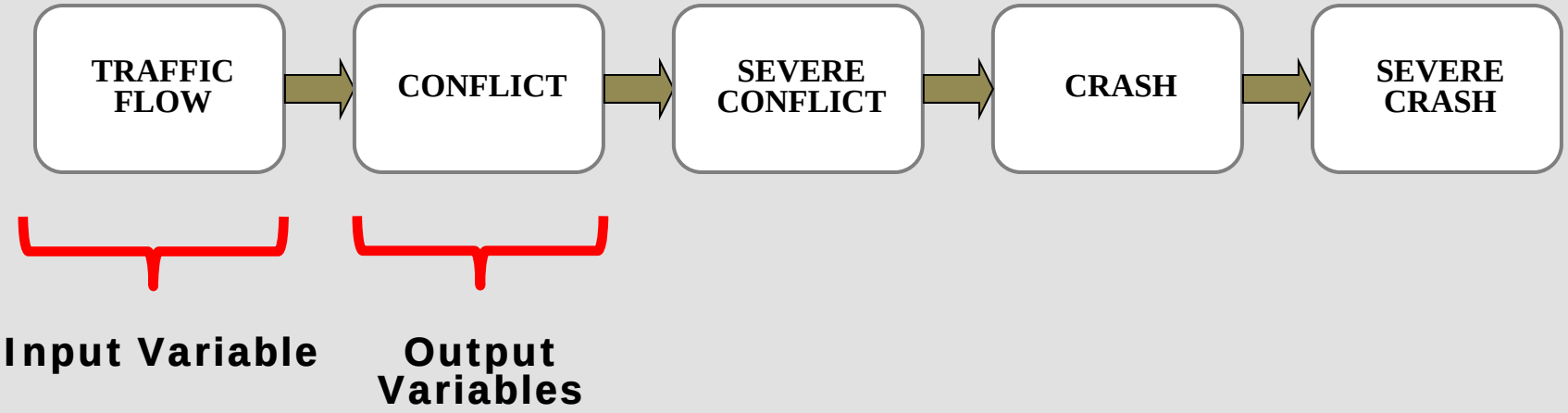
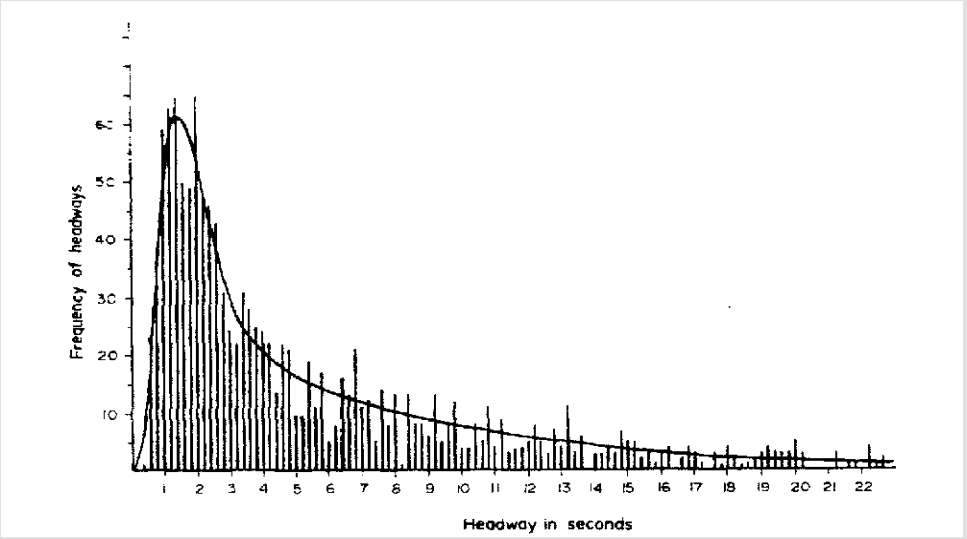
History (1980-1990): Conflict Models

Method: Using A Simulation Based Traffic Modelling Framework



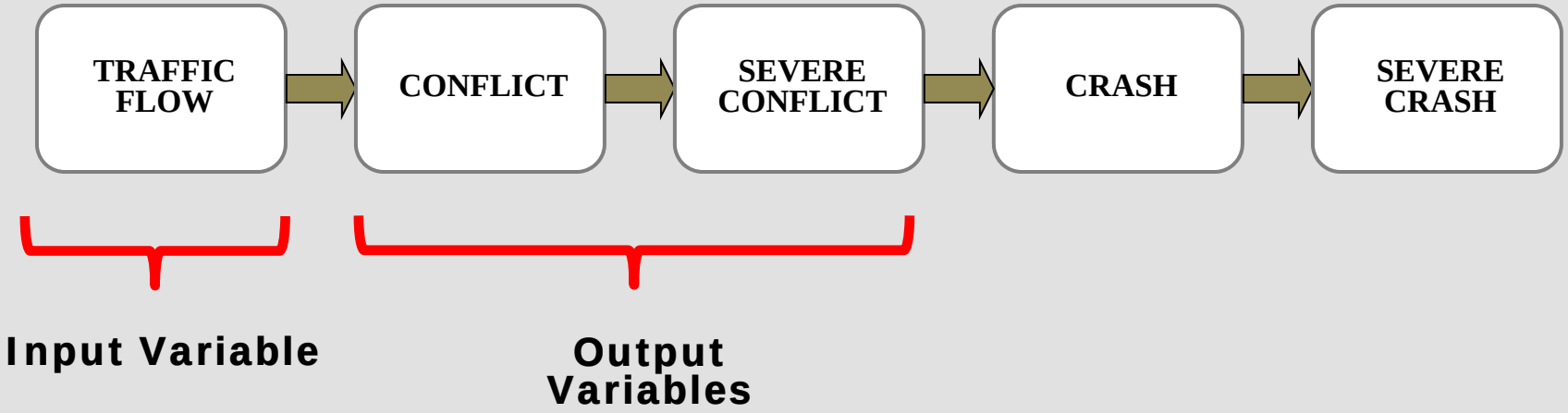
Conflict models

- **Measures of conflict, deviation or deceleration**
- **Headway distributions**
- **Models of intersections**



History (1990-date): Surrogate Safety Measures

Method: Using A Safety Simulation Based Framework with conflict measures of performance



Surrogate safety measures

- **SSAM**
- **Hauer**
- **Time to Collision**
- **Post encroachment time**
- **Required braking rate**

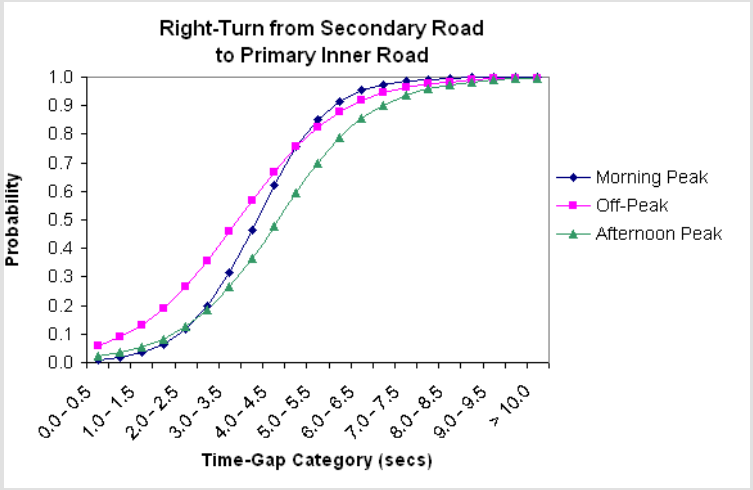
$$\textit{Expected number of crashes } (\lambda) = (\textit{number of conflicts } (c)) * (\textit{crash-to-conflict ratio } (\pi)).$$

Vehicle and surrogate safety models

- **Studied to date**
  - Passenger car
    - > Gap acceptance
    - > Rear end
    - > Signal control
    - > Link
    - > Network
  - Heavy Vehicles
    - > Signalised intersections
  - Bus
    - > At Bus stops

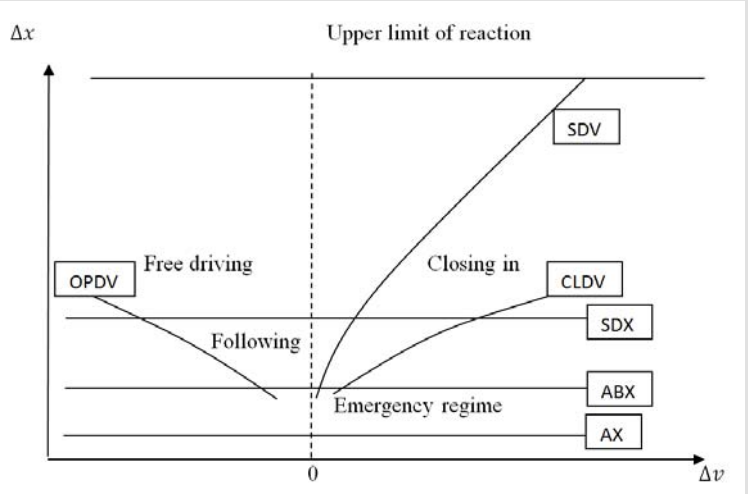
Crossing conflicts

- **Sayed et al**
- **Archer and Young**
- **Probabilistic distributions**



Rear end conflicts

- **Cunto and Saccomanno**
- **Car-following models (VISSIM, PARAMICS, AIMSUM)**
- **Wiedemann car-following model**



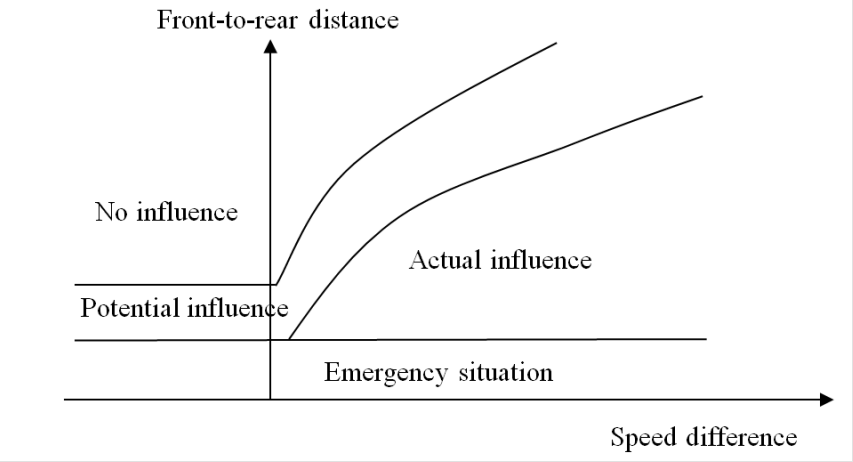
$$v_n(t+T) = min\begin{cases} v_n(t) + 2.5a_nT(1 - v_n(t)/V_n)(0.025 + v_n(t)/V_n)^{1/2} \\ b_nT + \{b_n^2T^2 - b_n[2(x_{n-1}(t) - s_{n-1} - x_n(t)) - v_n(t)T - v_{n-1}^2(t)/b\hat{}]\}^{1/2} \end{cases}$$

Stop / go decisions

- **Archer and Young**
- **Probabilistic distributions**

Lane-changing models

- **Debes et al**
- **Weidemann model**



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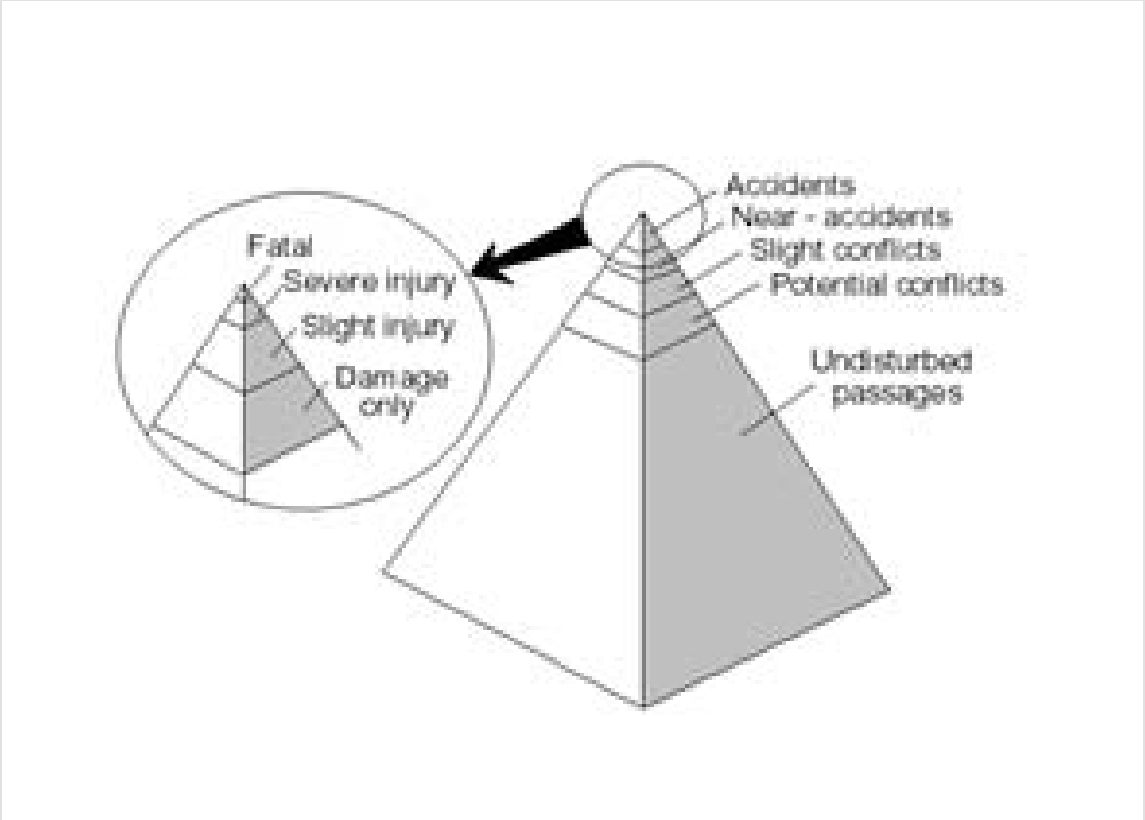
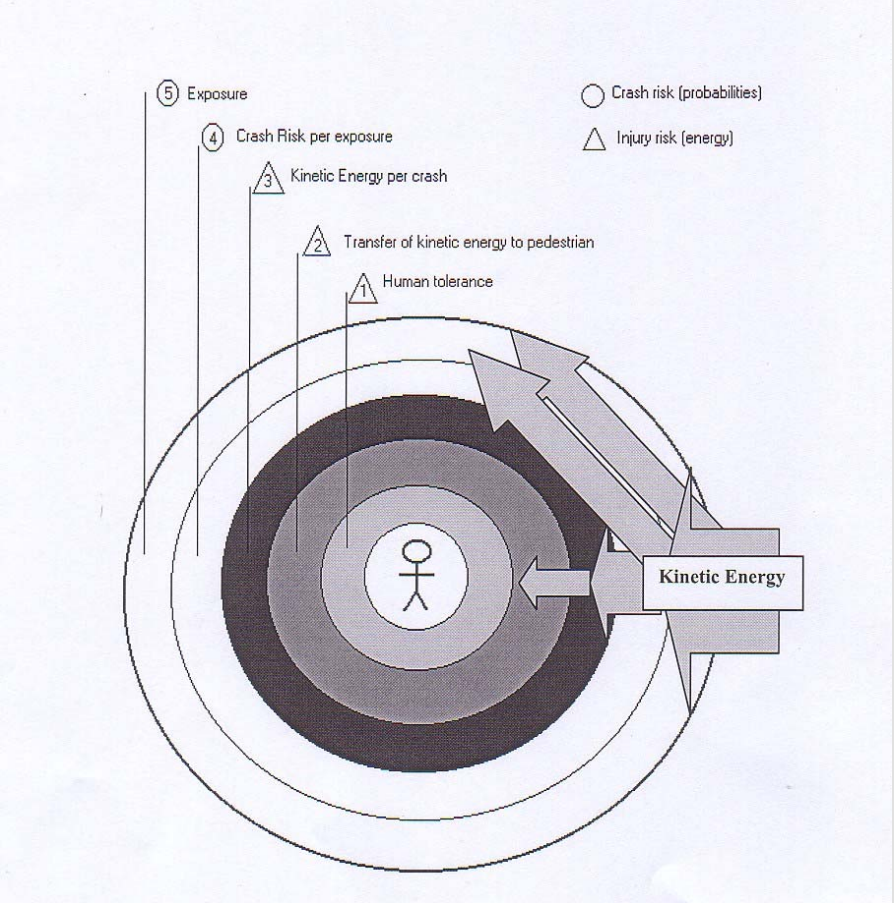
- **Looking forward**
- **Concluding remarks**

History:
Hyden's Triangle



- **Hyden**
- **Tarko et al**

History:
A Visionary Model of Road Safety



Corben et al

History:
Crash continuum.

By exploring the continuum between:

- **the initial conditions leading to the event (P(u)),**
- **the evasive or avoidance actions (P(x|u)), and**
- **the crash related outcomes (P(y|x,u))**

Davis et al (2011) generated the conditional probability relationship:

$$P(y,x,u) = P(y|x,u).P(x|u).P(u)$$

Davis et al (2011)

History:
The safety analysis chain (SACH)

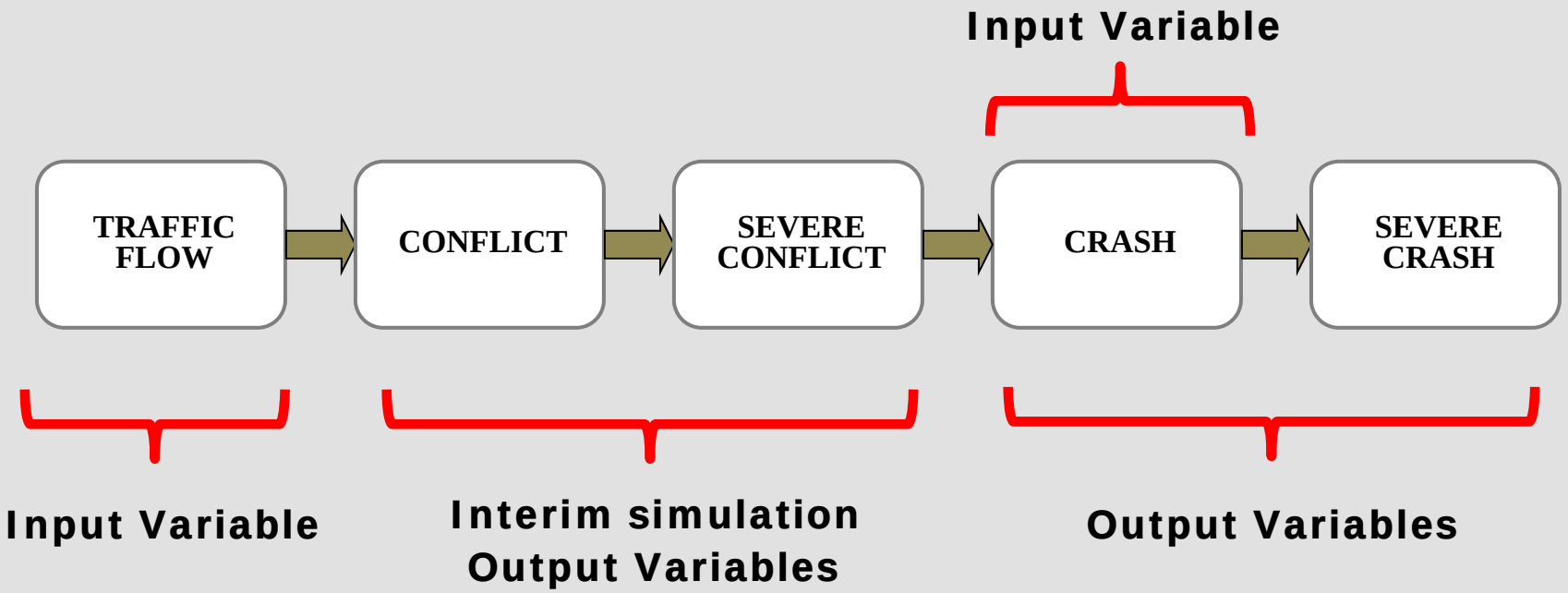
Sobhani et al

History: Model types

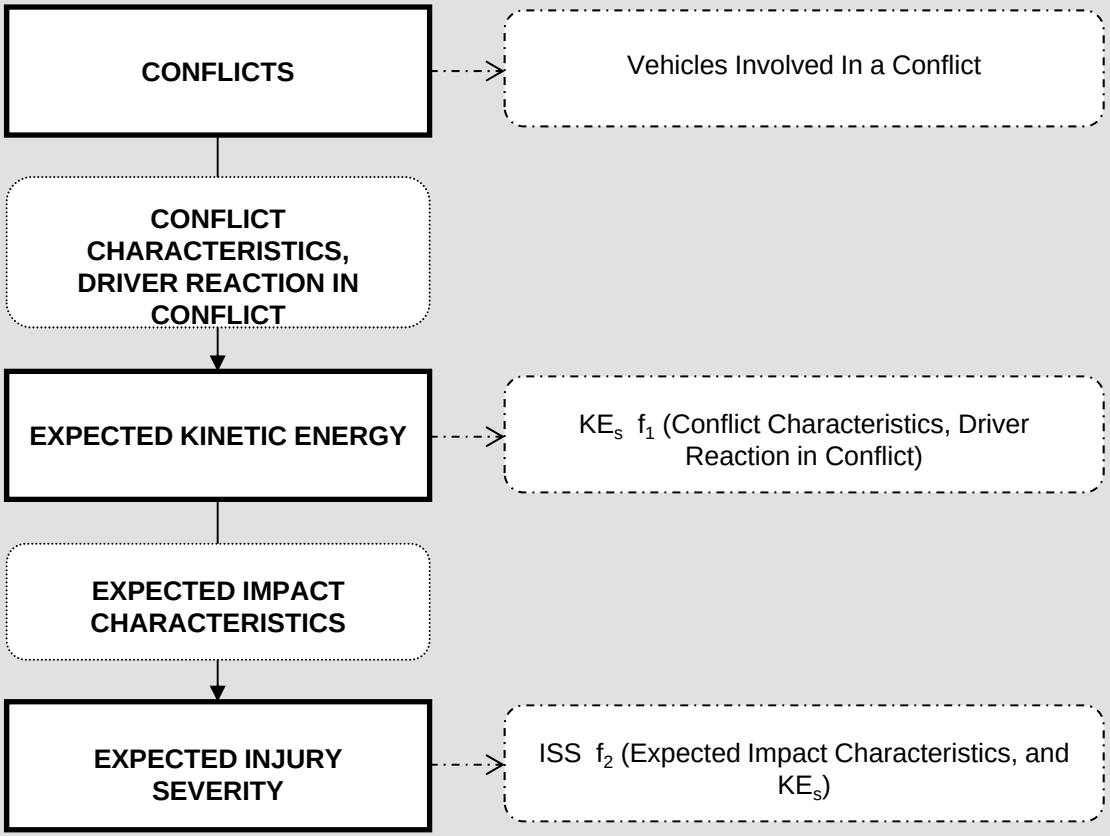
Viewpoint	Method	Variables (Major Focus)	Output
Transportation	Statistical Analysis Simulation Analysis	Road and Environmental Characteristics	Crash and Conflict Outcomes
Crash Analysis	Statistical Analysis Newtonian Mechanics	Crash Characteristics	Crash severity
Medical	Statistical Analysis	Human Body Characteristics	Crash Severity

Recent developments:
Road Safety Simulation Models

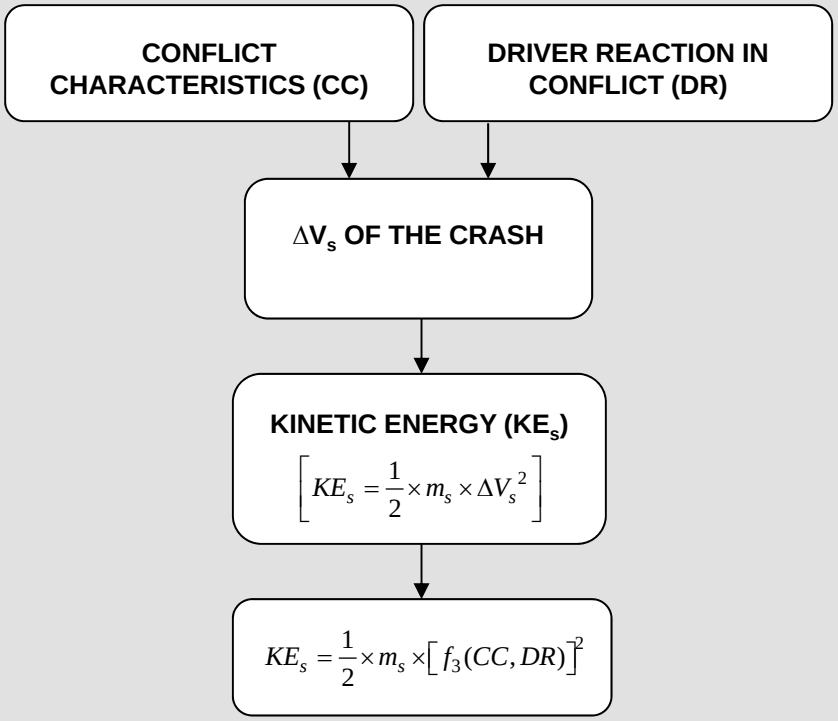
Method: A simulation model of crashes



Recent Developments: Methodology



Recent developments: Methodology



Potential developments: Vehicle type studies

- **Future activities**
  - Heavy Vehicles
  - Public Transport Vehicles
  - Pedestrians,
  - Bicyclists
  - Motor Bikes

Potential developments: Associated developments

- **Data:**
  - Crash
  - Video
  - Naturalistic Data Sets
- **Driver Simulators**
  - Behavioural aspects of models
  - Integration of road based simulation models into simulators
- **Machine learning real time models**
  - Fuzzy Logic,
  - Neural networks
  - Artifical intelligence

Contents

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Summary and Conclusion

- **Simulation approaches have been used to model road traffic safety, vehicle movement, crash dynamics, and driver injury.**
- **Road safety simulation models have been developed for cars and to determine Surrogate Safety Measures.**
- **The next step in road safety simulation model development is the detailed investigation of the crash.**
- **Parallel developments which may facilitate improvements in road safety simulation models are:**
  - Naturalistic Data Sets
  - Driver Simulators
  - Machine learning real time models.

Questions