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Assessing the robustness of sensitivity analysis results. Application to traffic simulation models

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Outline

- Background of traffic simulation
- Uncertainty management in traffic modeling
- Sensitivity analysis of a car-following model
- Conclusions

Traffic simulation models

- In the last century, contributions from engineers, physicists, mathematicians, and behavioral psychologists have led to a better understanding of ***driver behavior*** and ***vehicular traffic flow***.

- The focus is on applications ranging from novel **driver-assistance** systems, to intelligent approaches to **optimizing traffic flow**, to the precise detection of **traffic jams**, the short-term forecasting of traffic for dynamic **navigation aids**, to the assessment of the impact of new **transportation infrastructures**.

Traffic models – study area

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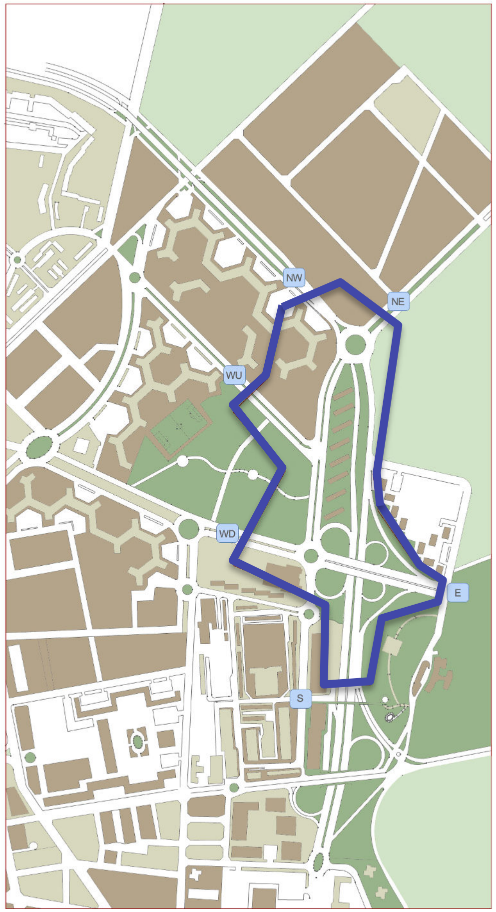
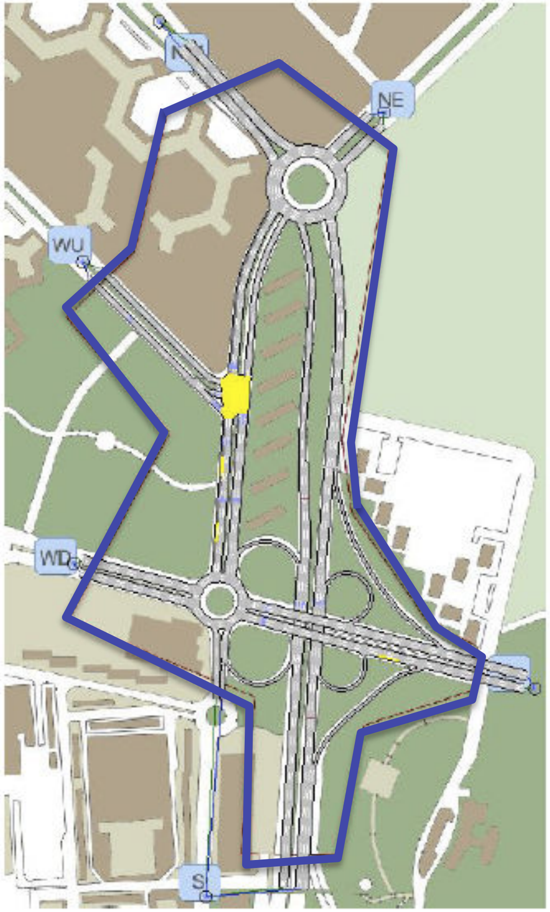
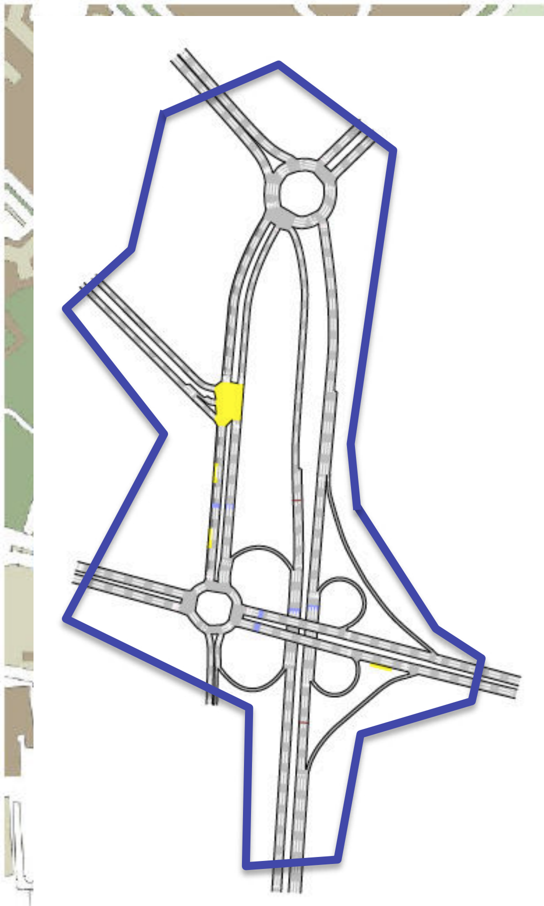


Traffic models – Transportation supply

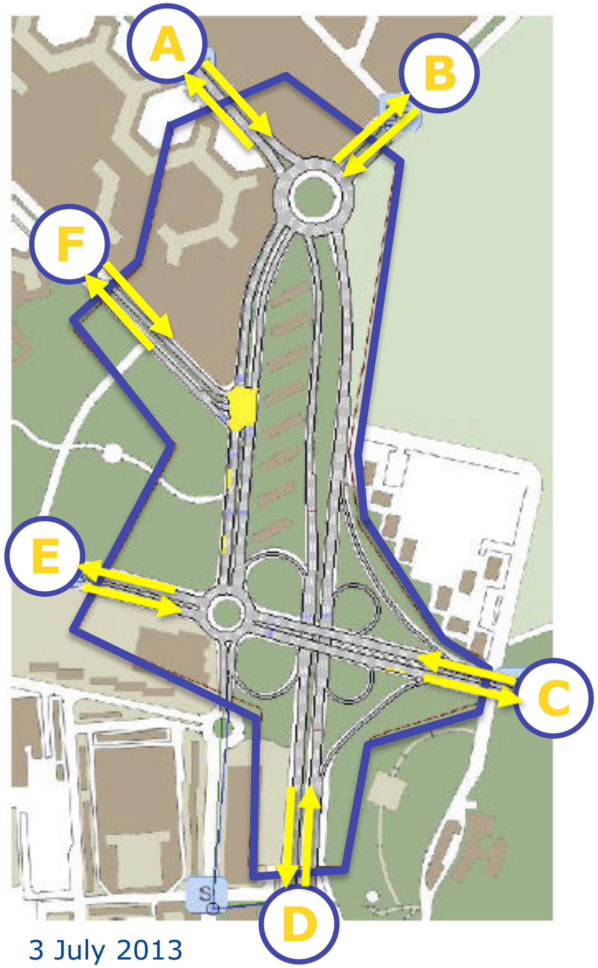


Traffic models – Transportation supply



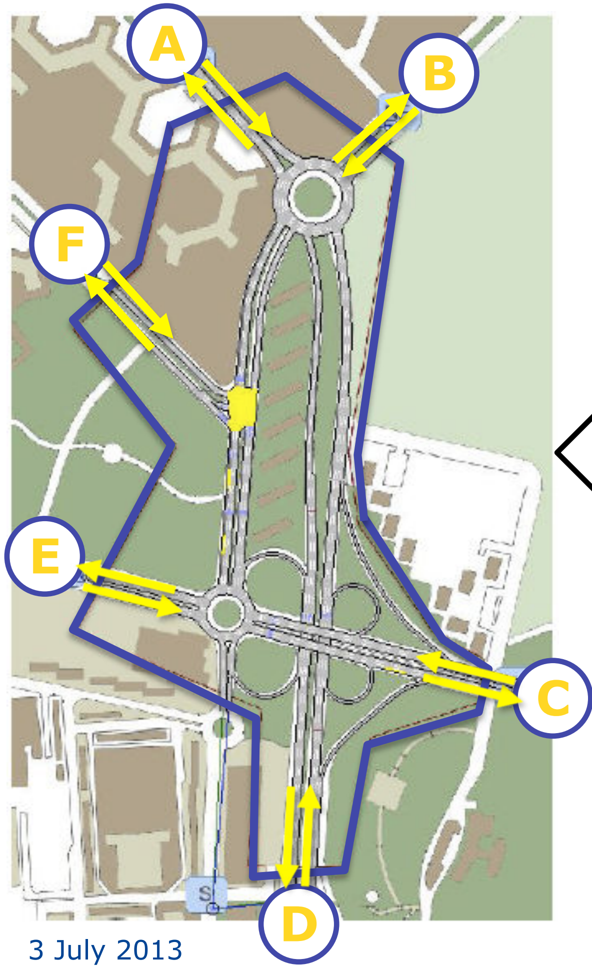
- The transportation system is modeled both from a geometrical and operational point of view

Traffic models – Transportation demand



OD	A	B	C	D	E	F	
A	f_{AA}	f_{AB}	f_{AC}	f_{AD}	f_{AE}	f_{AF}	O_A
B	f_{BA}	f_{BB}	f_{BC}	f_{BD}	f_{BE}	f_{BF}	O_B
C	f_{CA}	f_{CB}	f_{CC}	f_{CD}	f_{CE}	f_{CF}	O_C
D	f_{DA}	f_{DB}	f_{DC}	f_{DD}	f_{DE}	f_{DF}	O_D
E	f_{EA}	f_{EB}	f_{EC}	f_{ED}	f_{EE}	f_{EF}	O_E
F	f_{FA}	f_{FB}	f_{FC}	f_{FD}	f_{FE}	f_{FF}	O_F
	D_A	D_B	D_C	D_D	D_E	D_F	

Traffic models – Supply/demand interaction



OD	A	B	C	D	E	F	
A	--	f_{AB}	f_{AC}	f_{AD}	f_{AE}	f_{AF}	O_A
B	f_{BA}	--	f_{BC}	f_{BD}	f_{BE}	f_{BF}	O_B
C	f_{CA}	f_{CB}	--	f_{CD}	f_{CE}	f_{CF}	O_C
D	f_{DA}	f_{DB}	f_{DC}	--	f_{DE}	f_{DF}	O_D
E	f_{EA}	f_{EB}	f_{EC}	f_{ED}	--	f_{EF}	O_E
F	f_{FA}	f_{FB}	f_{FC}	f_{FD}	f_{FE}	--	O_F
	D_A	D_B	D_C	D_D	D_E	D_F	

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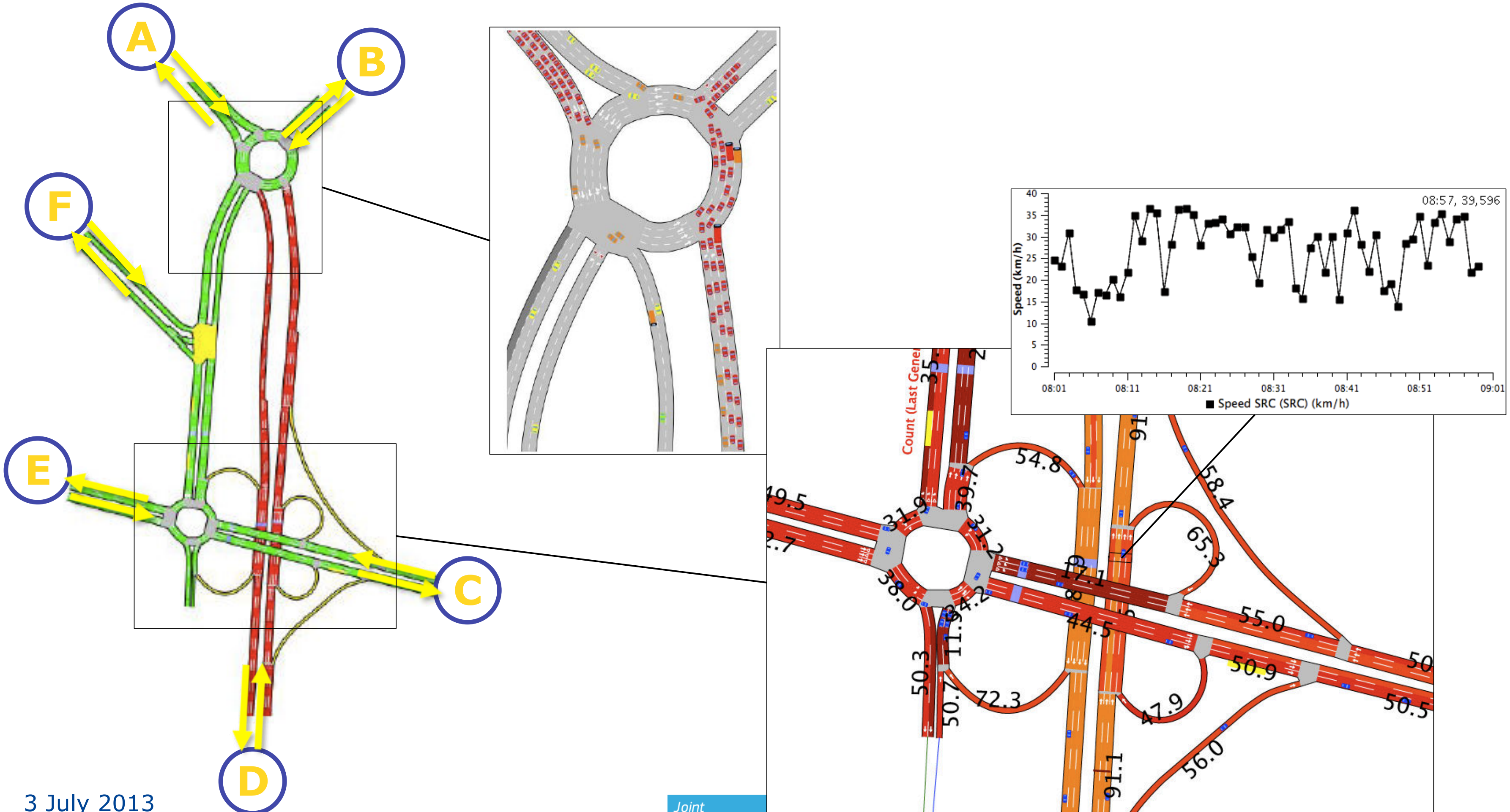
Traffic models - Results



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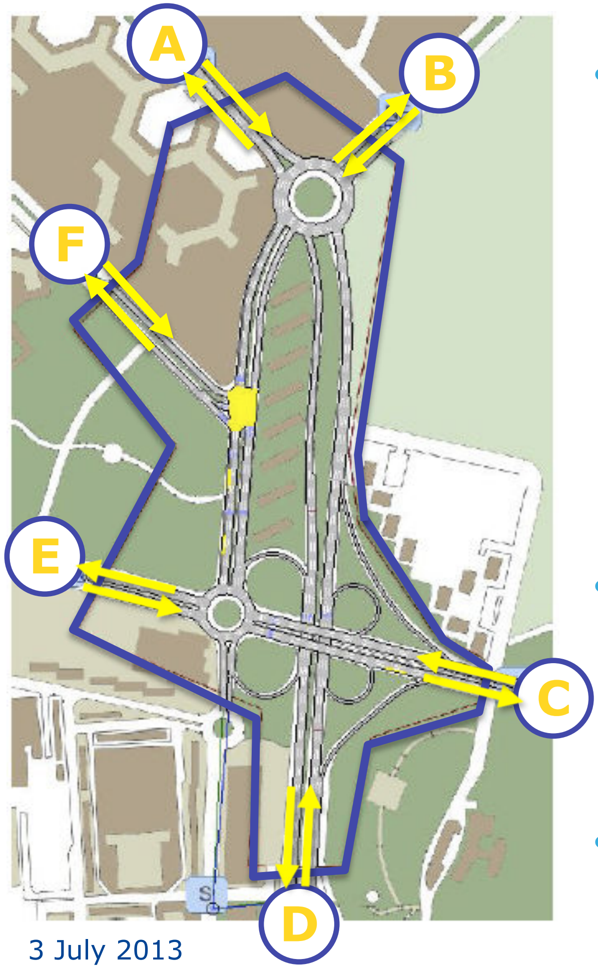
Possible sources of uncertainty



- OD flows are only aggregate measures of traffic patterns
  - None or limited capability to resemble space-time dynamics
  - None or limited capability to identify drivers heterogeneity
  - Deficiencies usually ignored
- Parameters of the supply model are mostly uncertain (but kept fixed in the practice)
- Parameters of the traffic models are uncertain. Model calibration to fix them

Uncertainty management in traffic modeling

The management of uncertainties from hundreds of possible sources is reduced to the calibration of few selected model parameters with the objective of reducing the distance between model outputs and site measurements

No established procedure for parameters selection, other than personal experience

Several possible issues:
- inaccuracy and unreliability of model results
- unrealistic values for the calibrated parameter

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The role of Sensitivity Analysis

Until recently, SA only marginally used and with very simplistic approaches (e.g. OAT or ANOVA based on fractional factorial design, etc.)

Only in the last few years more sophisticated techniques (e.g. Elementary Effects, Sobol indices, meta-model-based approaches) have been introduced (mainly by participants in the MULTITUDE Project)

Main obstacles for SA widespread:

- Computation time (traffic simulation can be very time consuming)
- SA results difficult to be generalized

Looking for general results

Practitioners in traffic modelling look for “Rule-of-Thumbs” by model developers

Model developers more interested in producing “fancy” than “useful” tools

SA is mainly used by researchers in the attempt of understanding the behaviour (in terms of meaningfulness and stability) of the available models

Results “conditioned” by specificities of the chosen case-study

SA of a car-following model

Car-following models are the building blocks of traffic simulation models

They describe the longitudinal interaction among vehicles

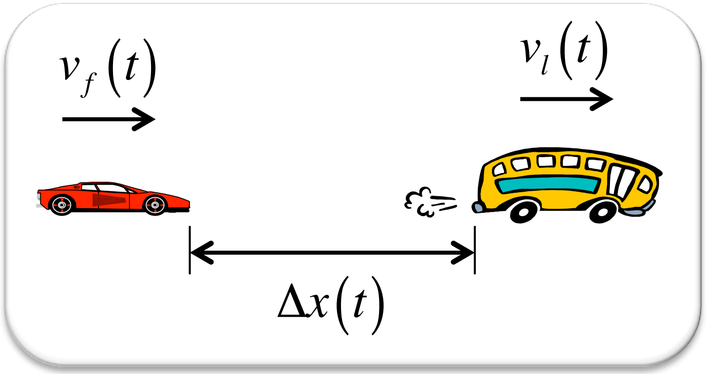
Car-following models are the main responsible of traffic models instability

Alone, they are very cheap to analyze

IDM car-following model

$$a_f(t) = a_{max} \cdot \left[1 - \left(\frac{v_f(t)}{v_{max}} \right)^{\alpha} - \left(\frac{\Delta x^*(t)}{\Delta x(t)} \right)^2 \right]$$

$$\Delta x^*(t) = \Delta x_0 + \max\left(0, v_f(t) \cdot T + \frac{v_f(t) \cdot \Delta v(t)}{2\sqrt{a_{max} \cdot b}} \right)$$



Where:

Parameters

a_{max}>0, maximum acceleration rate

v_{max}>0, desired speed

α>0, a constant

Δx_0, minimum gap

T, minimum time headway

b, comfort deceleration rate

Inputs

$V_f(t)$, speed of the follower at time t

$\Delta x(t)$, inter-vehicle spacing at time t

$\Delta v(t)$, speed difference at time t

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SA of IDM car-following model

Variance-based method (Saltelli et al., 2008):

- First order sensitivity indices (Saltelli et al., 2010)
- Total order sensitivity indices (Jansen, 1999)

Quasi Monte Carlo framework based on Sobol sequences of quasi random numbers

Both inputs and model parameters involved in the analysis

- Presence of correlated inputs: $v_f(t)$, $\Delta x(t)$, and $\Delta v(t)$ are strongly correlated as they drive the interaction among two vehicles in car-following conditions

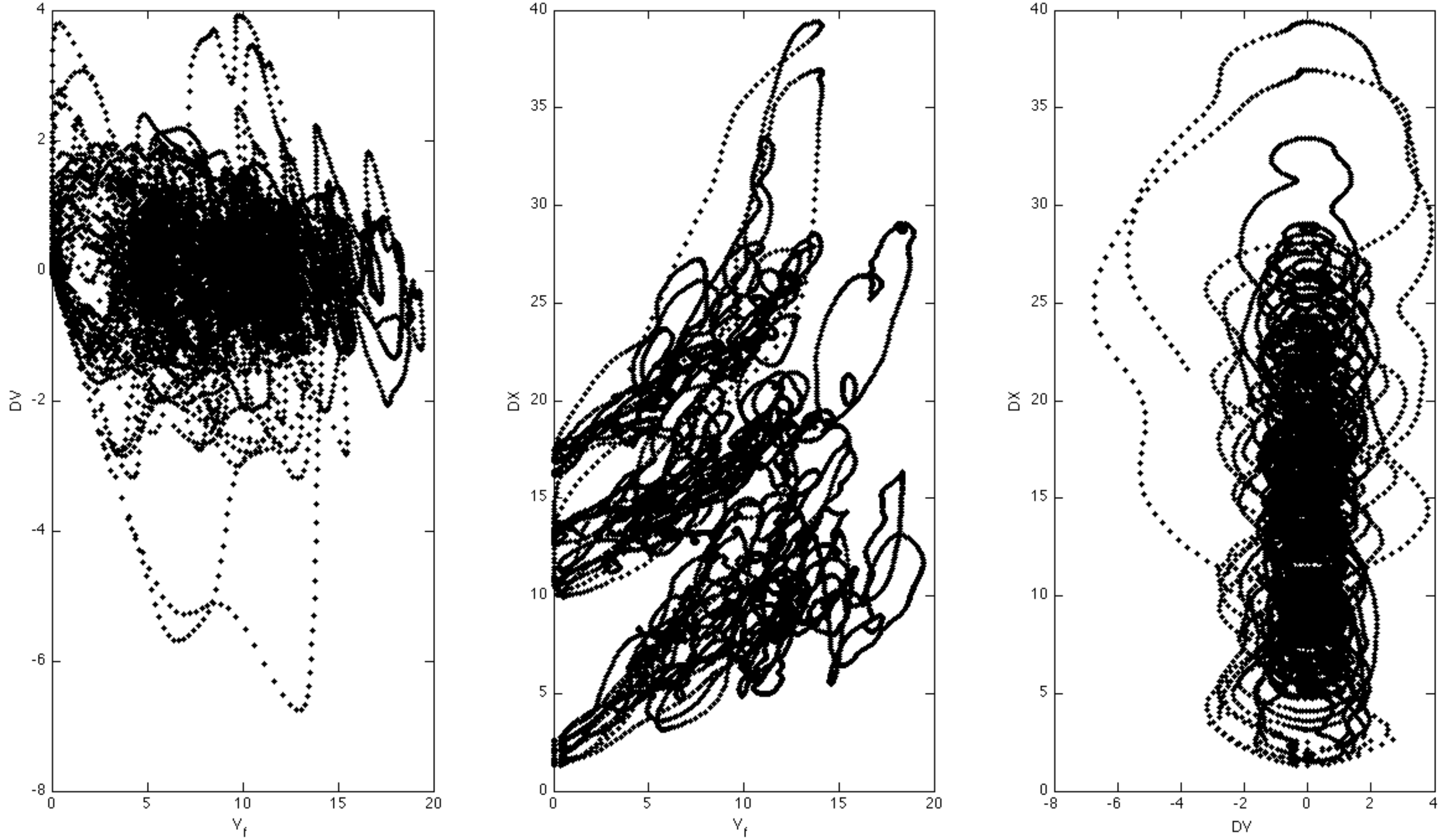
Dealing with correlated inputs

Since a theoretical general correlation structure among the three variables is not available an empirical one was derived by merging several worldwide databases of vehicle trajectories

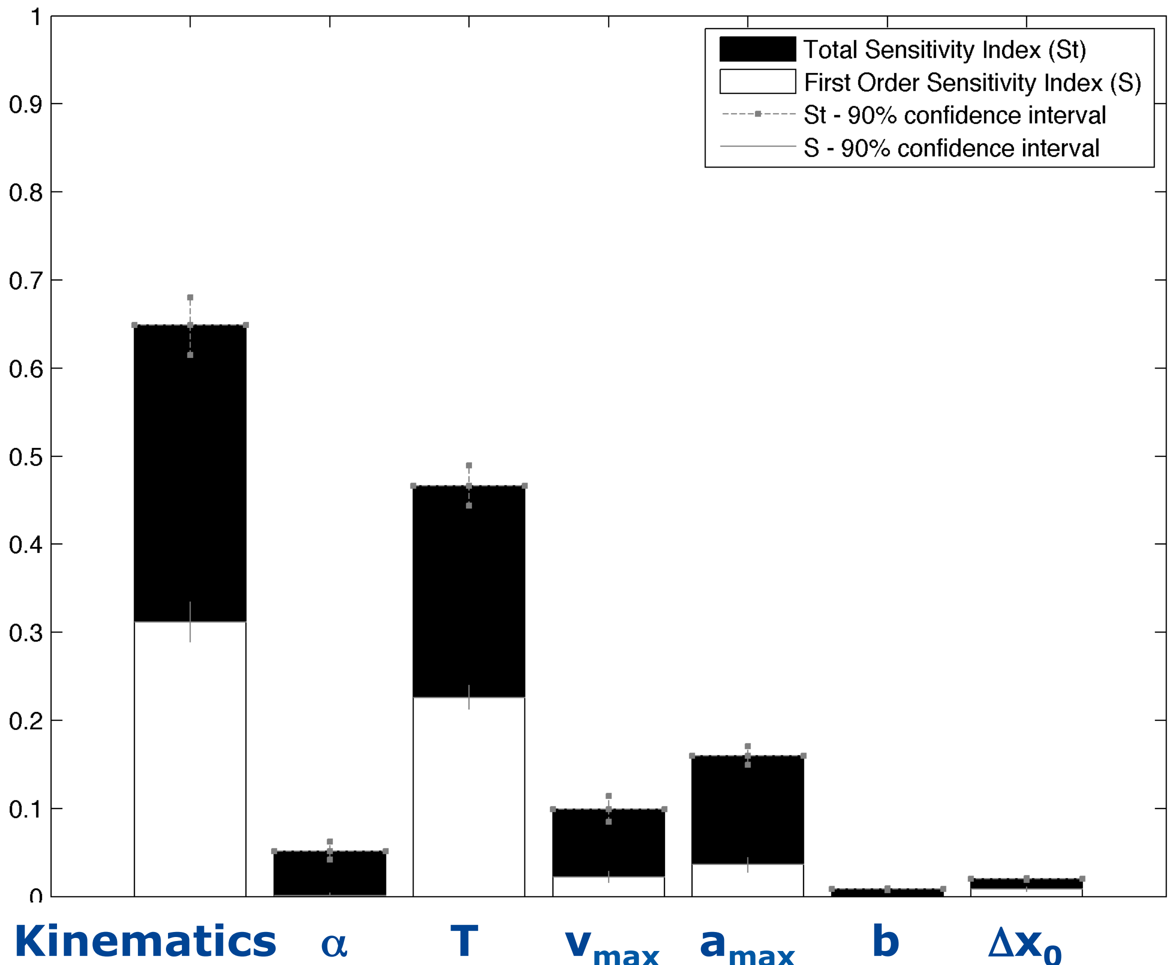
10.000 combinations of the three input factors were chosen as representative of different car-following conditions

In the SA, the three input variables were substituted by a single discrete variable "***kinematics***", whose value determines the specific combination of $v_f(t)$, $\Delta x(t)$, and $\Delta v(t)$ to use in the Monte Carlo experiments

Dealing with correlated inputs



Results


Total Sensitivity Index (St)
First Order Sensitivity Index (S)
St - 90% confidence interval
S - 90% confidence interval
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Kinematics
α
T
v_{max}
a_{max}
b
Δx_0

Conclusions

- Sensitivity Analysis is expected to significantly contribute to increase the reliability of traffic simulation models
- A gap is still existing between theory and practice of SA in traffic modelling
- Looking for general SA results is an important and ambitious issue, but researchers cannot deal with it alone
- Researchers and practitioners in SA and UA can contribute to speed up the process spreading their experiences in dealing with the most delicate issues of a SA (inputs identification, distribution selection, analysis of correlation, etc.)