Route Choice Behaviour and Optimal Traffic Management during Evacuation

BIN Tokyo lecture Dr. ir. Adam Pel

A Traffic Engineer's Perspective...

Quantitative modelling and simulation

Establishing models that are predictively valid...

Transport and Traffic Modelling

- Developing theory and models that can predict network traffic operations in case of an evacuation
- Conditional on disaster dynamics, information and evacuation instructions, traffic management, etc.
- Taking into account all relevant behavioural aspects and uncertainties therein

Usage of models

- Evacuation potential and plan assessment
- Optimisation of instructions, evacuation management and control

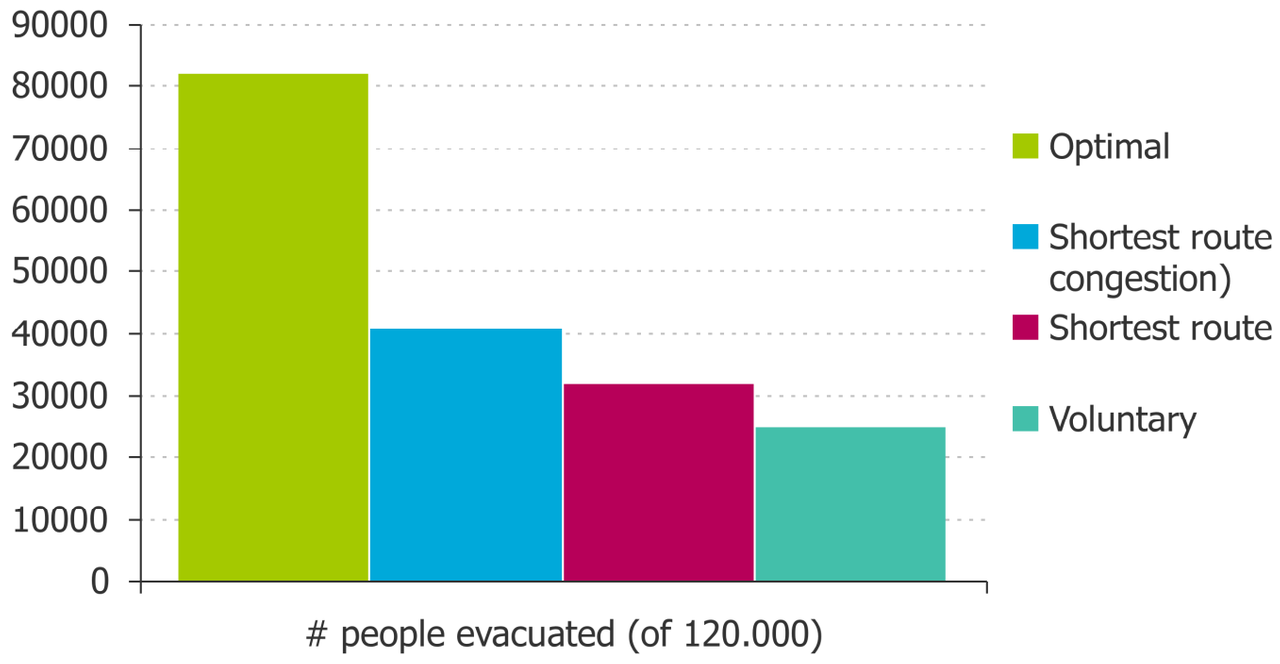
A Traffic Engineer's Perspective...

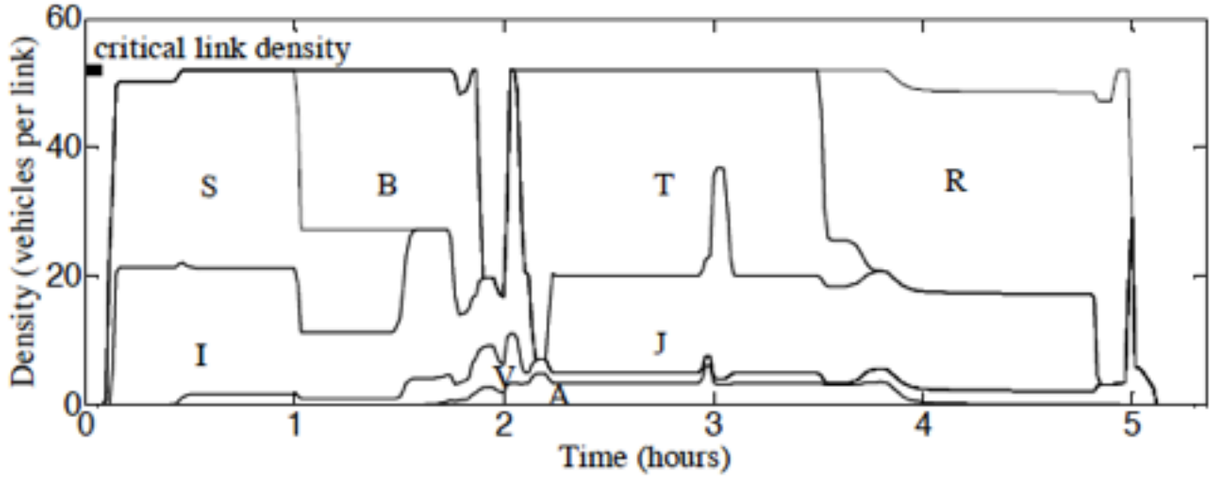
Quantitative modelling and simulation

...and use them to optimise evacuation instructions

Example application: model based optimisation of evacuation instructions

- Describe optimisation problem as a bi-level problem
- Optimisation approach schedules and routes such that all critical links are fully used (assuming high compliance)
- Reduction of computational complexity by innovative fixed-point problem formulation for fast computation of optimal solutions





Evacuation Traffic Dynamics and Travel Behaviour

To evacuatie or not to evacuate, that is the question…

…but this is hard to determine if your models are not predictively valid!

- Many evacuation model studies hampered by severe limitations in predictive validity of models used, and hence outcomes should be used with caution
- Typical (behavioural) aspects to consider in modelling:
  - Travellers are not familiar with situation and hence have limited expectations regarding prevailing traffic conditions
  - Driving behaviour changes due to stress, emotion, driving task attention loss, weather conditions, etc., causing large changes in road capacity
  - Infrastructure may be affected substantially (flooded tunnels) or used differently (lane reversal)
  - Adaptation of decision-making mechanisms affecting travel behaviour
- Large role of heterogeneity in behaviour and high levels of uncertainty (in behaviour and in conditions) further complicate modelling tasks

Part I: Empirical Observations & Experimental Findings

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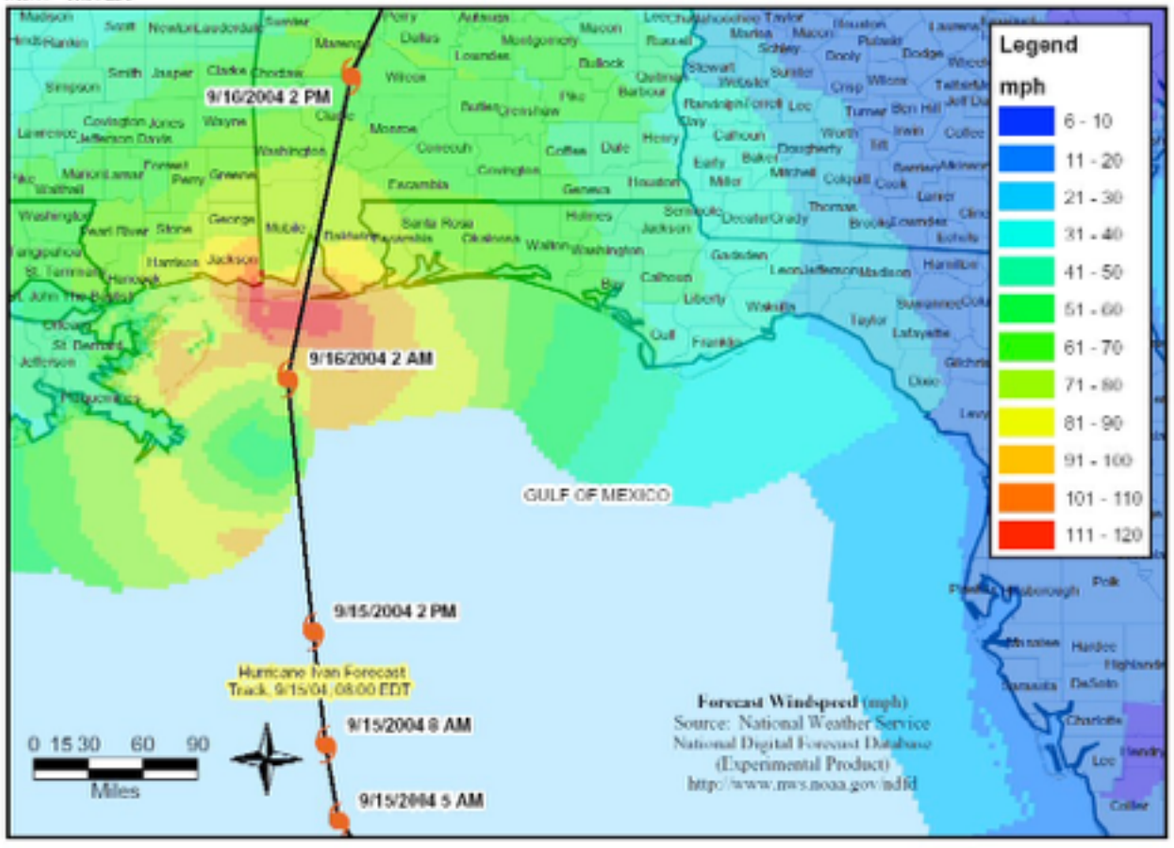
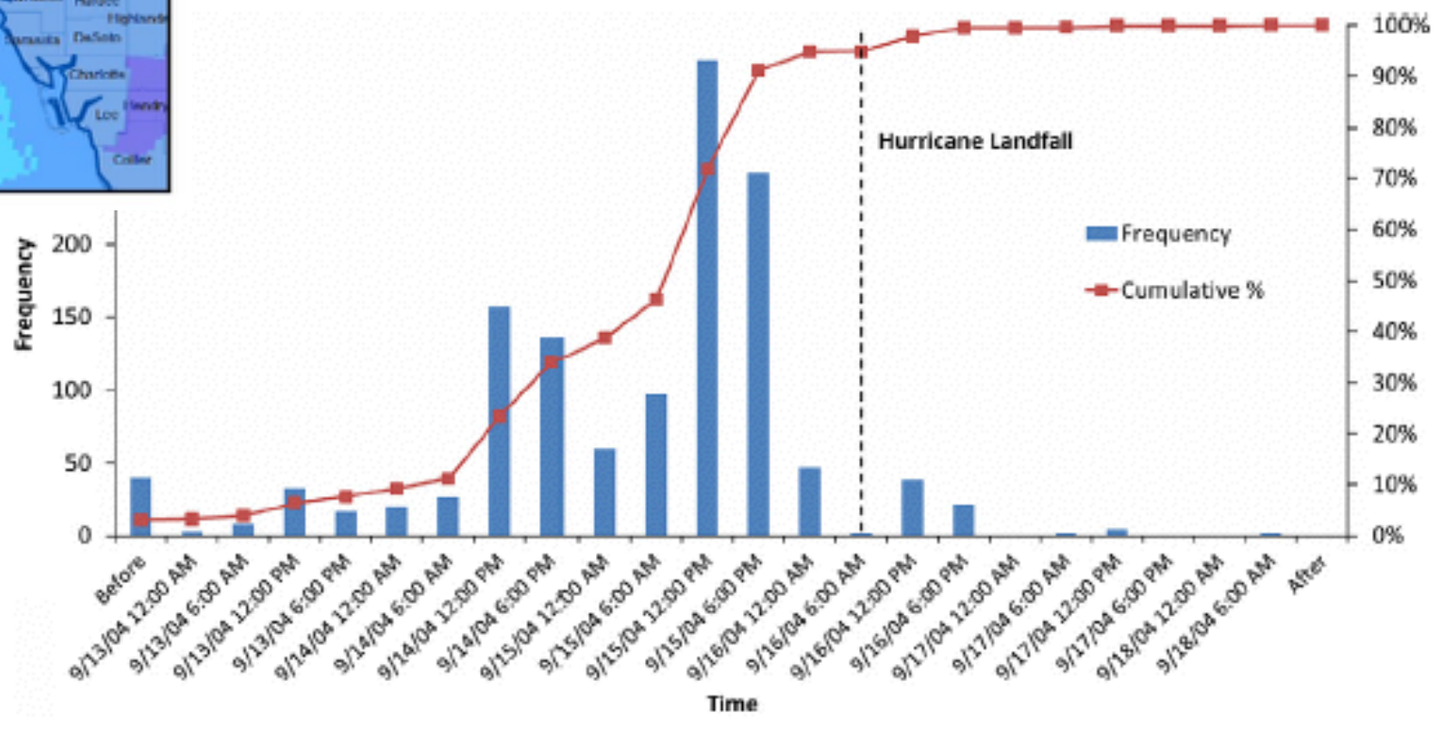
Evacuation Response Rate

Empirical observations for hurricane response

Gulf Shores, Alabama evacuation hurricane Ivan 2004…



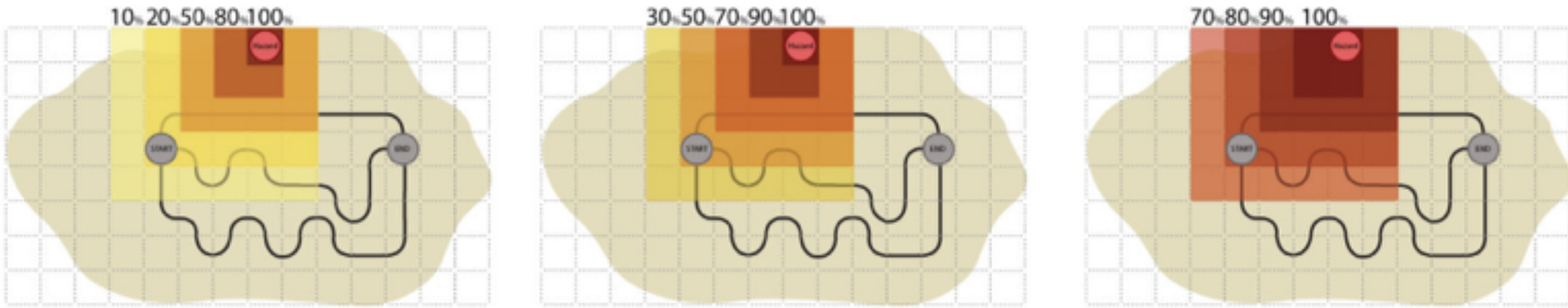
- Similar response patterns observed for various ‘predictable’ hazards
- Differences lie in temporal scale
- Typically approximated by Sigmoid or Weibull curve



Other factors influencing behaviour…

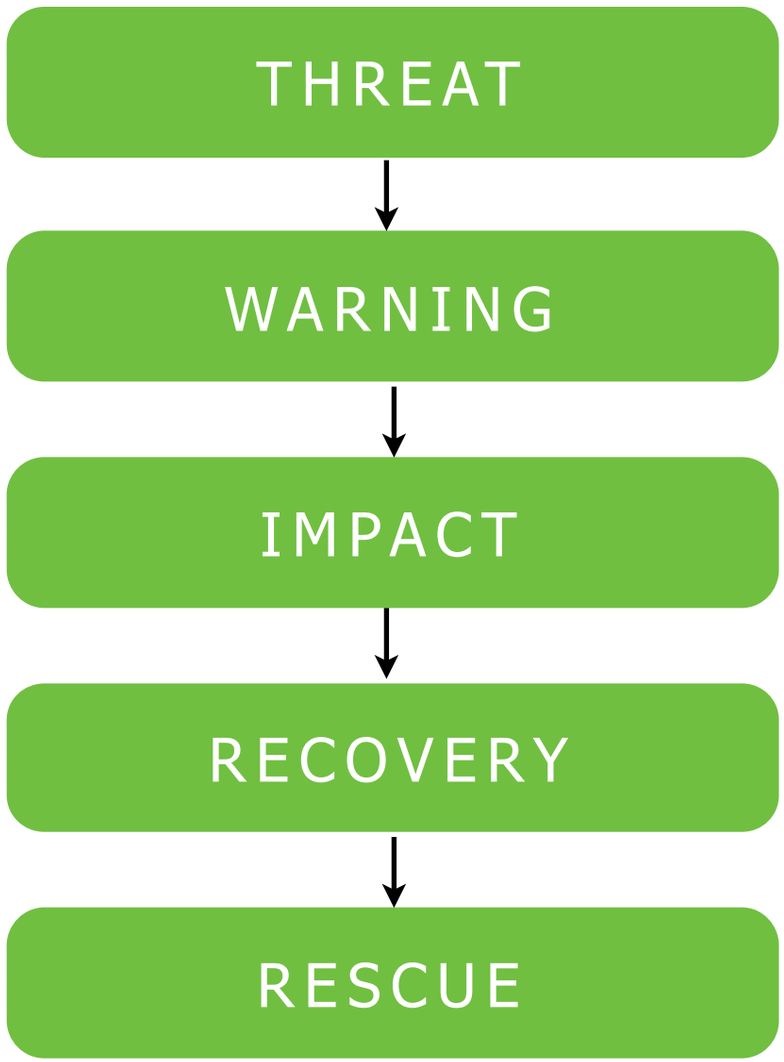
Results of web-based survey show impact of different attributes

Towards modelling behavioural aspects of evacuation…



H2. level 1 (small) H2. level 2 (moderate) H2. level 3 (high)

Code	*Description*	*β(mean)*	*β(CI95%)*	*se(β)*	*p-value*
ASC	Model constant	-1.48	-1.92 / -1.04	0.19	0.02
DIS	Hazard distance (3.32=far, 0=close)	-0.54	-0.61 / -0.46	0.06	0.08
ETIME	Time passed during experiment (min)	-0.01	-0.01 / -0.01	0.00	0.01
EVACM	Mandatory evacuation	1.51	1.37 / 1.66	0.06	0.00
EVACR	Recommended evacuation	1.52	1.34 / 1.70	0.08	0.00
EVACV	Voluntary evacuation	0.95	0.82 / 1.07	0.06	0.00
GEN	Gender (0=male, 1=female)	0.64	0.56 / 0.72	0.03	0.00
HIC	Complete hazard information	1.06	0.81 / 1.31	0.11	0.00
HIL	Limited hazard information	0.78	0.51 / 1.05	0.12	0.01



Major behavioural differences per phase

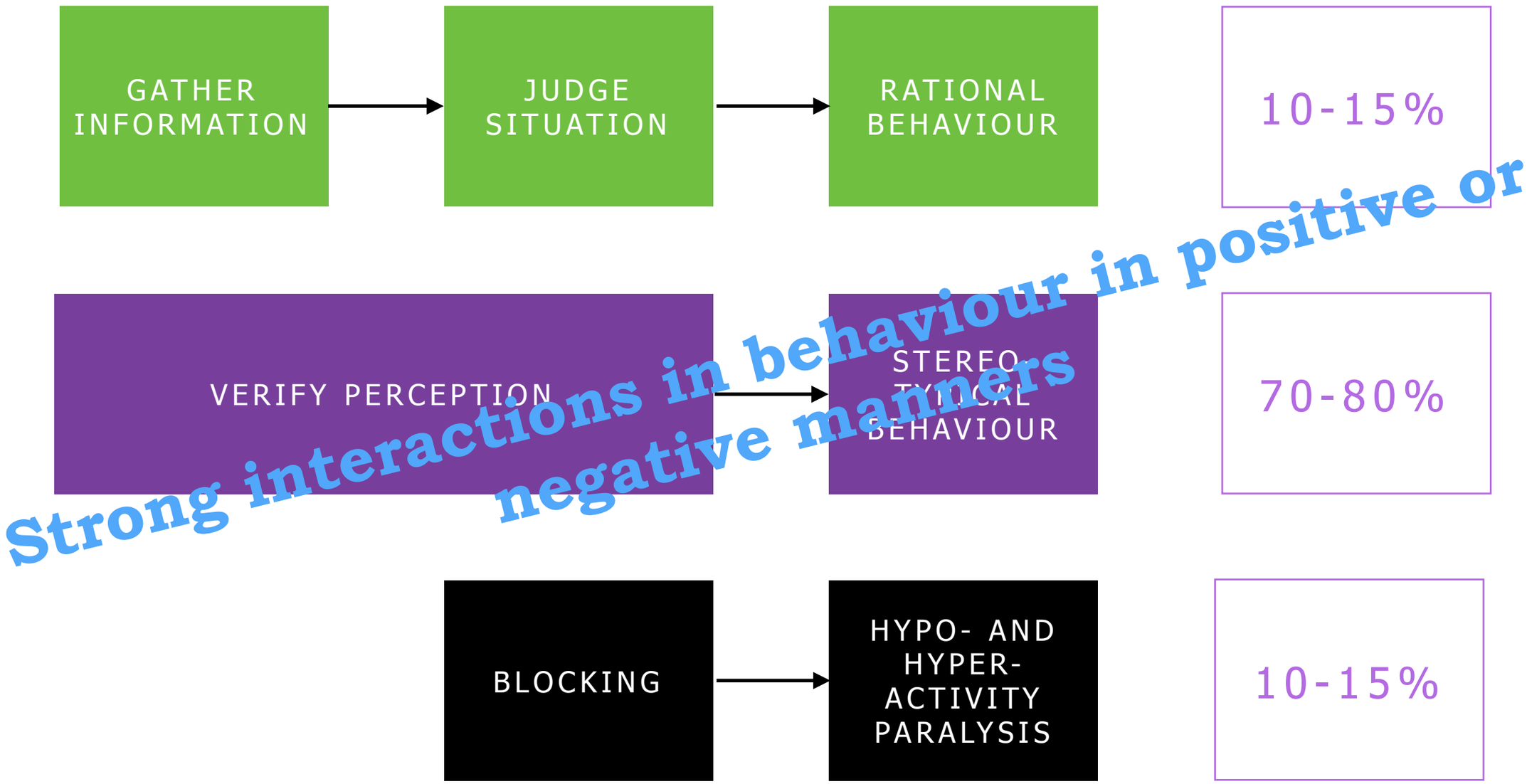
- **Threat and warning phase** characterised by denial (in general) to reduce 'feeling of discomfort'
- Denial includes response to warnings, but may be improved by relevant information
- **Impact phase** is characterised by disbelief, denial, often due to overload of sensory information
- Although necessary, evacuation is difficult due to (mental, emotional) state of evacuee

But there are also big differences in behaviour between evacuees…

Insights from Survival Psychology

Behaviour Dynamical Framework in case of Calamities

John Leach (1994) - Survival Psychology



Insights from Survival Psychology

Heterogeneity in Behaviour

Leaders, followers, and blockers…

Innovative Deployment of VR environments

Studying Herding Behaviour in Evacuation Decision Making

Towards modelling behavioural aspects of evacuation…

Studying Evacuation and Travel Behaviour

- Environment appears immersive according to participants responses
- Preliminary data analysis shows impacts of information and interaction effects
- Sequential choice modelling predicting decision to stay or leave based on different attributes (earthquake, news bulletin, number of people seen leaving)
- Probability to leave is determined by stochastic utility of staying:

$$U_i(t) = ASC + \beta_1 \cdot n_{leaving}(t) + \beta_2 \cdot earthquake + \beta_3 \cdot news(t) + \varepsilon$$

  with $ASC = 0.80, \beta_1 = -0.43,$ and $\beta_3 = -0.60$

- Situation is ambiguous: People see others as source of information!
- Importance of herding is supported by results of questionnaires showing that more then 30% indicated to be influenced by others

Innovative Deployment of VR environments

Studying Herding Behaviour in Evacuation Decision Making

Towards modelling behavioural aspects of evacuation…

Expected Behaviour Adaptation

Empirical and Experimental observations at Strategic level

Findings for route choice behaviour during evacuation

- Excess travel demand and unknown network conditions lead to a strong need for (traffic) information
- Lack of information impairs rerouting, which creates bias towards familiar routes and motorways (perceived as reliable)
- Generally low compliance
- Self-organisation fails

Expected Behaviour Adaptation

Empirical and Experimental observations at Operational level

…using remote sensing and driving simulator experiments

Characteristic	Incident	Fog	Emergency
Free speed	-	-	+
Max acceleration	0	-	+
Min headways	+	-	-

- Due to distraction, capacity per lane reduces with 30-50%
- Changes further include increased headway, reduced speed, and increased reaction time
- Driver simulator experiments show impacts on driving behaviour for evacuation situations
- More aggressive behaviour, unstable flows, faster = slower

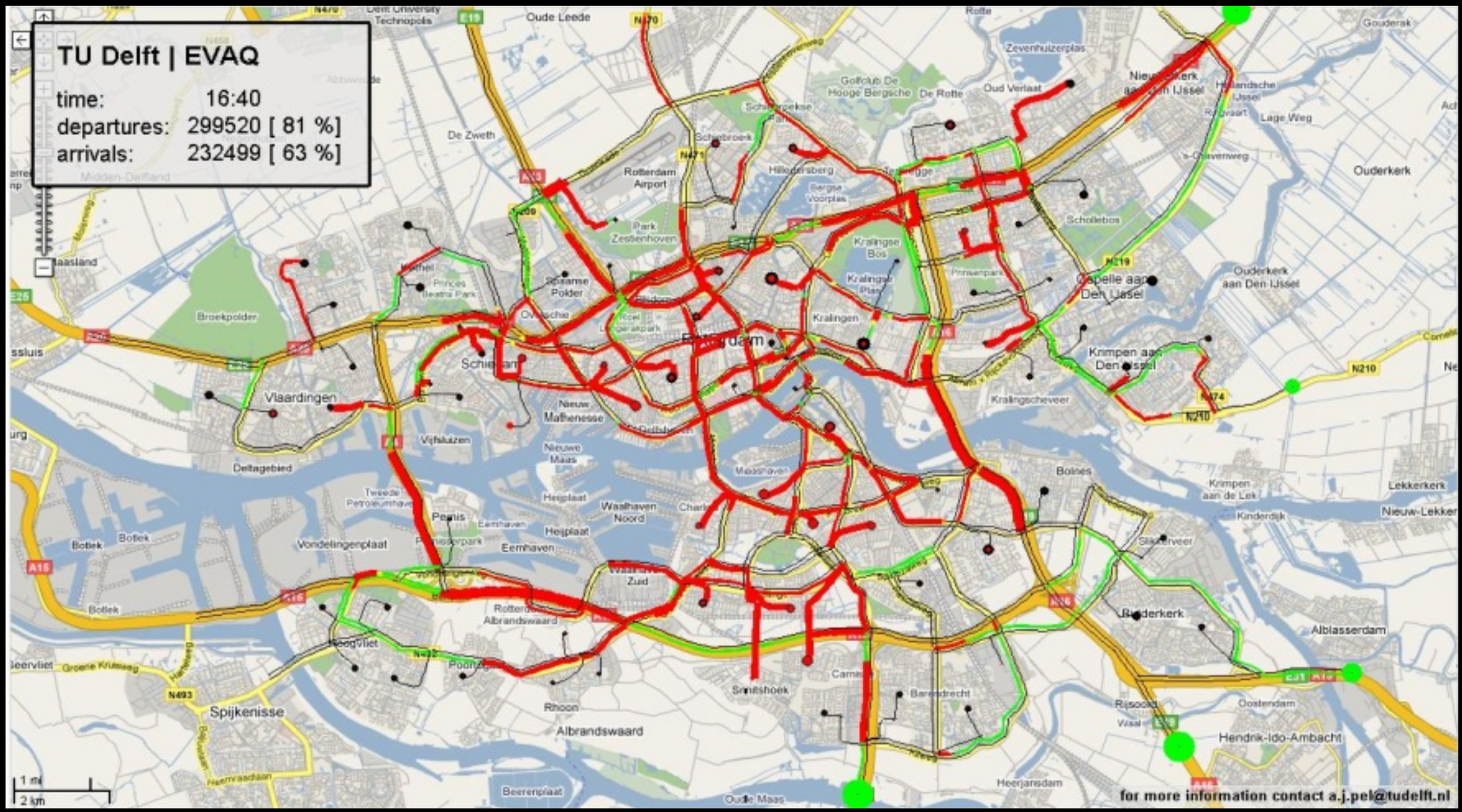
Summary so far...

Behavioural aspects of Evacuation Modelling and Management

Insights from empirical observations and experiments...

Insights:

- Changes in driving behaviour lead to reduction in efficiency
- Dynamically adaptive choice behaviour responding to uncertain and changing conditions
- Prominent role for information
- Strong interactions and heterogeneity among individuals
- Empirics and experiments allow quantification of behaviour!



Part II: Modelling Evacuations

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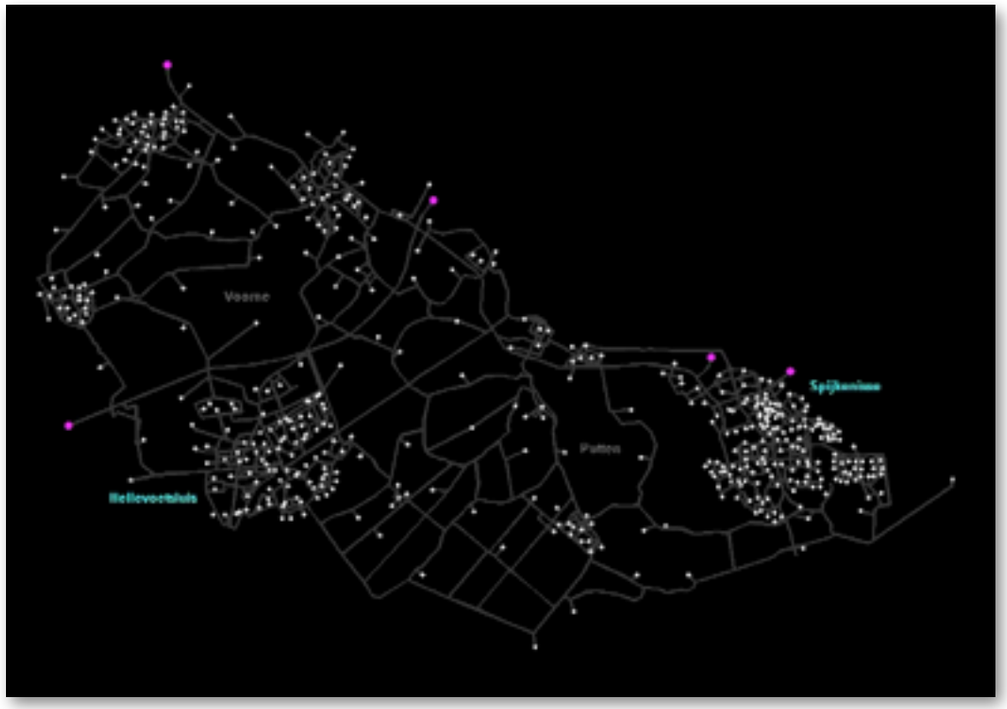
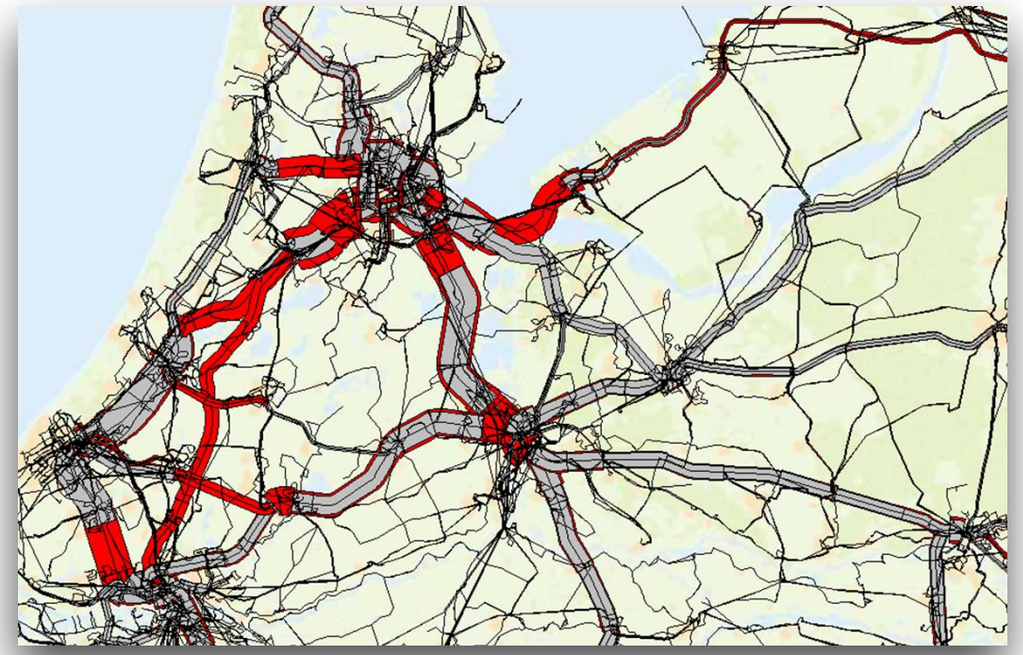




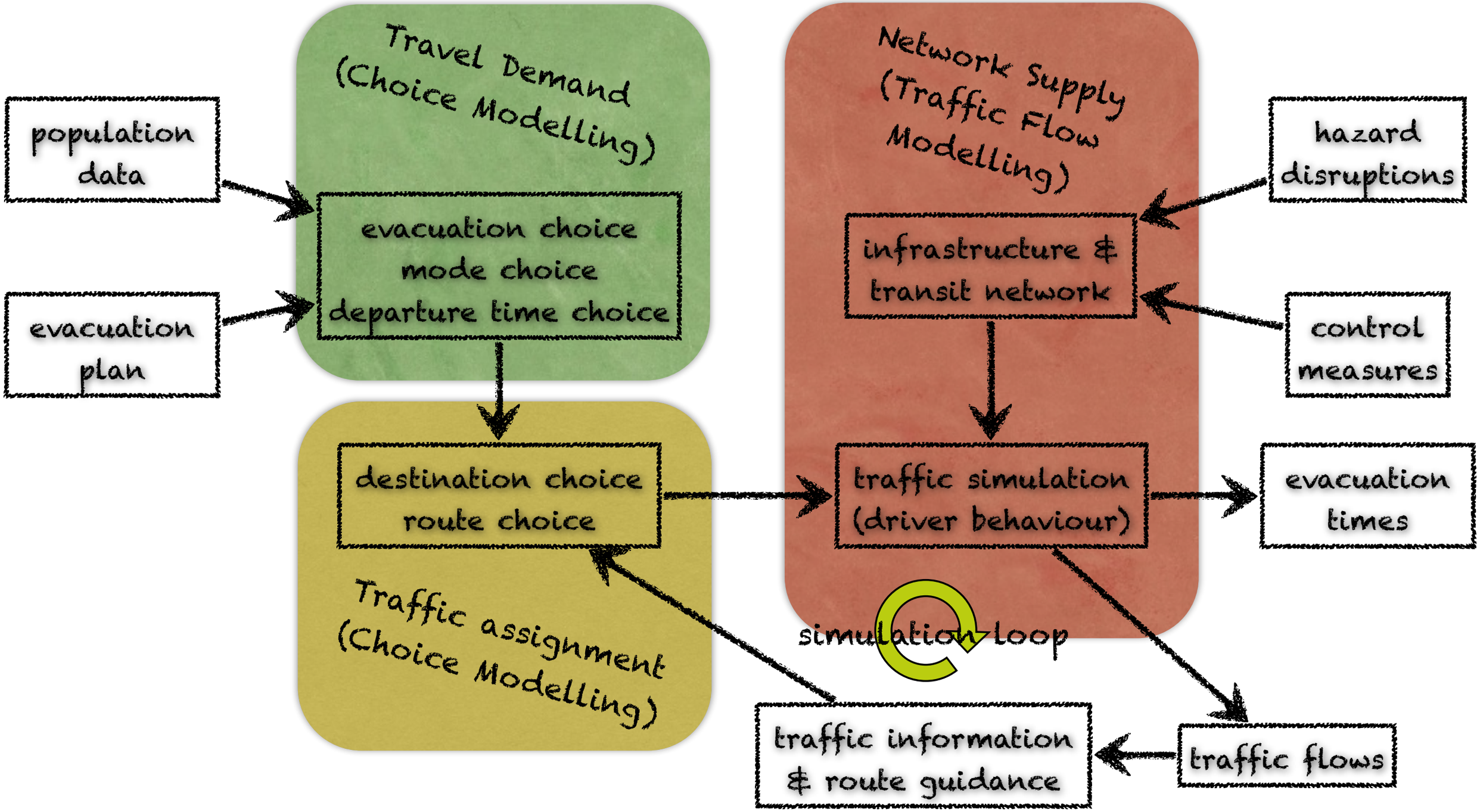
Models in evacuation studies

- DYNEV
- OREMS
- PARAMICS
- CORSIM
- VISSIM
- INTEGRATION
- DynaSMART
- DynaMIT
- DynusT
- TransCAD
- INDY
- EVAQ

Models used in Evacuation Studies

Realism in modelling paradigms differs strongly!

Evidently, a model should be predictively valid within the intended application area

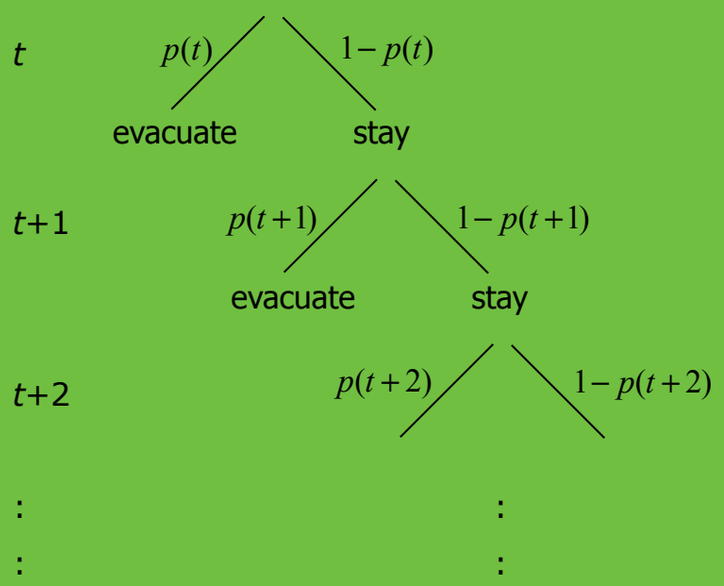


Modelling efforts

Bounded Rationality Framework of EVAQ

Quantifying behavioural aspects in mathematical and simulation models

Demand modelling



Sequential probability function:

- Travellers decide to stay or leave each time period
- Decision is based on characteristics of disaster, household, instructions, information, etc.

Traffic assignment

Hybrid route choice modelling:

- Pre-trip route choice based on expectations or compliance to instructions
- En-route information may lead to adaptation of route choice during trip

Traffic Operations

Advanced queuing modelling:

- Speeds and capacities are dependent on road conditions and weather conditions and control measures
- Inclusion of spillback, capacity drop, etc.

Modelling efforts

Bounded Rationality Framework of EVAQ

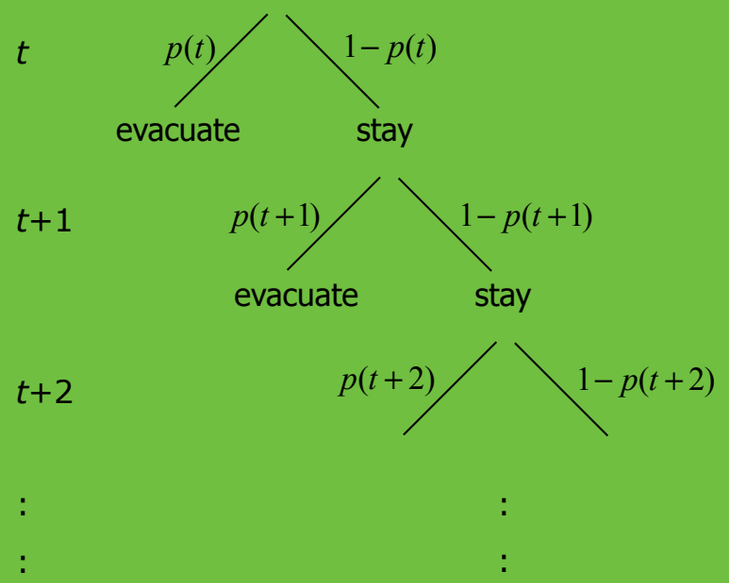
Quantifying behavioural aspects in mathematical and simulation models

Modelling efforts

Bounded Rationality Framework of EVAQ

Quantifying evacuation travel demand…

Demand modelling



Sequential probability function:

- Travellers decide to stay or leave each time period
- Decision is based on characteristics of disaster, household, instructions, information, etc.

- Binomial Logit model is sequentially applied over time to simulate evacuation decisions
- Utility functions are estimated for hurricane evacuation (post-hurricane survey) and wildfire evacuation (stated-choice experiment)
- Typically, explanatory variables include instantaneous conditions and socio-demographic characteristics
- Dynamically updated to account for changes in disaster conditions, evacuation order, traffic conditions, etc.

Modelling efforts

Bounded Rationality Framework of EVAQ

Quantifying evacuation traffic assignment…

Traffic assignment

Hybrid route choice modelling:

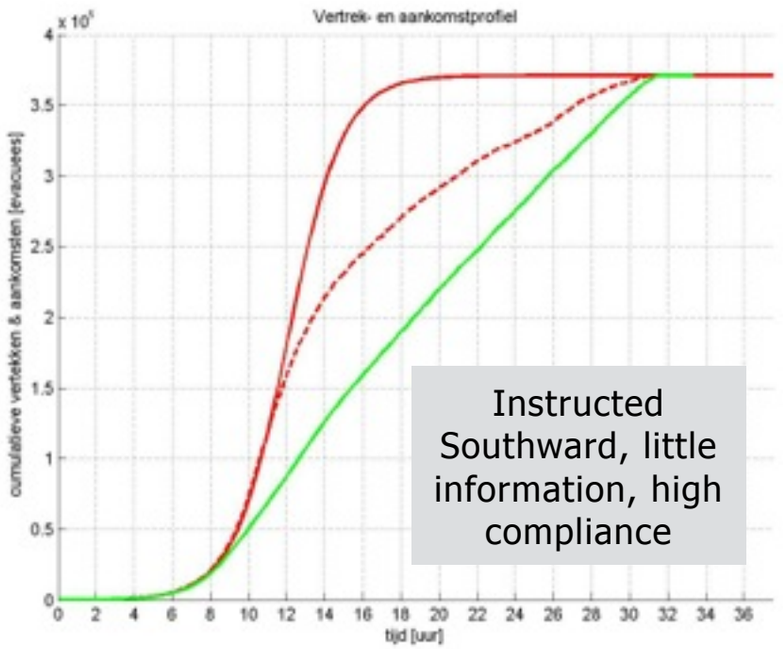
- Pre-trip route choice based on expectations or compliance to instructions
- En-route information may lead to adaptation of route choice during trip

- Multinomial Logit model is applied to route choice decisions at origins and intersections
- Utility functions may include (information on) traffic conditions, disaster conditions, and bias towards motorways, familiar routes, and instructed routes
- Dynamically updated to account for changes in network disruptions, traffic management, and traffic information
- Choice coefficients determine individuals' willingness to comply with instructions
- Incorporates destination choice

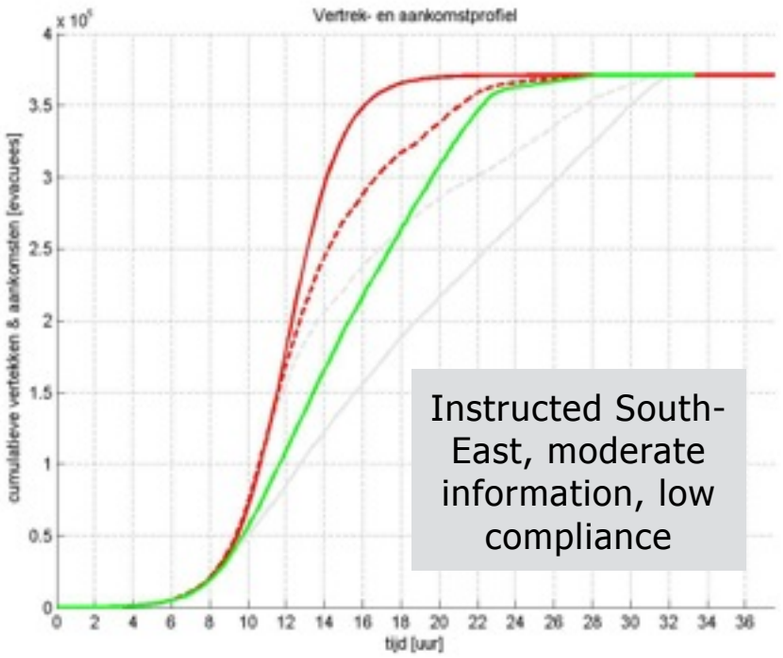
Example case studies

Impacts of instructions, information, and compliance

Modelling departure time choice in case of emergencies



Instructed Southward, little information, high compliance



Instructed South-East, moderate information, low compliance

- Evacuation of Rotterdam area in case of emergency
- EVAQ used to assess different evacuation instructions and scenarios

Example case studies

Impacts of instructions, information, and compliance

Modelling departure time choice in case of emergencies

- To improve traffic conditions: control travel demand (phasing) and extend network supply (peak lanes, hard shoulders, contraflow)
- To accelerate evacuation: increase bottleneck capacity (ramp metering, contraflow across onramps)
- Traffic information improves traffic conditions and fulfil travellers' desire to be informed
- However, traffic regulation is more effective than self-organisation

Intermediate Remarks…

Modelling Evacuation Choice Behaviour and Traffic Management

The adequacy of evacuation models…

Insights:

- Models need to account for dynamics
- Models need to capture effects of information and compliance
- Simulation of traffic management measures allows for planning
- Multi-modality is key
- Check for sensitivity towards uncertain parameters
- Model calibration and validation!

Part III: Optimal Traffic Management for Evacuation

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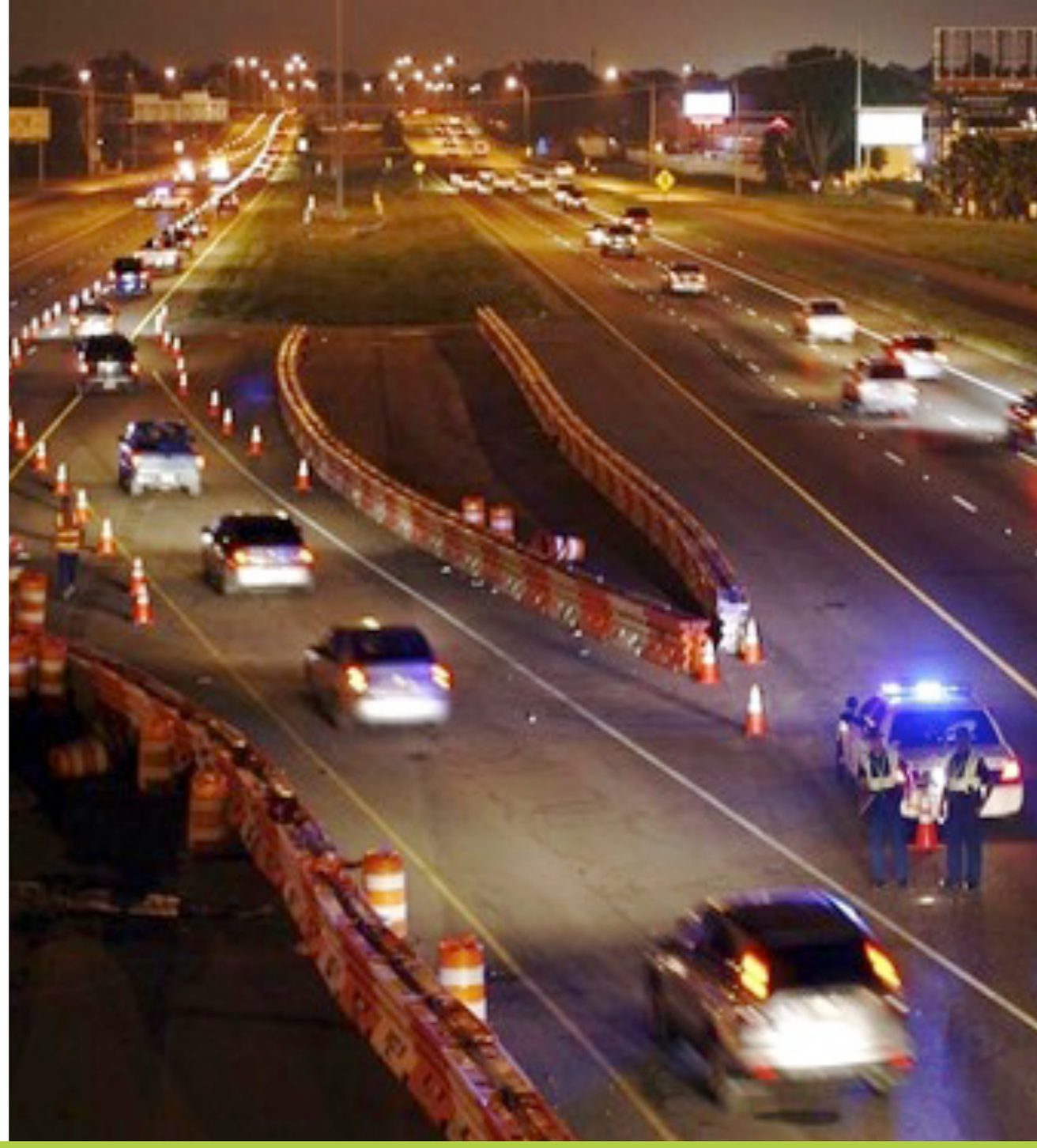
Traffic management

- Contraflow: reversing lane direction shows up to 1.5 - 1.7 increase in outbound traffic flows
- Crossing elimination: preventing conflicts at intersections yields 40% lower travel times
- Adapted signal timings: align with mobility management strategy

Mobility management

- Sheltering in place
- Phased evacuation: regulate network inflow by departure time windows
- Route guidance: distribute flows over network to avoid capacity drop and spill back



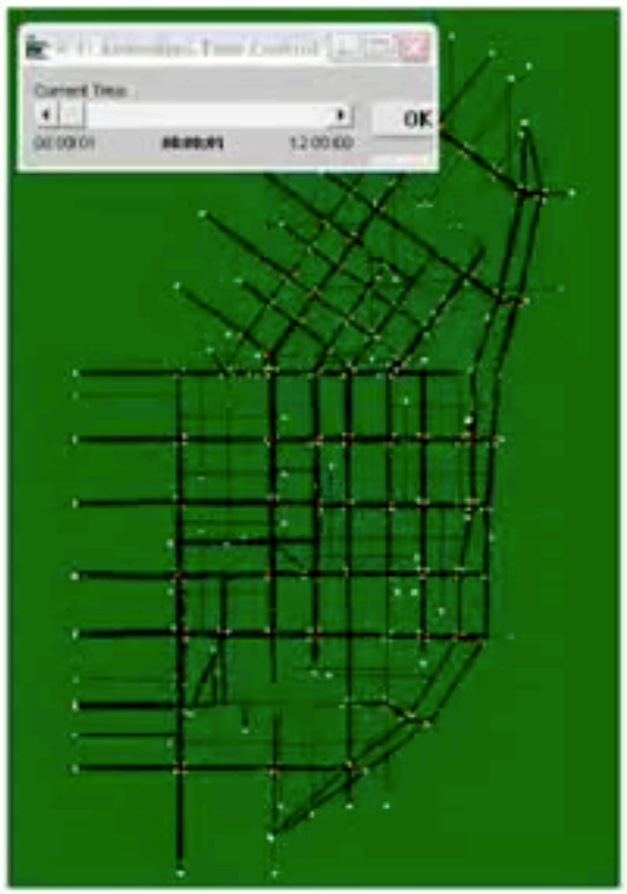
Mobility and Traffic Management Measures

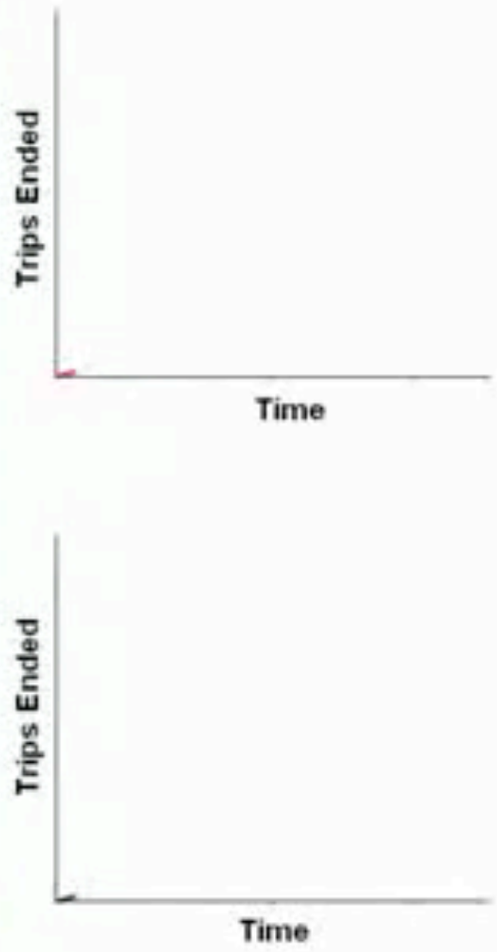
Deploying measures to control the evacuation

Towards an integrated network management strategy for evacuations…

Effect of Perimeter Control

No Control





With Control

Geroliminis and Daganzo (2007)

Importance of Regulating Network Inflow

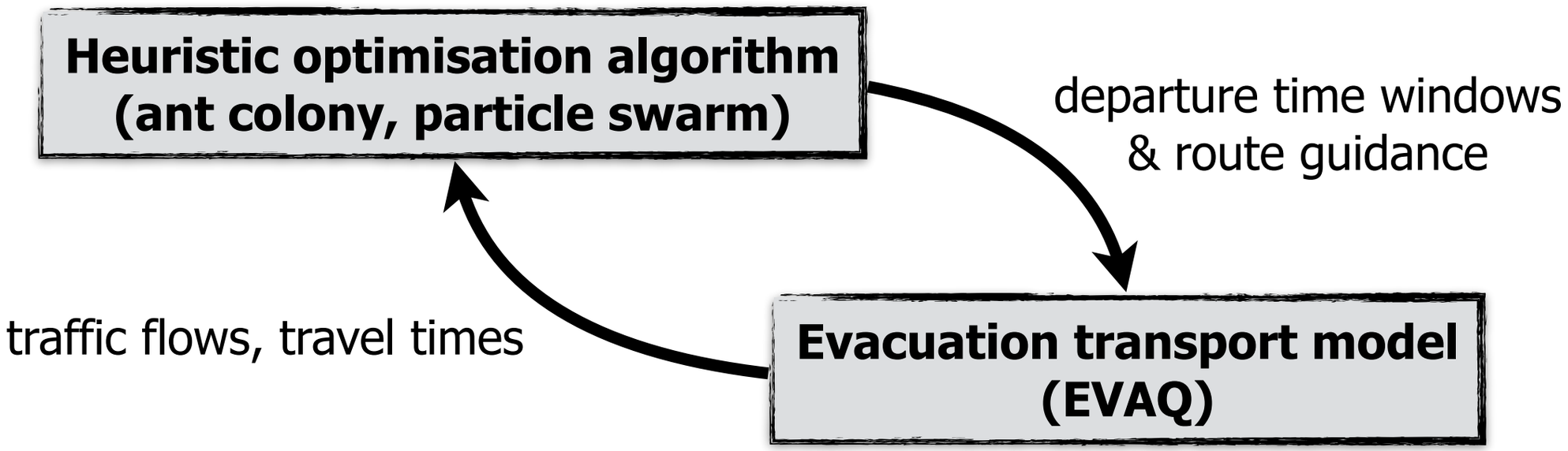
Performance reduction due to capacity drop & spill back

Perimeter control prevents under- or over-load of transport network…

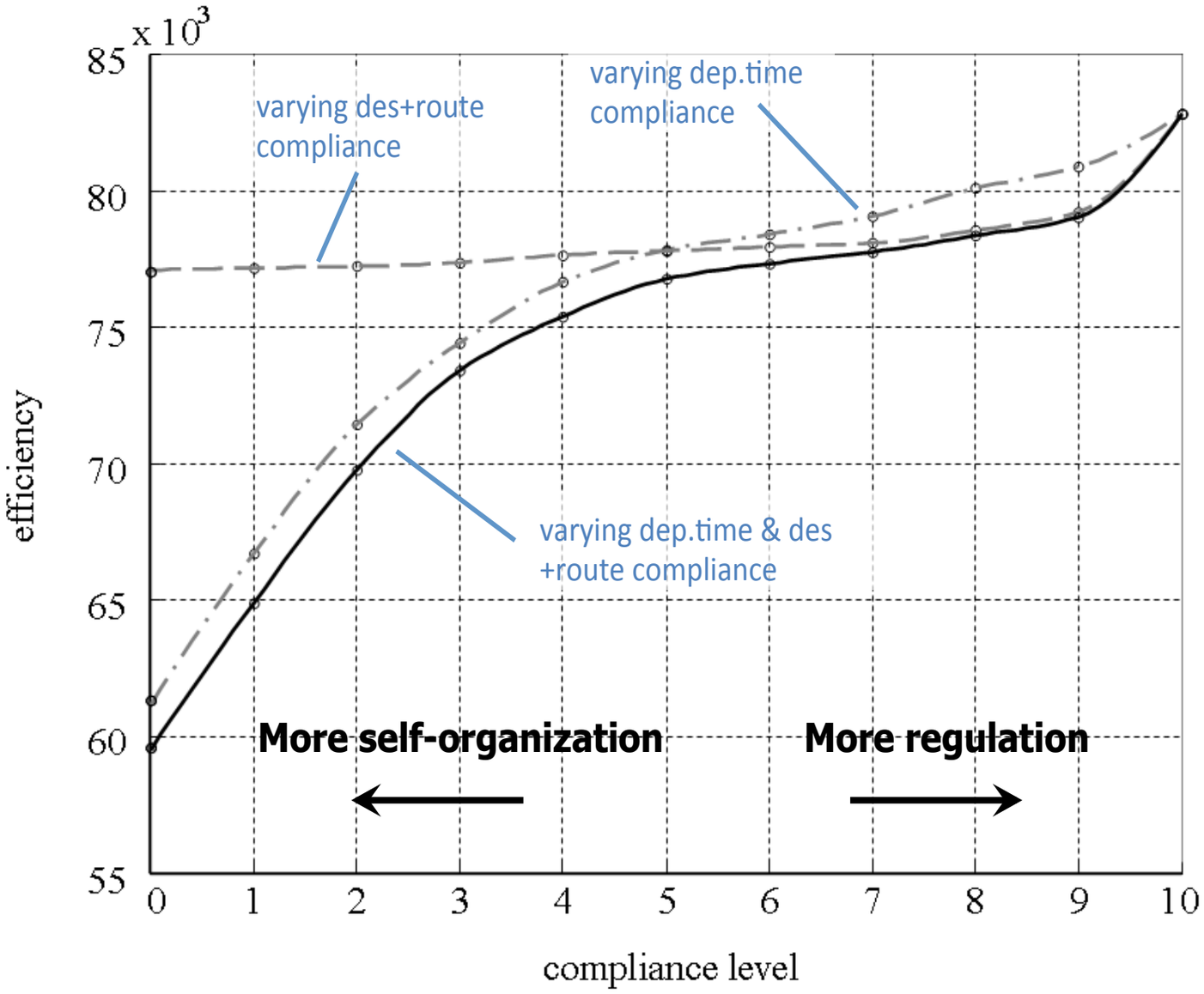
Optimisation of Mobility Management

Bi-level model-based optimisation framework

Mathematical optimisation of evacuation phasing and route guidance



- Assume disaster dynamics are known, and willingness to comply is known
- Upper level: set time windows for neighbourhoods and route guidance at intersections (to maximise arrival rates)
- Lower level: evaluate evacuation process according to plan and compute traffic flows and travel times



- Optimal integrated evacuation planning has high potential
- For optimal evacuation planning: non-compliance strongly reduces the efficiency monotonically, but non-linearly (threshold values)
- Route guidance still efficient for low compliance levels if network accumulation is below critical
- Mobilising and metering traffic inflow into network is essential!

Investigating the Impact of Compliance

When regulation becomes more efficient than self-organisation

The importance of evacuation phasing and route guidance…

Including Uncertainty in Optimisation

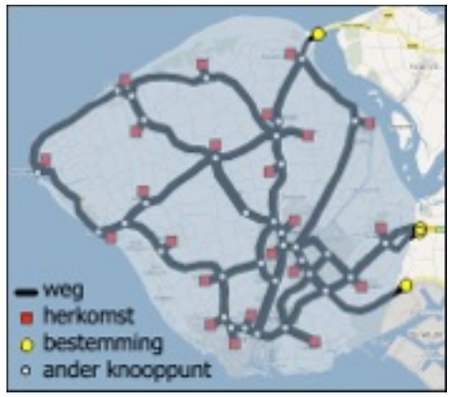
Robust optimisation of evacuation instructions

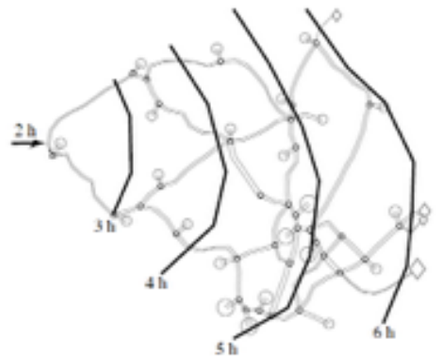
Dealing with limited knowledge and other sources of uncertainty

Anticipate on uncertain compliance levels

- Efficiency always increases upon anticipating compliance correctly when optimising
- Low compliance level show large improvements
- Low compliance with anticipation outperforms high compliance without anticipation
- Instructions optimised on lower compliance level appear less sensitive

optimized for	applied to	
	high	low
full compliance	77,754	73,411
high compliance	81,428	76,080
low compliance	80,817	80,437





Robust optimisation framework allows to include uncertainty in disaster dynamics

Investing in Enforcement

Where to send the military to…

An example of impacts of increasing compliance

	Minimum	Maximum
Cost	680	1.560
Performance	63.195	78.023
Arrivals	92.387	114.194

- Where to deploy limited resources for higher compliance
- Compare and test different strategies
- First results show considerable improvement with (limited) levels of enforcement
- Strategic deployment of enforcement can thus be beneficial!

Conclusions on Evacuation Management…

The importance of human response behaviour

Towards a behaviour-robust network management strategy

Insights:

- Integrated mobility and traffic management has high potential
- Not anticipating human response yields inefficient evacuation plans
- Evacuation plans can be adapted to accommodate non-compliance
- Mobilisation and metering of travel demand is essential
- Much uncertainty in evacuation asks for robust optimisation!

"The Netherlands is a bathtub. A six-lane motorway is of no use when flooded."

– Melanie Schultz, Minister of I&E
(Volkskrant, 26 Jan 2013)

Conclusions…

To evacuatie or not to evacuate, that is the question…

…lessons from 7 years of evacuation modelling and management

- Development of adequate dedicated models for evacuation assessment is needed and possible
- Evacuation can be improved by improving instructions and plans, and is necessary because shelter-in-place is not always the best option
- Survival psychology shows caution is needed when relying on self-reliance:
  - People tend to fall back on ‘known behaviour’
  - Importance of good (=relevant!) information and training for professionals
- First ‘succes’ in ‘action plan’ (handelingsplan) Traffic Information and Management Rijkswaterstaat

HANDELINGSPLAN RIJKSWATERSTAAT

FASE	*ACTIES*	*HOOFDDOEL PER FASE*	*KADER*	*MOGELIJKE OPTIES PER KADER*	
VOORBEREIDING *NUL-FASE*	* Algemene, brede communicatie rijksoverheid: wat te doen bij crisis? * Voorbereiding (o.a. aanpassingen op wegennet) * Opstellen operationele scenario’s door veiligheidsregio’s * realisatie van aantal (no regret) maatregelen zoals koppelen VRI’s op vluchtroutes	DOEL: **INFORMEREN** EN **VOORBEREIDEN** **RWS-maatregelen:** • routes inventariseren en knelpunten van deze routes in beeld brengen: waaraan ontbreekt het? Zijn er alternatieven? • bepaling voorkeursvluchtroutes, gebaseerd op de mogelijke vluchtrichtingen • bebordingsplannen opstellen en realiseren • aanpassing belijning (indien wenselijk / noodzakelijk) • afstemming met veiligheidsregio’s ivm netwerkbenadering (dus HWN en OWN samen!) • aanschaf mobiele camera’s • Indien nodig en noodzakelijk: wensenlijst opstellen van aanvullende maatregelen (zie toolkit) • Voorkeuren mbt routes inbrengen in (lopende) planstudies **Maatregelen overige partijen:** • Opstellen operationele scenario’s / draaiboeken door veiligheidsregio’s • Aanschaf mobiele camera’s • Koppelen / herprogrammeren VRI’s (calamiteitenstand) • Shelters aanwijzen en indien wenselijk inrichten (denk ook aan bv aanbrengen bebording of speciaal logo ter herkenning)	OMSTANDIGHEDEN	SOCIAAL	wel personeel
					geen personeel
				FYSIEK	wel beperking
					geen beperking
			VOORBEREIDINGSTIJD	GEEN VOORBEREIDINGSTIJD	
				< 48 UUR	
				> 48 UUR	
			GEBIEDSKENMERKEN	NOORD	
				OOST	
				ZUID	
				WEST	
			AANTAL MOTORVOERTUIGEN	< 10.000	
				> 10.000 EN < 50.000	
				> 50.000	
			BESCHIKBAARHEID	WEL BEDIENINGS-MOGELIJKHEDEN	
				GEEN BEDIENINGS-MOGELIJKHEDEN	
VOORBEREIDING *DREIGINGSFASE*	Verkeers-management-maatregelen uitvoeren: * doorstroom vergroten * instroom beperken * spreiding over netwerk * tijdelijke bebording plaatsen * inzet extra mankracht ter ondersteuning maatregelen * check of calamiteitenstand in VRI’s ingesteld is	DOEL: EVACUATIE BURGERS -> **PREPARATIE** **RWS-maatregelen:** • spitstroken tijdig openen • indien nodig: testen of calamiteitendoorsteken ‘werken’ en dus beschikbaar zijn voor het geval dit nodig is • mobiele maatregelen plaatsen (oa camera’s en barriers) • tijdelijke belijning, markering, bebording aanbrengen • maatregelen treffen voor extra capaciteit (oa dubbel door de bocht en vluchtstrookgebruik) zoals opgenomen in het VCE (Verkeerskundig Concept Evacuatie) • indien noodzakelijk: knooppunten (deels) afsluiten conform VCE • indien nog niet gedaan: VRI’s HWN (aansluitingen snelwegen op OWN) aanpassen • toepassen maatregelen om reversed laning in te kunnen zetten **Maatregelen overige partijen:** • VRI’s OWN aanpassen (indien mogelijk) • shelters prepareren / inrichten • plaatsen van aanvullende bebording op OWN • weghalen eventuele bottlenecks op OWN (denk aan rotondes tijdelijk aanpassen of vluchtheuvels verwijderen, maar ook: plaatsen van varkensruggen om bepaalde straten af te sluiten)	OMSTANDIGHEDEN	SOCIAAL	wel personeel
					geen personeel
				FYSIEK	wel beperking
					geen beperking
			VOORBEREIDINGSTIJD	GEEN VOORBEREIDINGSTIJD	
				< 48 UUR	
				> 48 UUR	
			GEBIEDSKENMERKEN	NOORD	
				OOST	
				ZUID	
				WEST	
			AANTAL MOTORVOERTUIGEN	< 10.000	
				> 10.000 EN < 50.000	
				> 50.000	
			BESCHIKBAARHEID	WEL BEDIENINGS-MOGELIJKHEDEN	
				GEEN BEDIENINGS-MOGELIJKHEDEN	
VOORBEREIDING *WAARSCHUWINGSFASE*	Verkeers-management-maatregelen uitvoeren: * doorstroom vergroten * instroom beperken * spreiding over netwerk * inzet extra mankracht ter ondersteuning van maatregelen * VRI’s op vluchtroutes in calamiteitenstand schakelen	DOEL: EVACUATIE BURGERS -> **ALLES UIT DE KAST** **RWS-maatregelen:** • spitstroken zijn open • VRI’s HWN (aansluitingen snelwegen op OWN) aanpassen • extra capaciteit inschakelen (oa dubbel door de bocht en vluchtstrookgebruik) zoals opgenomen in het VCE (Verkeerskundig Concept Evacuatie) • indien noodzakelijk: knooppunten (deels) afsluiten conform VCE • inzet mankracht om evacuaties verkeerskundig te begeleiden • bepaalde toe- en afritten afsluiten (bv bij toepassen reversed laning) om doorstroom op vluchtroute te bevorderen • fysieke maatregelen treffen om ongewenst gedrag te voorkomen. Bv plaatsen van barriers bij toe- en afritten **Maatregelen overige partijen:** • plaatsen van aanvullende bebording op OWN • shelters openstellen / gebruik faciliteren • weghalen eventuele bottlenecks op OWN (denk aan rotondes tijdelijk aanpassen of vluchtheuvels verwijderen, maar ook: plaatsen van varkensruggen om bepaalde straten af te sluiten) • VRI’s aanpassen (indien mogelijk)	OMSTANDIGHEDEN	SOCIAAL	wel personeel
					geen personeel
				FYSIEK	wel beperking
					geen beperking
			VOORBEREIDINGSTIJD	GEEN VOORBEREIDINGSTIJD	
				< 48 UUR	
				> 48 UUR	
			GEBIEDSKENMERKEN	NOORD	
				OOST	
				ZUID	
				WEST	
			AANTAL MOTORVOERTUIGEN	< 10.000	
				> 10.000 EN < 50.000	
				> 50.000	
			BESCHIKBAARHEID	WEL BEDIENINGS-MOGELIJKHEDEN	
				GEEN BEDIENINGS-MOGELIJKHEDEN	

Route Choice Behaviour and Optimal Traffic Management during Evacuation

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Our current research

- Modelling multi-modal urban emergencies (software development)
- Time-dynamics and social interactions in choice behaviour (experiment & theory development)
- Changes and correlations in longitudinal and lateral driving behaviour (driving simulator study)
- Optimal integrated network management for emergencies (control strategy & algorithm development)
- Calibration of choice models! (experiments & model validation)

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