Route Choice Behaviour and Optimal Traffic Management during Evacuation

BIN Tokyo lecture Dr. ir. Adam Pel
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
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
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.

Evacuation Traffic Dynamics and Travel Behaviour

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

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

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>( \beta(\text{mean}) )</th>
<th>( \beta(\text{CI}_{95%}) )</th>
<th>se(( \beta ))</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASC</td>
<td>Model constant</td>
<td>-1.48</td>
<td>-1.92 / -1.04</td>
<td>0.19</td>
<td>0.02</td>
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<tr>
<td>DIS</td>
<td>Hazard distance (3.32=far, 0=close)</td>
<td>-0.54</td>
<td>-0.61 / -0.46</td>
<td>0.06</td>
<td>0.08</td>
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<tr>
<td>ETIM</td>
<td>Time passed during experiment (min)</td>
<td>-0.01</td>
<td>-0.01 / -0.01</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td>EVACM</td>
<td>Mandatory evacuation</td>
<td>1.51</td>
<td>1.37 / 1.66</td>
<td>0.06</td>
<td>0.00</td>
</tr>
<tr>
<td>EVACR</td>
<td>Recommended evacuation</td>
<td>1.52</td>
<td>1.34 / 1.70</td>
<td>0.08</td>
<td>0.00</td>
</tr>
<tr>
<td>EVACV</td>
<td>Voluntary evacuation</td>
<td>0.95</td>
<td>0.82 / 1.07</td>
<td>0.06</td>
<td>0.00</td>
</tr>
<tr>
<td>GEN</td>
<td>Gender (0=male, 1=female)</td>
<td>0.64</td>
<td>0.56 / 0.72</td>
<td>0.03</td>
<td>0.00</td>
</tr>
<tr>
<td>HIC</td>
<td>Complete hazard information</td>
<td>1.06</td>
<td>0.81 / 1.31</td>
<td>0.11</td>
<td>0.00</td>
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<tr>
<td>HIL</td>
<td>Limited hazard information</td>
<td>0.78</td>
<td>0.51 / 1.05</td>
<td>0.12</td>
<td>0.01</td>
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</table>
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...**

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**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...

Strong interactions in behaviour in positive or negative manners

- GATHER INFORMATION
  - JUDGE SITUATION
  - RATIONAL BEHAVIOUR
  - 10-15%

- VERIFY PERCEPTION
  - STEREOTYPICAL BEHAVIOUR
  - 70-80%

- BLOCKING
  - HYPO- AND HYPER-ACTIVITY PARALYSIS
  - 10-15%
Innovative Deployment of VR environments

Studying Herding Behaviour in Evacuation Decision Making

Towards modelling behavioural aspects of evacuation...

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:

\[ U_i(t) = A \cdot S(t) + \beta_1 \cdot n_{living}(t) + \beta_2 \cdot earthquake + \beta_3 \cdot news(t) + \epsilon \]

A = 0.80, \beta_1 = -0.43, and \beta_3 = -0.60

Importance of herding is supported by results of questionnaires showing that more than 30% indicated to be influenced by others

Basis for more advanced model development
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:

\[ U_i(t) = ASC + \beta_1 \cdot n_{leaving}(t) + \beta_2 \cdot earthquake + \beta_3 \cdot news(t) + \epsilon \]

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
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

- 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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Incident</th>
<th>Fog</th>
<th>Emergency</th>
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<tbody>
<tr>
<td>Free speed</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Max acceleration</td>
<td>0</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Min headways</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
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 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
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 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

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

Instructed Southward, little information, high compliance

Instructed South-East, moderate information, low compliance
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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Mobility and Traffic Management Measures

Deploying measures to control the evacuation

Towards an integrated network management strategy for evacuations...

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
Importance of Regulating Network Inflow

Performance reduction due to capacity drop & spill back

Perimeter control prevents under- or over-load of transport network...
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.
Investigating the Impact of Compliance

When regulation becomes more efficient than self-organisation

The importance of evacuation phasing and route guidance...

- 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!
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

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

- 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 evacuate 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
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ありがとうございます！
(Thank You!)
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)
References


Y. Yuan, A.J. Pel, S.P. Hoogendoorn [2014] The transition between normal and emergency driving behaviour during evacuation and its implications for traffic flow operations and traffic management. Under review for IEEE ITSC, Qingdao, China


A.J Pel, S.P. Hoogendoorn, M.C.J. Bliemer [2010] Impact of variations in travel demand and network supply factors for evacuation studies. Transportation Research Record 2196:45-55


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