Dynamic Meso-scopic Simulation Approach to Modeling Emergency Evacuations

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Outline

- Introduction
- Literature review
  - Evacuation planning
  - Evacuation modeling
  - Evacuation travel demand
- Research objectives
- Methodology and case study
Introduction

- Evacuation is among the major protective actions used in cases of regional emergencies

Definition:
- “The withdrawal action of persons from a specific area because of real or anticipated threat or hazard”

Goal:
- Mitigate the impacts of emergency events to avoid injury or death
Introduction

Types of evacuation:
- Mandatory
- Voluntary
- Recommended
Types of Emergencies

- **Emergency events**
  - Natural (hurricanes, tsunamis, floods, earthquakes, and fires)
  - Man-made (hazardous material spills, malfunctions of nuclear plants or chemical facilities, and terrorist attacks)

- **Warning times**
  - Long (hurricanes, floods, and fires)
  - Short (hazardous materials spills, terrorist attacks, and earthquake)
Transportation Related Measures

- **Pre-disaster**
  - Plan and identify evacuation routes
  - Develop alternate traffic control measures
  - Develop traveler information plan

- **During disaster**
  - Implement plan
  - Assess and make changes

- **Post-disaster**
  - Facilitate relief efforts and evacuees return
Evacuation Planning

- Originally required for the nuclear power industry following the 1979 Three-Mile Island nuclear power plant incident
  - Mandated by the Nuclear Regulatory Commission (NRC)

- Gained significant interest in recent years:
  - The terrorist attacks of September 11th
  - Hurricanes Rita and Katrina
  - The California wild fires
Evacuation Planning

- An essential element of any evacuation plan is a carefully prepared transportation plan.

Objectives

- Identify the best evacuation routes
- Provide Evacuation Time Estimates for different emergency scenarios
- Evaluate traffic operations strategies
Evacuation Planning

- What is the clearance time required to get the safely evacuate the public?
- Which roads should be utilized for the evacuation?
- What are the critical roads in the evacuation process?
- How can we improve the efficiency of the evacuation process?
Evacuation Planning

Hurricane Rita
Evacuation Modeling

Several modeling approaches have been utilized to address the performance of the transportation system

- Simulation-based models
  - NETVAC, MASSVAC
- Analytical models
  - PBS&J
Evacuation Modeling

- Simulation-based models are among the most powerful tools that could be applied
  - Simulation tools assist emergency managers and transportation officials in the decision-making process
- Human behavior analysis is an integral part of evacuation models
Simulation Models

- Advantages
  - Provide low-risk analysis tools for testing scenarios and alternative strategies

- Challenges
  - Cost of building simulation models and data requirements

- Examples
  - NetVAC, Transims, DYNASMA RT-P
Evacuation Modeling

- Transportation network performance
  - Demand/supply (i.e., volume/capacity)
- Human behavior
  - At-risk population response
  - Travel characteristics
    - Demand volumes
    - Loading rates
    - Origin-destination information
Evacuation Travel Demand

- Number of trips on the system

- Different than daily travel demand
  - Larger volumes of traffic in shorter period
  - Trip making behavior
    - Daily trips: work, school, shopping, etc.
    - Evacuation trips: move out of harms way
Evacuation Travel Demand

- Three main categories of the evacuating population
  - Residents: live in the at-risk area
  - Tourists and visitors: hotel and motel guests
  - Special facility population
    - Jails, schools, hospitals, and nursing homes
Evacuation Travel Demand

- Trip generation
  - Identify the demand or the number of vehicles (trips) that are going to be using the transportation network
  - The demand for travel is mainly based on the number of Households (HH) and family size
- 1.3 vehicles per HH most common estimate found in previous studies
Human Behavior

- Compliance rates
  - Response to evacuation orders
- Previous models
  - Hobeikah et al. (1994) assumed a 100% response rate
  - Lindell et al. (2002) used regression analysis
- Ranges by event type
  - High (up to 90%) for incidents involving hazmat or in major storm surge areas
  - Low for small storms or river floods
Evacuation Travel Demand

- Trips loading rates based on sigmoid curve
  - The sigmoid function is a special case of the logistic function:
    \[ P(t) = \frac{1}{1 + e^{-t}} \]
    where,
    \( P(t) \): Percentage evacuating at time \( t \)
    \( t \): Time elapsed since the beginning of the process
Evacuation Travel Demand

- Binary Logistic Regression:

\[
\text{Odds} = \frac{\Pi}{1 - \Pi} = \frac{P(Y = 1)}{P(Y = 0)}
\]

\[
\Pi = E(Y) = \frac{e^{\beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k}}{1 + e^{\beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k}}
\]

*Where:*

- \(Y\) = probability that the HH will evacuate
- \(x_1, x_2, \ldots x_k\) = independent variables
- \(\beta_0, \beta_1, \ldots \beta_k\) = parameters
Evacuation Travel Demand

Departure time curves for Tweedie et al. (1986) (TW⁺); Hobeika et al. (1994) (HO⁺); Lindell et al. (2002a) transients (TR⁺); Southworth (1987) (SW⁺); and Lindell et al. residents at home (RH⁺) and residents at work (RW⁺)
Research Motivation

- Increased emphasis on security planning and emergency management
- Need for practical models suitable for Metropolitan Planning Organizations (MPOs) recognizing
  - MPO resource availability
  - Data availability
- Interest from FM COG and availability of a rich case study
Research Objectives

- Develop a practical evacuation model
  - Link the model to existing regional travel model
  - Utilize available data and modeling resources

- Generate local human behavior data to support model development

- Demonstrate the applicability of the models to real-world evacuation scenarios and traffic operation strategies using a case study of the FM area

- Document research findings
The objectives of this research will be achieved in two stages:

- Transportation network
  - Demand quantity
  - Demand loading rates
- Development of the evacuation modeling tool
  - Citilabs Cube
  - DYNASMART-P
Case Study

- Fargo-Moorhead metropolitan area
  - Cities of Fargo and West Fargo in ND
  - Cities of Moorhead and Dilworth in MN
- 2005 regional travel model
  - 543 Traffic Analysis Zones (TAZ’s)
  - 1,709 nodes
  - 2,361 links
Case Study

Selection Criteria

- Case provided an adequate size and level of detail that is sufficient for the purpose of this study
- Small-medium size MPOs received less attention in security planning
  - Less resources than largest metropolitan areas
- The availability of background data, which were provided either through the Fargo-Moorhead Council of Government’s (FM-COG) or through the Advanced Traffic Analysis Center (ATAC)
- Regional travel model housed at ATAC
Methodology

- Tools used for the study
  - DYNASMA T-P (Dynamic Network Assignment-Simulation Model for Advanced Road Telematics for Planning purposes)
  - Cube modeling system (the traditional 4-step model)
  - An interface was developed earlier that enabled the exchange of data and output between Cube and DYNASMA T-P software
Methodology

- CUBE Modeling System
  - A transportation analysis and forecasting tool widely used by transportation agencies
  - Provides an effective method for organizing the script and is used to view and edit the input and output files
  - Provides full integration with the GIS
Methodology

- **DYNASMART-P**
  - Mesoscopic traffic simulation model
  - Originally designated by FHWA for evacuation planning applications
  - Key features
    - Information supply strategies
    - Route assignment rules
    - Traffic control measures
  - Model components
    - Simulator
    - User behavior
    - Path processing
DYNASMART-P

**INPUT**

- Simulation input files
- Graphical input files

**Output**

- Statistics about the vehicles on the system, and network-wide averages
Hybrid Model
## Model Comparison

<table>
<thead>
<tr>
<th></th>
<th>Original Model</th>
<th>Hybrid Model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input</strong></td>
<td>Network structure, socio-economic attributes</td>
<td>Network structure, static O-D matrix, operational characteristics</td>
</tr>
<tr>
<td><strong>Output</strong></td>
<td>V/C, ADT, Ave. TT, Screen line counts</td>
<td>System-wide averages, traffic simulation, driver's behavior, vehicle speeds and trajectories, links performance measures, traffic characteristics over the planning horizon</td>
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# Model Comparison

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<td></td>
<td>Travel demand estimation, select link analysis, work zone modeling</td>
<td>Travel demand estimation, network performance over time analysis, drivers behavior and information supply strategies analysis, work zone modeling, traffic accidents modeling, HOV and HOT lanes studies, studies with buses in the traffic stream, evacuation plans studies</td>
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Methodology

- Local data development
  - Survey selected sample of representative residents
    - Identify public response to evacuation orders
    - Develop driver behavior parameters and trip characteristics during an emergency evacuation

- Evacuation travel demand loading curves
  - Modify the dynamic O-D matrix input for DYNASMART-P software
Methodology

- Identify public response and driver behavior parameters
  - What has been done in the literature
  - Conduct a limited survey to estimate
    - drivers response to provided information
    - public response rates for different threat scenarios
    - public compliance with evacuation instructions
  - Compare local data with available information in the literature
Methodology

- Emergency scenarios
  - In consultation with local emergency managers
- For each scenario, the following will be determined:
  - Location
  - Threat level
  - Warning times
  - Affected areas shape and boundaries
  - Different evacuation network and traffic operation management measures
- Selected MOEs tabulated for different emergency scenarios and traffic operation strategies
Methodology & Case Study

- Model preparation
  - Use Calibrated 2005 FM COG Cube model
  - Build corresponding DYNASMAINT-P model

- Calibration of the simulation software
  - Modify different simulation parameters (adequate warm up period, simulation period, and travel speed statistics)

- Select key measures of effectiveness
  - Evacuation time estimates
  - Network performance
Methodology

- Incorporating the hypothetical emergency scenario within the hybrid model
  - Revise network (road closures, damage to the roadway, contra-flow, etc.)
  - Modify the O-D matrix and demand data
  - Implement emergency traffic control and management

- Run the models
  - Develop statistically acceptable runs
  - Summarize the output
  - Analyze the results

- Document research findings
Damage from June 1957 Fargo Tornado
Courtesy NOAA National Weather Service, Grand Forks, ND Weather Forecast Office