Outline

• Introduction
• Background
  – Evacuation Planning
  – Cellular Automata
  – Evolutionary Algorithms
• Self-Organizing Traffic Management System
  – Model
  – Assumptions and Hypotheses
• Model Implementation
• Initial Results
• Conclusions
Introduction

Recent natural disasters and terrorist attacks showed

– Substantially different modes of behavior of transportation systems operating under emergency evacuation conditions
– Lack of effective policies and strategies for evacuating densely populated areas
– Lack of effective analytical tools and models for dealing with such evacuations
Introduction

Hence

– Novel approaches are necessary to model, analyze, and optimize the performance of transportation systems operating in crisis mode

– Advanced methods of representing and optimizing traffic management strategies can be used to find efficient evacuation strategies

– Faithful simulations of developed evacuation strategies and testing of various what-if scenarios can be conducted using state-of-the-art traffic simulation systems
Background: Evacuation Planning

- Most of the models in this field (e.g., OREMS, IDYNEV) are old, static or planning-oriented, not designed for operations.
- Models have had only limited testing for a narrow set of evacuation conditions.
- Very little data from real evacuations available, which makes realistic testing difficult.
Background: Cellular Automata

- One of the simplest mathematical representations of complex systems
- Useful idealizations of the dynamical behavior of various systems
- Models for complex systems and processes consisting of a large number of identical, simple, locally interacting components
- Discrete dynamical system simulators used to study pattern formation and self-organization processes
Background: Cellular Automata

Simplest 1D Cellular Automata

Iteration process (steps 1-15)
Background: Cellular Automata

1D Cellular Automata: Mechanism

![1D Cellular Automata Diagram](image-url)
Background: Cellular Automata

2D Cellular Automata

Iteration

Neighborhoods

radius = 1
radius = 1
radius = 1
radius = 1
radius = 1

Moore neighborhood
von Neumann neighborhood
Diagonal neighborhood
North-South neighborhood
East-West neighborhood
Background: Evolutionary Algorithms

- Use a population of individuals
- Individuals are points in search space
- Individuals are evaluated for their “fitness”
- Population dynamics:
  - New individuals (samples) are created from existing high fitness parents using operators like:
    - Crossover
    - Mutation
  - Existing low fitness individuals are deleted
Assumptions and Hypotheses:

– A typical transportation network can be understood as a complex system with many entities and actors, all pursuing their own somewhat limited objectives and acting with variable and limited information inputs.

– All of the actors in the system have actions they can take that are perceived to improve their own performance, or to advance their assigned operational objectives, and they often make decisions with little or no knowledge of the impacts of their decision on the performance of the overall system.
Self-Organizing Traffic Management System

Assumptions and Hypotheses:

– The **emergent behavior** of the system and its subsystems is of great interest for finding effective technology and policy approaches to improving performance.

– **Systems operating in crisis mode exhibit self-organizing behavior**, so finding optimal operational strategies involves understanding and capitalizing on this attribute.
Self-Organizing Traffic Management System

Simple model of an urban area to be evacuated
Self-Organizing Traffic Management System

Symbolic representation of traffic signal system in the evacuated area

Possible states of traffic signals

2D cellular automaton updating the traffic signal system through simulation time

Traffic signal system representation
The input for each evacuation scenario simulation consists of:

– a configuration of vehicles (pedestrians will be introduced in later versions) in the urban area under consideration
– a specific cellular automaton model of a traffic control system to be evaluated
– simulation time during which the scenario is tested
– pre-determined threat situation, i.e., locations and types of terrorist attack/natural disaster
Self-Organizing Traffic Management System

Examples of possible types of terrorist attacks in an urban area
Model Assumptions:

- Traffic signal state durations (phase lengths) are fixed and constant. A traffic phase length is an integral multiple of the model’s fixed time step, and cycle times are a product of the modeling results. The length of the time step is a modeling variable.

- Vehicles move only in marked lanes (i.e., not on the shoulders, sidewalks, or off-road areas), in the normal direction (i.e., not in opposing lanes, even if they are empty), unless “all lanes one-direction” is being tested.

- The initial locations, destinations and travel paths of individual vehicles are given and constant, which determine the turning movement demand at individual intersections.
Model Implementation

The model has been implemented as a new application domain in a computer system called *Emergent Designer* developed at George Mason University.
Model Implementation: Architecture
Initial Results: Experimental Settings

Network topology:

- Simple network representing an urban area encompassing several city blocks
- Consists of:
  - 65 nodes
  - 80 links
  - 25 traffic signals
# Initial Results: Experimental Settings

## Parameters and their values

<table>
<thead>
<tr>
<th>Domain Parameters</th>
<th>Value(s)</th>
<th>EA Parameters</th>
<th>Value(s)</th>
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<td>Number of network nodes</td>
<td>65</td>
<td>Representation</td>
<td>2D cellular automata</td>
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<td>Number of network links</td>
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<td>CA rule types</td>
<td>Standard</td>
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<td>Number of traffic signals</td>
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<td>Type of EA</td>
<td>Genetic Algorithm</td>
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<td>Traffic signal states</td>
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<td>Traffic Assignment</td>
<td>O-D Table</td>
<td>Mutation rates</td>
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<td>Phase length</td>
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<td>Crossover rates</td>
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<td>Fitness</td>
<td>Number of vehicles leaving the affected area or total travel time</td>
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<td>Termination criterion</td>
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Initial Results

Optimization of evacuation scenarios based on 2D cellular automata – 35% reduction of the total travel time
Initial Results: Scenario Visualization
Initial Conclusions

• Only preliminary results presented
• Model of the self-organizing traffic management hazard response system presented
• Architecture of the system implementing the model described
• The system was used to validate the efficiency of the proposed model on a simple network
Initial Conclusions

• Initial results are promising
  – The proposed model generated feasible traffic management strategies
  – Optimization method based on evolutionary algorithms was able to produce significant improvements in the performance of traffic management system

• But … still a lot of work remains to be done in order to fully estimate the true potential of the proposed approach
Future Work

Evaluation of the proposed approach using other examples of transportation networks with greater simulation realism:

– More complex traffic control systems
– Introduction of 1D CA models of vehicle movements
– Incorporation of pedestrian traffic into the evacuation scenarios