Model of a Self-Organizing Traffic Management Hazard Response System[1]

R. Kicinger[1] and M. Bronzini[2]

[1]Department of Civil, Environmental and Infrastructure Engineering, George Mason University, 4400 University Drive, MS 4A6, Fairfax, VA, 22030; PH (703) 993-1658; FAX (703) 993-1521; email: rkicinge@gmu.edu
[2]Department of Civil, Environmental and Infrastructure Engineering, George Mason University, 4400 University Drive, MS 4A6, Fairfax, VA, 22030; PH (703) 993-1504; FAX (703) 993-1521; email: mbronzin@gmu.edu

Abstract

The terrorist attacks of September 11, 2001 and afterwards have caused renewed interest in developing effective policies and strategies for evacuating densely populated areas. The large-scale evacuations caused by Hurricane Katrina and other recent hurricane events have reinforced this need. Unfortunately, the current analytical tools for dealing with such evacuations are sorely lacking, in both theory and practice. The model and its computational implementation presented in this paper attempt to close this gap and make significant progress in traffic management and hazard response systems.

The overall goal of this research is to develop a fundamental understanding of the evolutionary and emergent behavior of transportation systems that are operating under emergency evacuation conditions. Initial ideas on building conceptual models of evacuation scenarios utilizing cellular automata, evolutionary computation, and advanced traffic simulators were presented in the authors' previous paper. This paper describes computational implementations of proposed conceptual models. It also discusses preliminary results of several computational experiments in which the models were used to determine robust configurations of traffic control systems operating under emergency conditions. In these experiments, optimal evacuation strategies were sought for vehicles located within a representative urban area affected by various types of terrorist attacks.

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Introduction

Transportation systems that are operating under emergency evacuation conditions exhibit behavior that is substantially different from typical modes of transportation systems' operations. Hence, novel approaches are required to model, analyze, and optimize the performance of such systems. Three hypotheses drive this research:

1. 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 often make decisions with little or no knowledge of the impacts of their decision on the performance of the overall system.
2. The emergent behavior of the system and its subsystems is of great interest for finding effective technology and policy approaches to improving performance.
3. Systems operating in crisis mode exhibit self-organizing behavior, so finding optimal operational strategies involves understanding and capitalizing on this attribute.

Agent-based models, with their use of individual agents following localized decision rules for interacting with other agents and the environment, appear to offer a powerful approach to capturing the many interactions in transportation systems. On the other hand, cellular automata (CAs) have been successfully used to model self-organization phenomena in various biological, chemical, and man-made systems. Hence, they offer an enormous potential for developing a new class of models of emergent behavior for traffic management and hazard response systems.

When such models are found, they can be subsequently used by transportation engineers to create effective operational strategies for robust hazard response systems. Evolutionary algorithms (EAs) can be used to identify optimal CA models in the vast solution spaces, i.e., they act as search and optimization mechanisms. They can also be employed to adapt and fine-tune solutions to specific types of transportation systems, geographical locations, etc.

Conceptual Model of a Self-Organizing Traffic Management Hazard Response System

The conceptual model of a self-organizing traffic management system was proposed in (Bronzini and Kicinger 2006). In this section, a brief description of the model and its assumptions is provided in order to facilitate the discussion of its implementation presented in the remainder of the paper.

In the model of a self-organizing traffic management hazard response system, two-dimensional cellular automata (2D CAs) (Wolfram 1994) are used to model emergent behavior of transportation systems operating under emergency conditions. Figure 1 shows a simple example of the application of this model in which the configuration of states of traffic signals within several city blocks is represented as a 2D CA. The spatial (north-south-east-west) relationships among elements of the traffic control system and their relative distances (1 block away, 2 blocks away, etc.), are represented explicitly as by cells of a 2D CA (see Figure 1b).

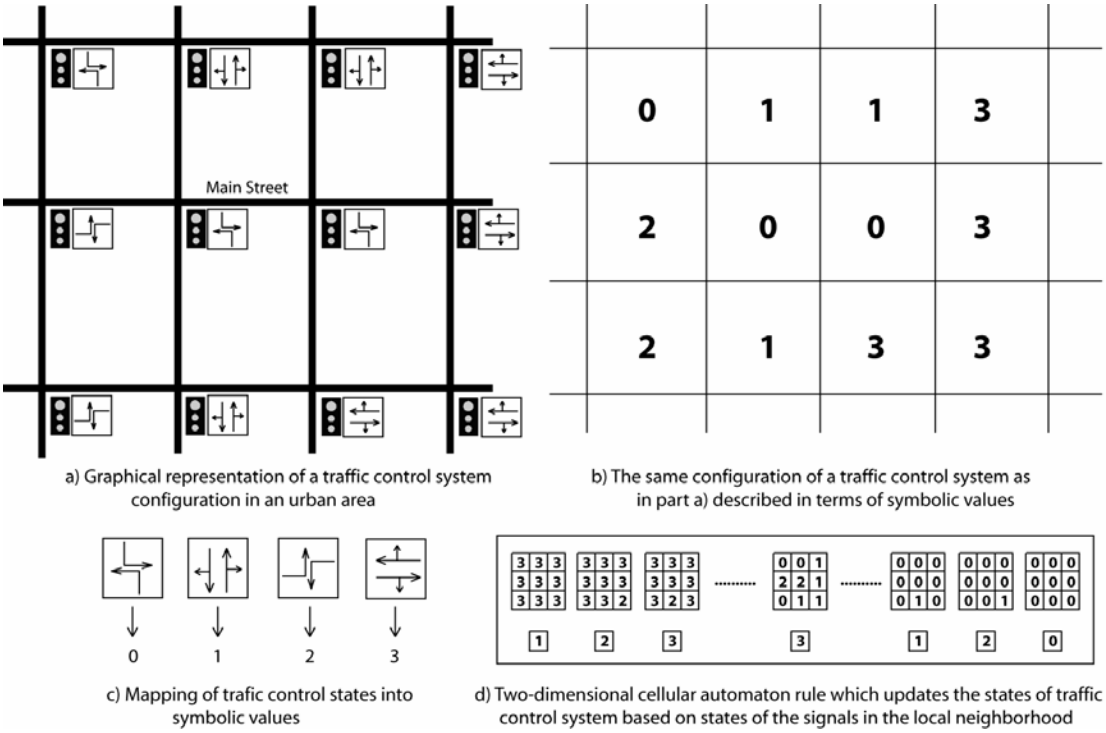

Figure 1. Simple model of an urban traffic control system based on two-dimensional cellular automata.

Individual states of traffic signals can be easily represented by discrete values of a cellular automaton as shown in Figure 1c. Here, four possible states of traffic signals are encoded as integer values 0-3. Finally, a 2D CA rule presented in Figure 1d is used to update the state of each traffic signal in this network based on the states (values) of traffic signals located in its local neighborhood. The value shown in the bottom row of Figure 1d defines the state of this traffic signal at the next phase. The advantage of such representation is that range and directions of local interactions among elements of an urban traffic control system can be explicitly modeled.

In the course of traffic simulation, the configurations of traffic signals are updated multiple times using multiple iterations of a 2D CA rule. Each iteration of the rule uniquely defines the states of all traffic signals at a specific simulation time period.

Because one of the goals of this research is to identify optimal evacuation strategies for a given urban area, cellular automata representations of traffic control systems are optimized by evolutionary algorithms. The goal is to find optimal initial configurations of states of a traffic control system as well as optimal 2D CA rules which update these states during an evacuation process, so that the number of vehicles that leave the affected area is maximized and their travel time is minimized. The actual implementation of this simple model is presented in the following section.

Model Implementation

The conceptual model of a self-organizing traffic management system proposed in (Bronzini and Kicinger 2006) and briefly described in the previous section was implemented in a computer system called Emergent Designer (Kicinger et al. 2005). It is an integrated research and design support tool which utilizes models of complex systems, including cellular automata and evolutionary algorithms, to represent engineering systems and the related design processes.

In order to verify the usefulness of the proposed model, a new application domain, i.e., traffic simulation, was added to Emergent Designer as shown in Figure 2. A cellular automata representation of a simple traffic network in an urban area was developed and combined with an evolutionary algorithm (for more detailed description see (Bronzini and Kicinger 2006)). Solutions generated by this evolutionary design process consisted of initial configurations of traffic signal states and 2D CA rules which updated the configurations of traffic signals at multiple phases of the traffic simulation process. These symbolic solutions were first translated into a traffic simulation file (a TRF file in this case) and subsequently executed by CORSIM, an advanced mezoscopic traffic simulator which was integrated with Emergent Designer. CORSIM simulated the movement of vehicles in the affected urban area and provided two measures of effectiveness, i.e., the number of vehicles which left the affected area during the course of simulation as well as the total travel time of vehicles in the affected area, through its output file. These measures provided feedback for an evolutionary algorithm and defined the quality, or fitness, of solutions, produced during the evolutionary design process.

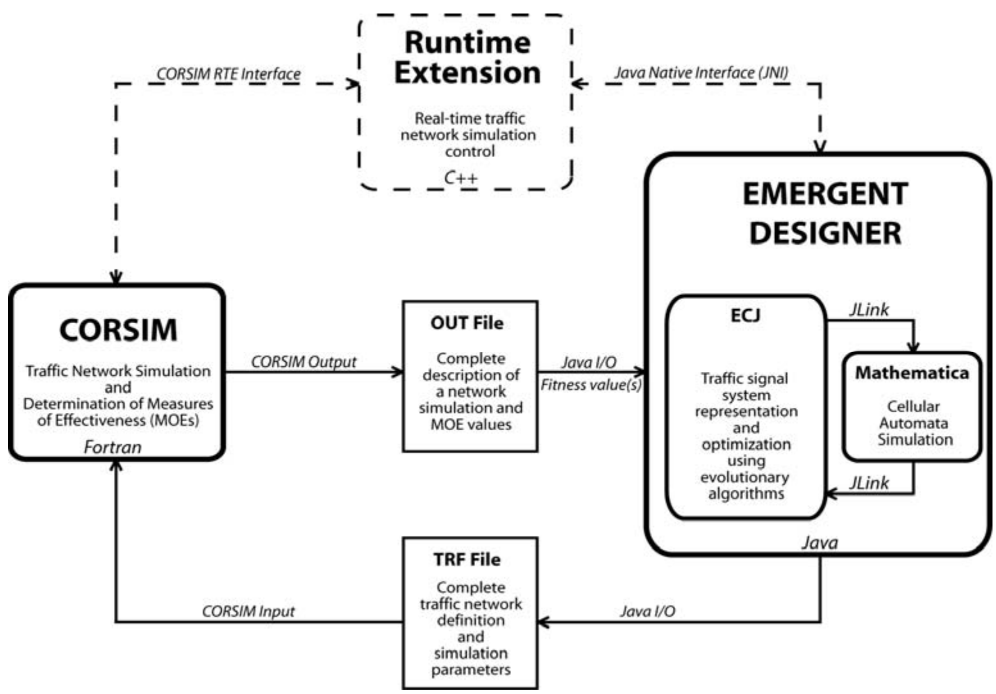

Figure 2. Implementation of the traffic simulation domain within Emergent Designer.

Due to limitations of the current version of CORSIM (TSIS 5.1), the entire process of updating traffic signal states at various phases of simulation was encoded within TRF files in terms of multiple time periods. In the future, this approach will be replaced by direct communication with CORSIM Runtime Extension (RTE) as shown in the upper part of Figure 2.

Initial Results

Initial computational experiments with the proposed self-organizing traffic management hazard response system focused on determining the feasibility of the model and comparisons of its efficiency with other traffic control strategies. In order to achieve these goals, a simple transportation network of an urban area spanning several city blocks of, e.g., Washington, DC, was developed as shown in Figure 3. Several simulation runs were performed to identify effective evacuation strategies for this urban area. The progress of evolutionary design processes was determined by calculating the percentage improvements in the number of vehicles which left the affected area during the course of simulation as well as in minimizing the total travel time of vehicles located in the affected area.

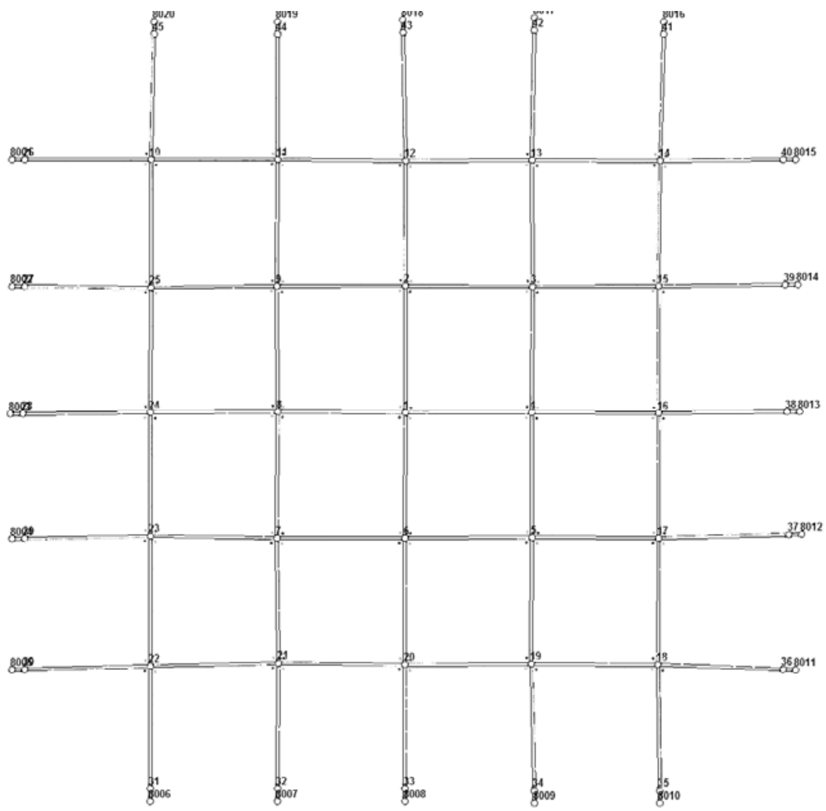

Figure 3. Simple model of a transportation network in an urban area used in initial computational experiments.

Table 1 shows the values of domain and evolutionary computation parameters used in the initial computational experiments reported in this paper.

Table 1. Parameters and their values used in the reported experiments

Domain Parameters	**Value(s)**	**EA Parameters**	**Value(s)**
Number of network nodes	*65*	Representation	*2D cellular automata*
Number of network links	*80*	CA rule types	*Standard*
Number of traffic signals	*25*	Type of EA	*Genetic Algorithm*
Traffic signal states	*2 (corresponding to combined states 0-1 and 2-3 in Figure 1c)*	Population size	*10*
Traffic Assignment	*O-D Table*	Mutation rates	*0.05*
Phase length	*30s*	Crossover rates	*0.8*
Simulation time	*420s*	Fitness	*Number of vehicles leaving the affected area or total travel time*
		Number of runs	*3*
		Termination criterion	*1,000 fitness evaluations*

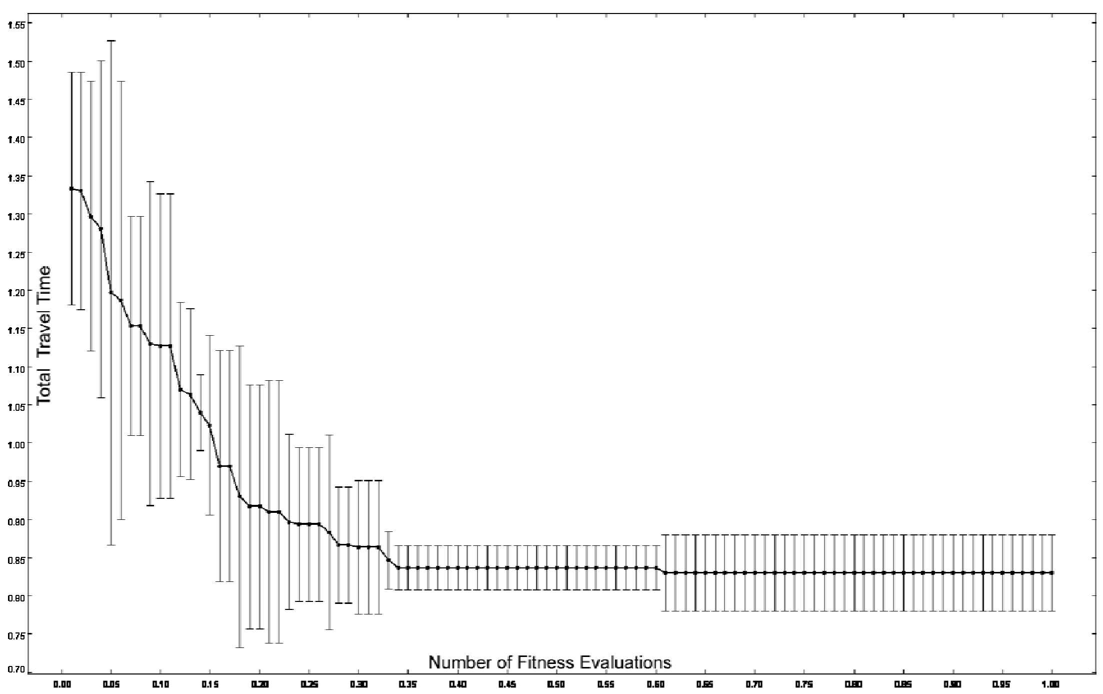

Figure 4. Minimization of the total travel time of vehicles located in the affected urban area obtained by 2D cellular automata models of traffic control systems evolved by evolutionary algorithms.

Figure 4 presents initial results of computational experiments described in Table 1. It shows a gradual improvement of generated 2D cellular automata models of traffic control systems measured by the total vehicle travel time in the affected urban area as a function of the number of fitness evaluations (a measure of an evolutionary progress). The vertical bars represent 95% confidence intervals of mean best-so-far values presented in this graph. Figure 4 shows that the approach presented in this paper is feasible and significant improvement in reducing the total travel time can be achieved. In this specific case, a 35% reduction of total travel time was achieved between initial solutions generated by an evolutionary algorithm and final solutions produced at the end of evolutionary design processes.

Initial Conclusions and Future Work

In this paper, a computational implementation of a self-organizing traffic management hazard response system was discussed and the architecture of a computer system which implements it was presented. It was shown on a simple transportation network that the proposed model and its computer implementation can be effectively used to find evacuation strategies for a representative urban area. On the other hand, the conducted research has also revealed some limitations of existing traffic simulation software.

Even though the initial results are promising, much work remains to be done in order to more comprehensively evaluate the usefulness and efficiency of the proposed approach. First, other examples of transportation networks need to be developed and tested in order to identify more reliably the strong and weak points of this model and the points where greater simulation realism is needed. Next, the complexity of the simulations needs to be expanded in at least three directions: more complex traffic control systems; introduction of one-dimensional CA models of vehicle movements (replacing some elements of the vehicle system simulation); and incorporation of pedestrian traffic into the evacuation scenarios.

References

Bronzini, M., and Kicinger, R. "Conceptual model of a self-organizing traffic management hazard response system." *Compendium of Papers CD-ROM Transportation Research Board 85th Annual Meeting, Washington, DC, January 22-26, 2006*, Washington, DC.

Kicinger, R., Arciszewski, T., and De Jong, K. A. (2005). "Emergent Designer: An integrated research and design support tool based on models of complex systems." *International Journal of Information Technology in Construction*, 10, 329-347.

Wolfram, S. (1994). *Cellular automata and complexity: collected papers*, Addison-Wesley, Reading, MA.