An Agent-Based Self-Organizing Traffic Environment for Urban Evacuations

(Extended Abstract)

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CCS Concepts

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1. INTRODUCTION

Traffic congestion has many negative effects on our daily lives, the economy and the environment. These effects get worse in critical situations (e.g., emergency urban evacuations) when human lives are at risk. As smart cities are becoming a reality, technologies known as Intelligent Transportation Systems (ITS) have been considered as viable solutions for the many negative effects of congestion.

Several ITS strategies for urban evacuation have been investigated. Among these strategies, researchers and practitioners have proposed the use of road reversal operations as a mean to efficiently utilize the traffic network capacity in critical times [4, 14, 11, 13, 12, 6, 7, 8]. Although road reversal operations have shown an improvement in traffic flow management, the proposed approaches are based on the execution of mathematical models to identify upfront, optimal road-reversal settings for the entire evacuation process. Even though these approaches have shown an improvement in traffic flow, to the best of our knowledge and according to a study conducted by Wang et al. [9], none of these strategies considers the time needed to implement a safe road reversal operation.

In addition to road reversal strategies, several studies have investigated the use of *zoning* strategies to manage evacuation operations [5, 10]. A zoning strategy is based on dividing the traffic environment into small areas called zones. Traffic within each zone is directed towards safe destinations based on priorities or a phased evacuation plan. To this end, the emergency type is used to determine the optimal number of zones needed for the entire evacuation process as well as the size of each zone. However, these fixed parameters do not reflect the highly dynamic feature of traffic which might require a redefinition of the number of zones and their sizes.

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In this paper, we present a self-organizing traffic model that integrates the use of road-reversal operations and zoning strategies for the implementation of a dynamic, self-organizing traffic network for urban evacuation. The self-organizing traffic model has been implemented and validated in MATISSE 2.0 [3], a large-scale multi-agent based traffic simulation platform.

2. A SELF-ORGANIZING MODEL FOR URBAN TRAFFIC EVACUATIONS

The model presented in this section is defined in the context of the Agent-based Transportation System (ATS) model[15]. ATS is a multi-layered, integrated ITS which consists of *micro-* and *macro*-level agent-based elements; micro-level elements include *vehicles* and *traffic devices* and macro-level elements consist of specialized agents called *zone* and *traffic managers*. A *zone manager* is responsible for informing, monitoring, and guiding micro level agents to ensure that micro-level behaviors and interactions are consistent with the global system behavior. A *traffic manager* identifies appropriate global traffic management strategies.

In order to manage the traffic environment efficiently, the traffic manager partitions the environment into small areas called *zones*. Each zone has one evacuation exit and is assigned a zone manager. The zone boundaries are initially set in such a way that the traffic is evenly distributed across zones. Figure 1 illustrates a scenario where the traffic environment is initially partitioned into three zones around evacuation exits.

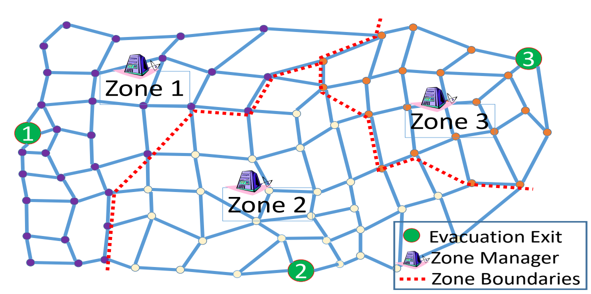

Figure 1: Partitioning the environment into zones

In ATS, self-organization of traffic occurs within and across zones:

1. Self-Organization Within the Traffic Zone: Each zone manager defines and implements a road reversal plan for major evacuation roads within its zone. The purpose of this plan is to utilize the available network capacity and maximize the traffic flow toward the evacuation exit.

Although road reversals toward the evacuation exit lead to a better utilization of the network capacity, it might result in a rigid traffic network topology that cannot cope with highly dynamic traffic scenarios. To avoid this situation, the zone manger defines a road reversal configuration that preserves a flexible traffic network within its zone. This flexibility allows the zone manager to dynamically diverts the traffic flow between major evacuation routes to alleviate any congestion related to unexpected events (e.g, accidents). In addition, the zone manager ensures that the reorganized network topology contains an inbound route that can be used by vehicles to reach a neighboring zone in case the evacuation exit becomes unreachable.

For instance, Figure 2 shows a traffic environment with three evacuation zones. In this example, the roads marked with green triangles refer to the reversed roads. The presence of red nodes in the network indicates the existence of bidirectional roads that can be used to dynamically reorganize the traffic network. For example, the route marked in red in $zone_3$ is highly congested. Meanwhile, the neighboring route marked in orange has a medium congestion level and the other neighboring route marked in dashed green has a low traffic density. As such, the traffic flow is diverted from each node in the red route to its connecting node in the dashed green route. The traffic diversion operation continues until the traffic densities are balanced between the two routes. Finally, we can notice that the roads marked in double solid black lines are kept as backup bidirectional roads that can be used by vehicles to reach neighboring zones.

It is important to note that the actual implementation of a road reversal operation is a complex process that requires collaboration between intersection control agents. Detailed information on these processes can be found in [1, 2].

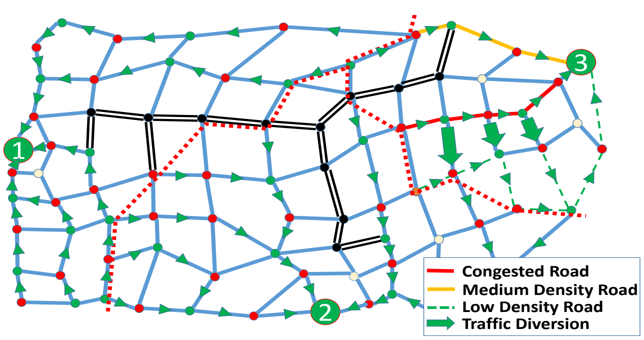

Figure 2: Self-Organization Within the Traffic Zone

2. Self-Organization Across Traffic Zones: The traffic manager periodically receives information from zone managers about traffic densities in their zones. In case one of the zone managers can no longer evacuate vehicles effectively due to unexpected conditions, the traffic manager dynamically reorganizes the zones' boundaries to improve the overall evacuation efficiency.

For example, Figure 3 illustrates a scenario where $zone_2$ becomes highly congested and $zone_3$ is the neighboring zone with the minimum traffic density. In this scenario, the traffic manager adjusts $zone_3$ boundaries to the solid black line depicted in Figure 3 and transfers all roads attached to the boundary nodes from $zone_2$ to $zone_3$. Upon receipt of the new roads, the zone manager at $zone_3$ reorganizes the new roads within its zone according to the same strategy described earlier. Hence, four new roads (marked with blue triangles in Figure 3) are marked for reversal toward exit 3, while the other new roads are kept bidirectional.

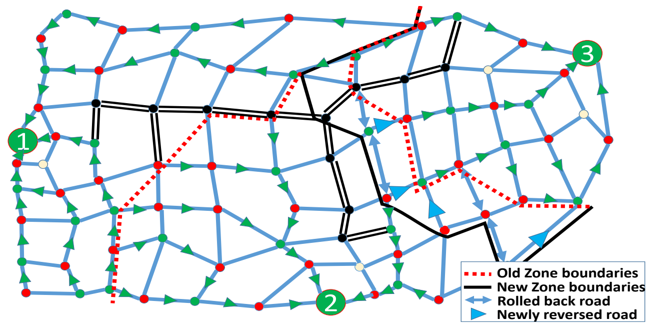

Figure 3: Self-Organization across zones

3. CASE STUDY: URBAN TRAFFIC EVACUATION SCENARIO

The self-organizing model has been fully implemented and tested in MATISSE 2.0. The case study takes place in a virtual traffic network that consists of 384 road segments and 63 intersection. Also, four safe evacuation exits are specified at the outskirt of the traffic environment and are used to evacuate vehicles in case of emergencies.

In this experiment, vehicles drive randomly in the traffic environment when an external event related to an emergency siren is triggered. Each vehicle attempts to reach the evacuation exit in its zone. After 500 simulation cycles, two explosions are triggered close to evacuation exits 2 and 4. These explosions cause full road closures for all roads attached to these exits.

We didn't compare our work with other road reversal approaches as they fail to cope with the presented scenario. Road reversal configuration in these approaches will result in a rigid network configuration where most of the roads within zone 2 and 4 are reversed toward the evacuation exit. This will cause vehicles within zone 2 and 4 to stuck and will not be able to find any alternative route to reach evacuation exit points in other zones. On the other hand, the self-organizing model presented in this paper is able to handle such scenario and all vehicles are able to evacuate the environment.

4. CONCLUSIONS

In this paper we presented an agent-based self-organizing traffic model which integrates dynamic lane reversal and zoning strategies. We have implemented this model using MATISSE 2.0, a large scale agent-based traffic simulation system. The experimental results show that the proposed model successfully self-organizes the traffic network dynamically to cope with highly dynamic traffic conditions.

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