An Intelligence-based Framework for Post-Event Management of Transportation Systems

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Problem Statement

"Transportation systems are very sensitive to external disturbances" [1]

How to improve Urban Road Networks' resilience by combining:

Geographical Information Systems, Graph Theory, Social Networks, microscopic simulation, Data Mining, and Vehicular Ad Hoc Networks to recover from different events

Urban road networks; Road network Resilience; GIS; Traffic simulation; Microscopic simulation; Integrated GIS; Data Mining; Vehicular Ad Hoc Networks; Events

Defining the Scope of Work

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What is our Goal?

Assist *decision makers* in **analyzing** the effects of the occurrence of different events on transportation systems and in **absorbing** these effects efficiently to restore the functionality of those transportation systems.

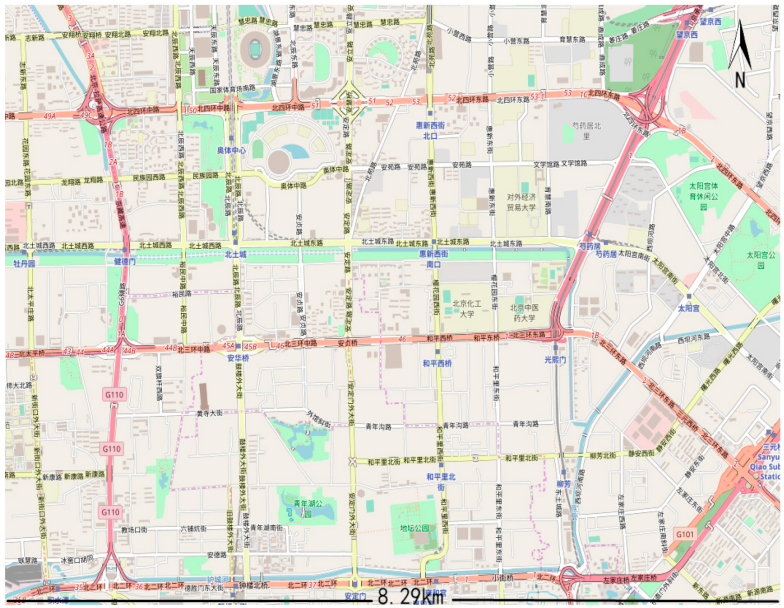
What is the data we are planning to use?

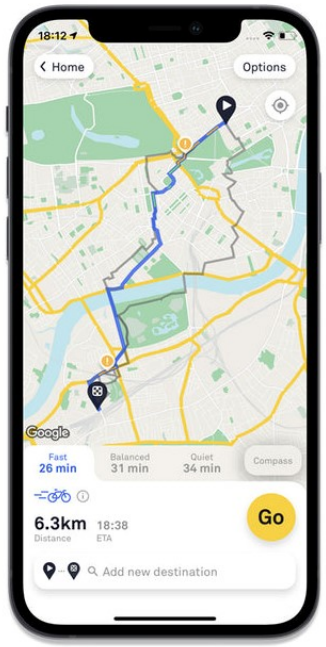
Main:

- Road networks
- Traffic

Additional:

- Historical
- Real-time events





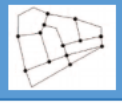
Approach

The proposed approach has two phases,:

- In the first phase, we do structural analysis using **GIS**, **graph theory**, **social network analysis**, and **traffic simulation** to extract a criticality index (CI) representing the criticality of different links (roads)
- In the second phase, we integrate **VANETs** and **Data Mining** for decision making to deal with events by taking into consideration the functionality of the whole network mainly considering the calculated CI

Map Transformation to Graph Module

Graph



Indices Selection by Relativeness

Congestion (Cg)

Between-ness (Be)

Community Links (Cl)

Community Detection

Flow (Fl)

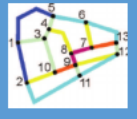
⋮

Original Map

Different Indices Determination Module

Criticality Index Calculation Module

Weighted Graph



VANET Addition for V2X communication and Decision making

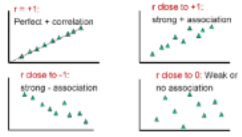
Assign Weights to Indices

$CI_i = \alpha Cg_i + \beta Fl_i + \delta Be_i + \dots$

Calculate Criticality Index (CI) matrix

Simulate removal of links

Study Correlation Between Total Trip Time after Link Removal and calculated CI

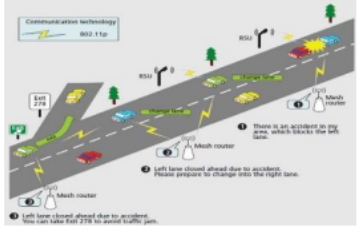


Acceptable Correlation?

No

Yes

In normal VANET with Data Analysis use case if an accident is detected the incoming cars are redirected by RSUs to closest alternative routes.

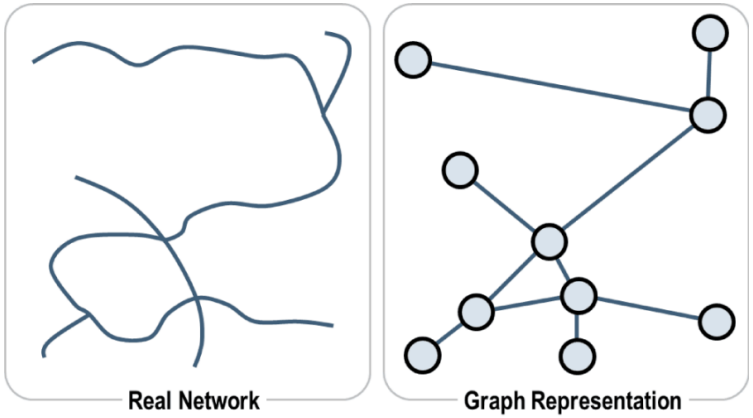


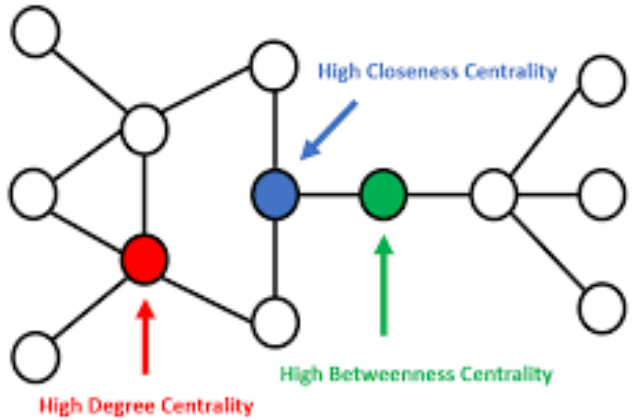
+ CI

Considering the CI index rerouting decisions will consider the functionality and efficiency of the whole system.

Structural analysis

- Transform road network into graphs and extract different *indices*
- Introduce a mathematical model to represent *criticality* of links (roads)





Link Criticality Analysis - State of Art

An assessment method for highway network vulnerability [2]

- introduces a methodology to assess the level of vulnerability of road transport networks
- using *fuzzy logic* to combine vulnerability attributes with different weights **into a single vulnerability index** for network links
- *exhaustive search technique* is then employed to **identify the optimal weight contribution** of each fuzzified attribute

Link criticality Analysis - State of Art

- studied the correlation between *VI* and *RTTpT* after link removal using different weights
- used **OmniTrans** which does not allow dynamic route-choice modelling
- links with high *VI* and low *RTTpT* were recorded and associated with unsatisfied demand

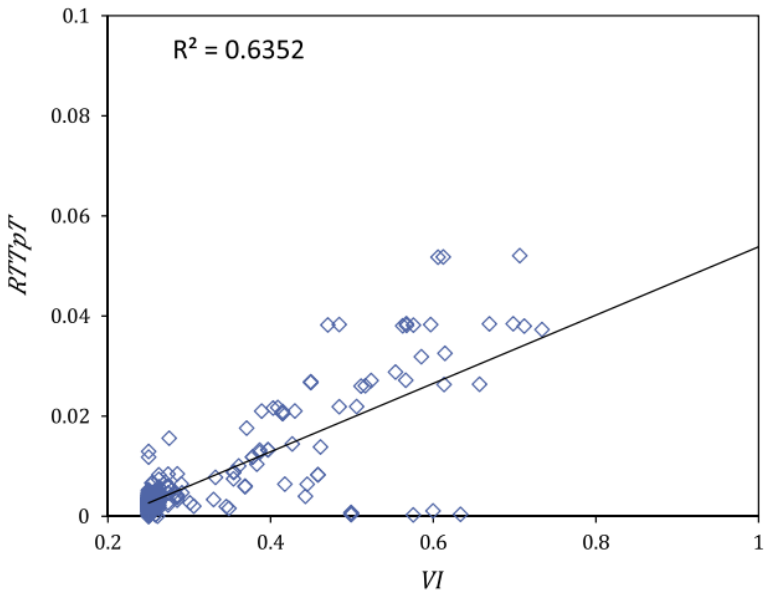


Fig. 5. Vulnerability Index and *RTTpT* for all links.

Link criticality Analysis - State of Art

Detecting critical links of urban networks using cluster detection methods [3]

"A network link is considered critical if loss of it significantly diminishes the integrity or functionality of the network"

- *Integrity* of the network is measured by the relative size of the giant component and *functionality* of the network is measured by the temporal network efficiency
- Used **Infomap** for community detection
- Showed that links connecting neighboring clusters are the most critical links of the network and the second indicator is betweenness.

Link criticality Analysis - State of Art

- *Link-level vulnerability indicators for real-world networks [4]*
- *Urban Transportation Networks Resilience: Indicators, Disturbances, and Assessment Methods [5]*
- *The role of travel demand and network centrality on the connectivity and resilience of an urban street system [6]*
- *Integration of stress testing with graph theory to assess the resilience of urban road networks under seismic hazards [7]*
- *Determining Critical Links in a Road Network: Vulnerability and Congestion Indicators [8]*

Integrating Traffic Simulation

In order to evaluate CI we propose

- Simulating the normal (base) case where cars are flowing naturally without road blockages
- Analyzing the effect of "critical link"'s blockage on the overall flow of the traffic simulation

Integrating Traffic Simulation - State of Art

"Traffic simulation models can capture the complex dynamics of transportation networks by using limited available traffic data and can help central traffic authorities in their decision-making, if appropriate input is fed into the simulator." [9]

- *Integrating GIS and Microscopic Traffic Simulation to Analyze Impacts of Transportation Infrastructure Construction [10]*
- *Flood Impacts on Road Transportation Using Microscopic Traffic Modelling Techniques [1]*
- *Investigating the Effects of Pluvial Flooding and Climate Change on Traffic Flows in Barcelona and Bristol [11]*

VANET and Data Mining Integration

To recover from link failures:

- Data Mining and Intelligence will allow decision makers to consider the criticality of roads when taking effective decisions.
- The resulting decisions will be implemented using VANETs which allow V2X communication.

VANET Integration - State of Art

- *REALTIME CONGESTION AVOIDANCE USING VANET [12]*
- *An approach to avoid traffic congestion using VANET [13]*
- *An experimentation of VANETs for traffic management [14]*
- *Managing Emergency Situations in VANET Through Heterogeneous Technologies Cooperation [15]*

Evaluation Parameters

Throughout our work, in order to evaluate the different algorithms, we are going to use different parameters:

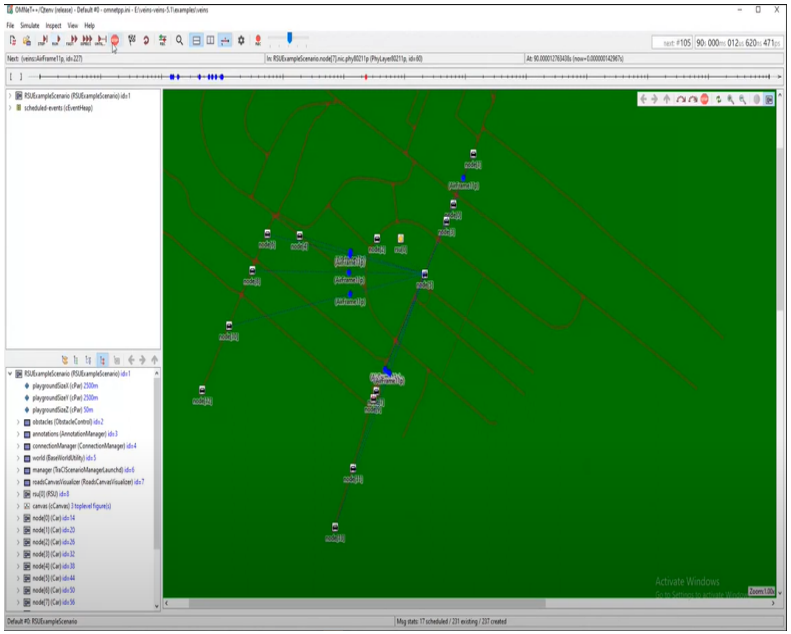
- Overall time taken for the simulation to finish with every car going from its source to its destination
- The average time taken by each vehicle to reach its destination
- The average speed of cars throughout the simulation

Implementation Options

For the implementation of this whole framework, we had two clear options:

- Either do it all from scratch.
  - we control everything
  - able to add and forgo components depending on what we need
- Using multiple widely used simulation tools and libraries
  - they have support bases where we can get help doing everything
  - professionality and trust
  - advanced and realistic

Traffic Simulation (SUMO)



VANET Network Simulation (Veins)

Implementation - State of Art

- *OSMnx: New methods for acquiring, constructing, analyzing, and visualizing complex street networks [16]*
- *Comparative Evaluation of Road Traffic Simulators based on Modeler's Specifications: An Application to Intermodal Mobility Behaviors [17]*
- *Realistic urban traffic simulation as vehicular Ad-hoc network (VANET) via Veins framework [18]*
- *Veins extensions to implement a message based algorithm for Dynamic Traffic Assignment in VANETs simulations [19]*

VANET Simulation

The advantage of using Veins in VANET simulations is the interaction between OMNET++ and SUMO that allows one to:

- Dynamically change the vehicles' behavior and route in SUMO using information disseminated by means of OMNET++ messages.
- Generate OMNET++ messages based on the vehicles' states and routes

Conclusion

In this presentation we have:

- Properly defined the Scope of Work and Problem Statement
- Presented our proposed approach combining the different fields
- Described each stage with a peek into the state of art
- Stated some evaluation parameters and simulation options

Thank You for Listening...

Questions?

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