

Model Reference Adaptive Control Framework for Real Time Traffic Management Under Emergency Evacuation

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The Idea Is Simple

- Utilize the *available network capacity* as MUCH as possible
- By comparing the difference between the *system optimal* and real-world *observations*
- And *adaptively* adjust the traffic control strategies

- Control Paradigm: “*observe, evaluate, control and advise, cyclically and frequently*”,



Emergency Evacuation

- A mass movement of people (and their properties) from disaster-impacted areas to safer ones in a timely manner to mitigate disastrous effects
- Evacuation Study
 - Disaster Type
 - Disciplinarity
 - Study Focus
 - Methodology Applied



Characteristics of Existing Evacuation Study

- Majority of Them Have Focused on Evacuation Planning
- “If this is scenario X then follow plan x ”.
- Can not Predict Real World Evacuation Scenario Very Well
- Strong Need for Real Time Traffic Management



Why Adaptive Control?

- ❑ Traditional Network Analysis Techniques, Especially the User Equilibrium, Might not Work for Modeling Real Time Traffic Management under Evacuation

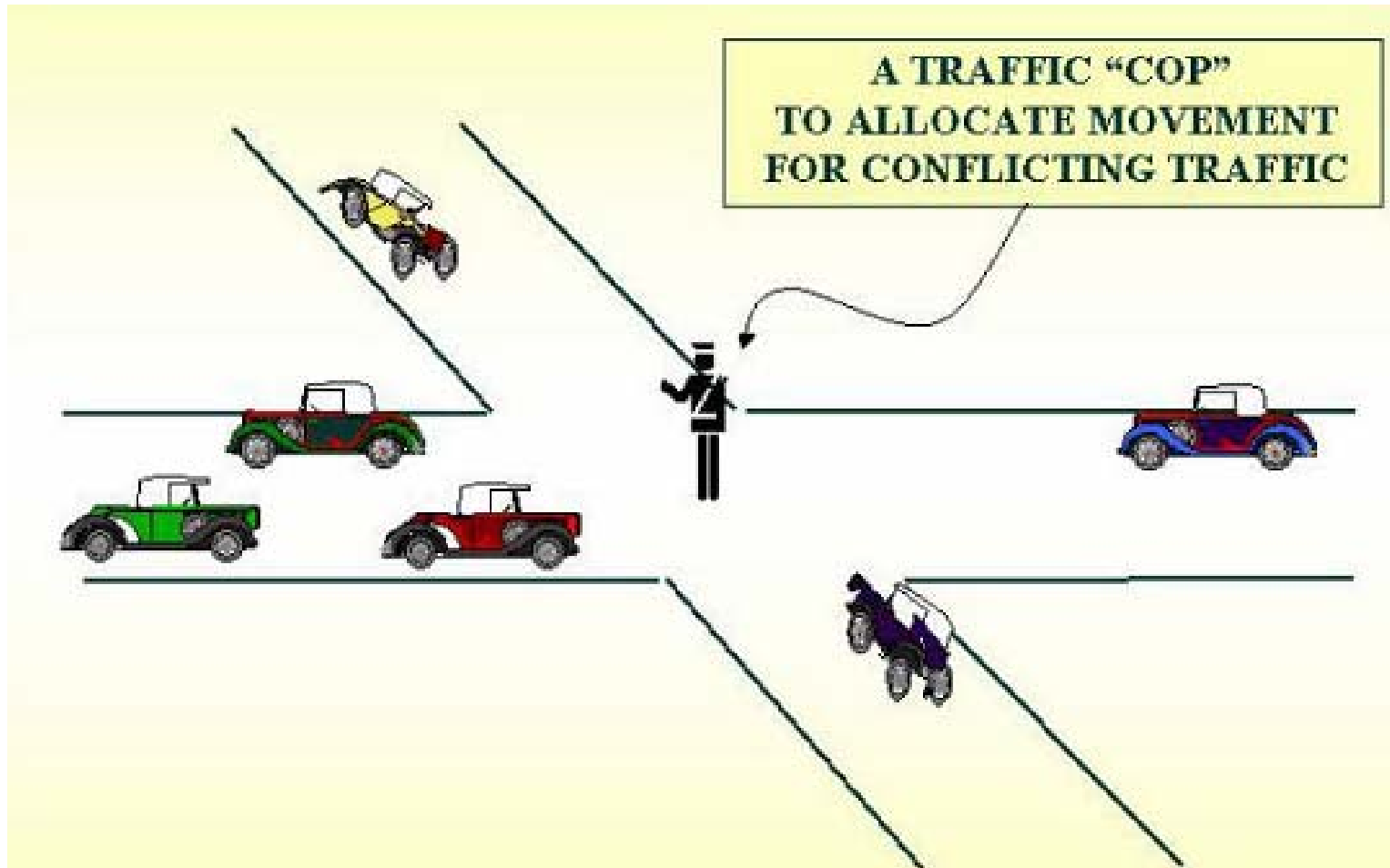
- ❑ Evacuation Is An Extreme Event and Thus Traditional Assumptions May Not Be Valid
 - Heavy OD Trips towards Safer Zones
 - Highly Dynamic
 - Highly Uncertain
 - Panic and Unpredictable Behavior



Adaptive Control for Emergency Evacuation

- ❑ Strict Traffic Control and Guidance is Desirable under Evacuation
 - Management Authority: Minimize Clearance Time and Fatalities
 - Individual Evacuee: Traffic Guidance to Evacuate as Soon as Possible
- ❑ Traffic Data Are Available
 - Existing Traffic Data Collection System
 - Emergently Deployed Sensing Devices (WSN, Mobile Sensors, etc.)
- ❑ Traffic Control Devices Are Available
 - Existing Traffic Control Devices
 - Emergently Deployed Control Devices (Officers, VMS, etc.)

Traffic Control System for Emergency Evacuation

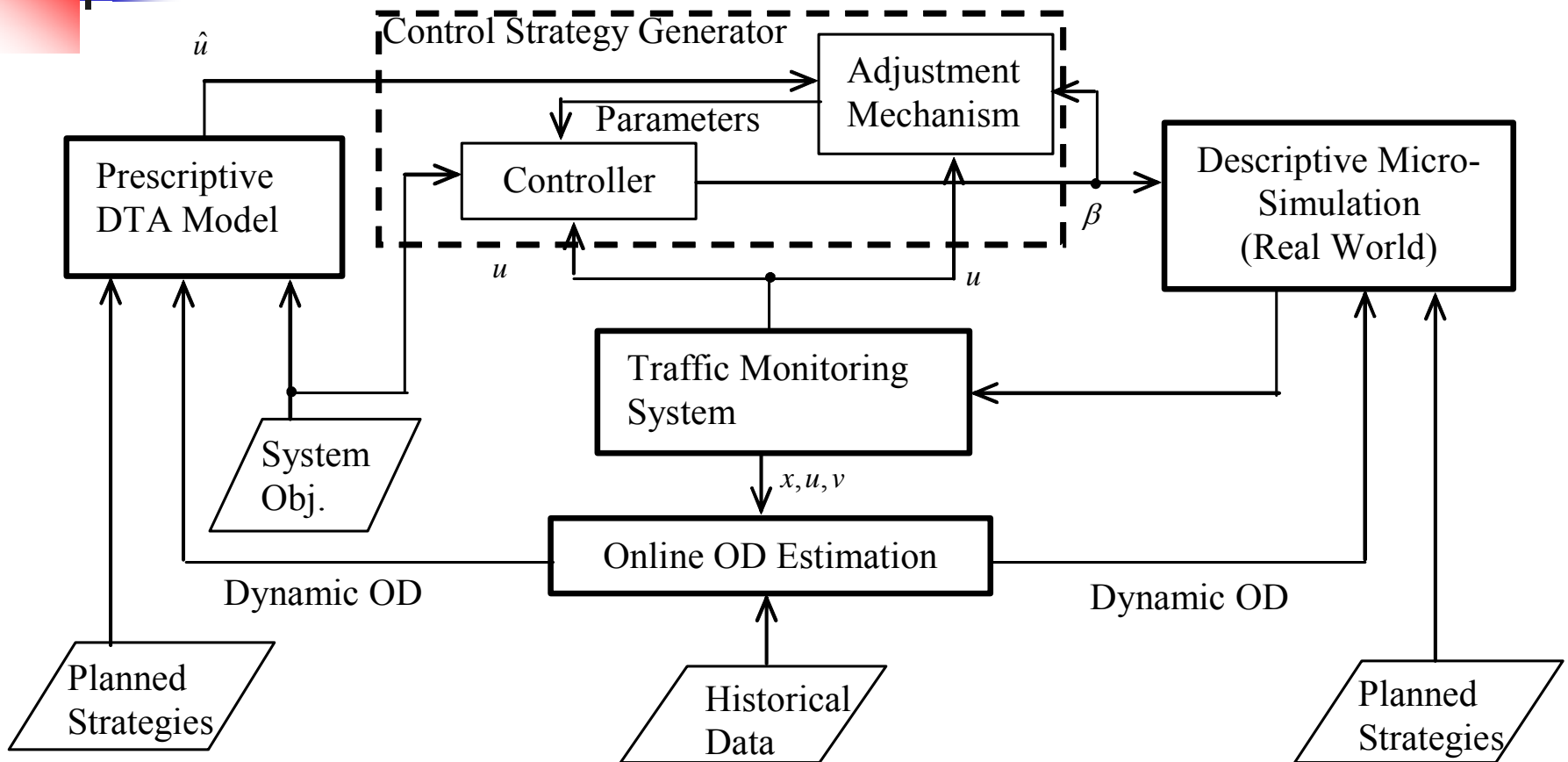




Identify Control System

- Control System/Plant/Process: Traffic Flow (and Network) under Evacuation
- System Output: link flow, inflow, and exit flow (x, u, v)
- Control Variable: Splitting rate $\beta_{a,b}(t)$ from link a to link b at time instant t .
- Feedback: Turning Movement Volume
- Adaptive Controller
 - Model Reference Adaptive Control (MRAC)
- Assumptions
 - Super Zone Concept

MRAC Based Framework



u : real time dynamic turning volume

\hat{u} : desired dynamic turning volume

β : splitting rate at intersections

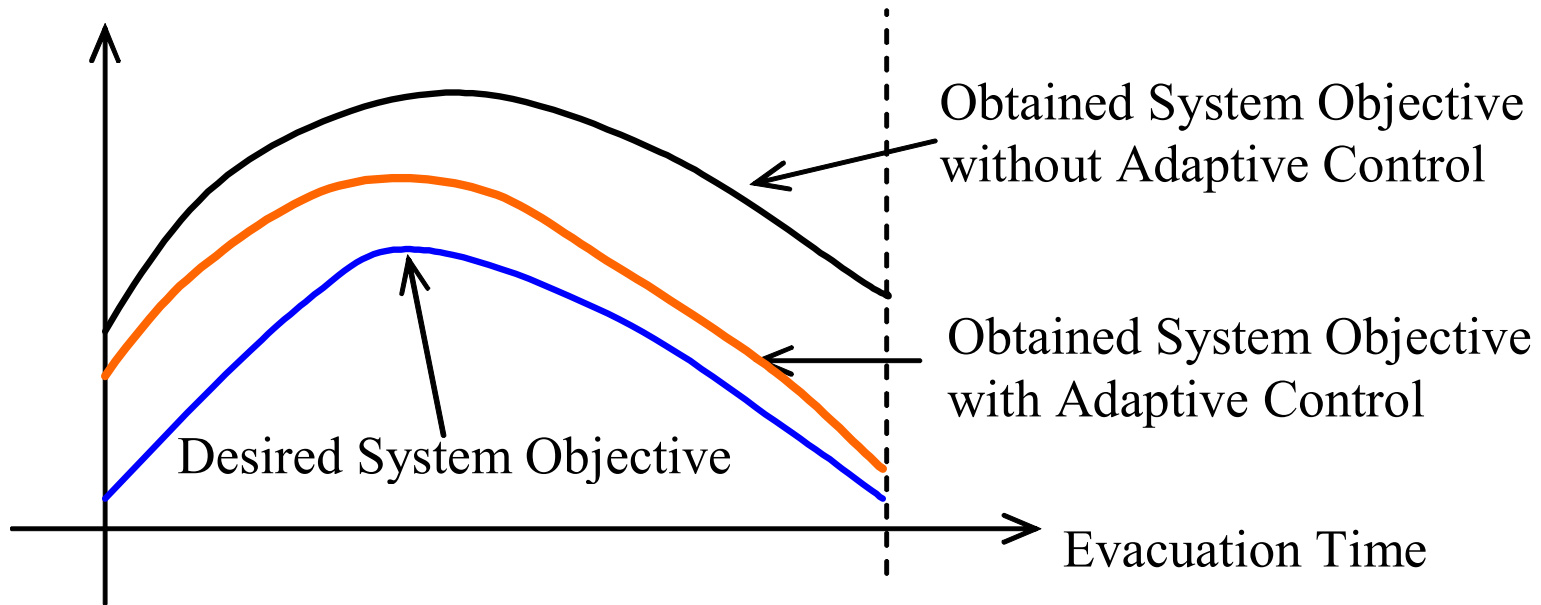


MRAC Based Framework

- Five Major Components
 - Prescriptive DTA
 - Descriptive Micro-Simulation
 - Controller
 - OD Estimation
 - Resource Allocation

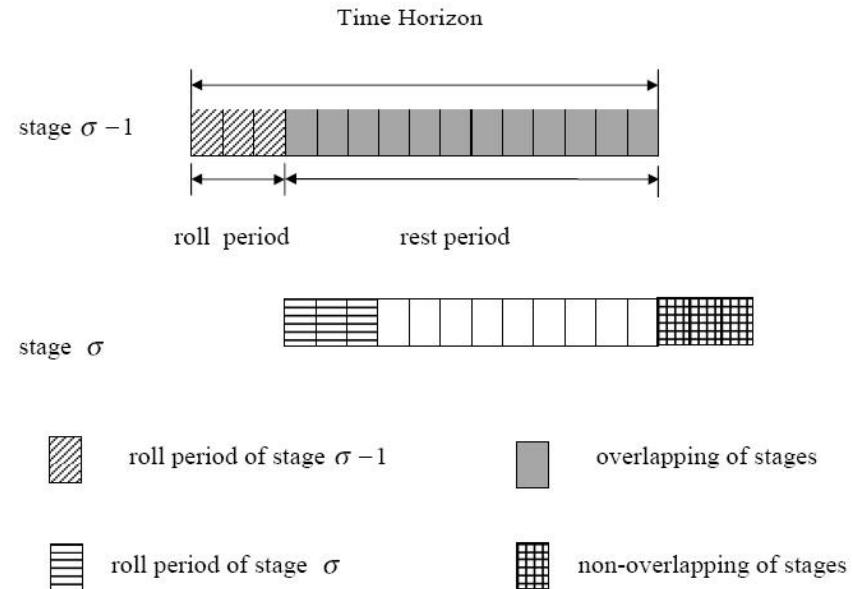
MRAC Based Framework (Con'd)

- Goal Is to Guide/Control Traffic To Achieve Certain System Objective
- Desired Performance of the Proposed Framework



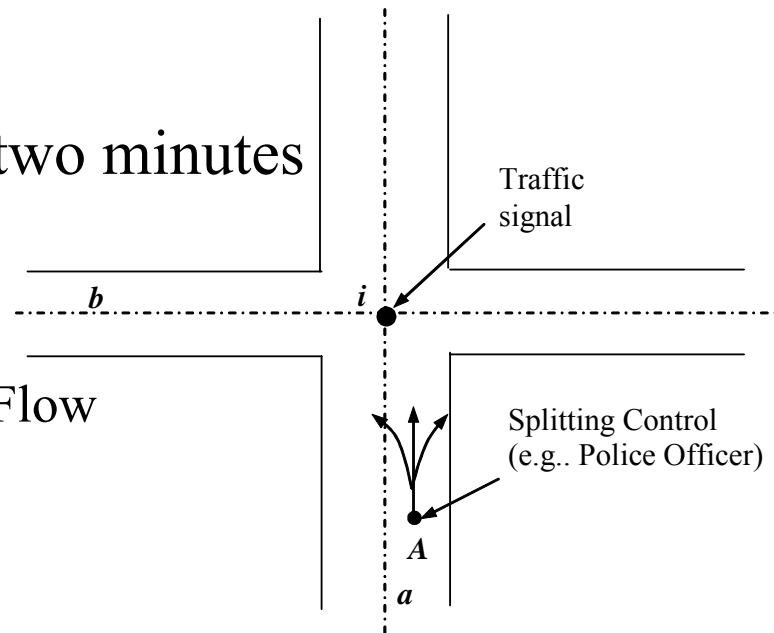
Prescriptive Dynamic Traffic Assignment

- A Prediction Model and the Reference Model for MRAS
- Produce the Desired Traffic States Based on Certain System Optimal Objective
- Runs in Short-Term and Rolling Horizon (e.g. 10 Min. as the Roll Period)
- Implementation
 - Computational Efforts is the Critical Issue
 - System Optimal Model
 - Analytical DSO Model
 - CTM-based Model
 - Other Embedded Models
 - Feed Back from Real World (Descriptive Micro-Simulation)



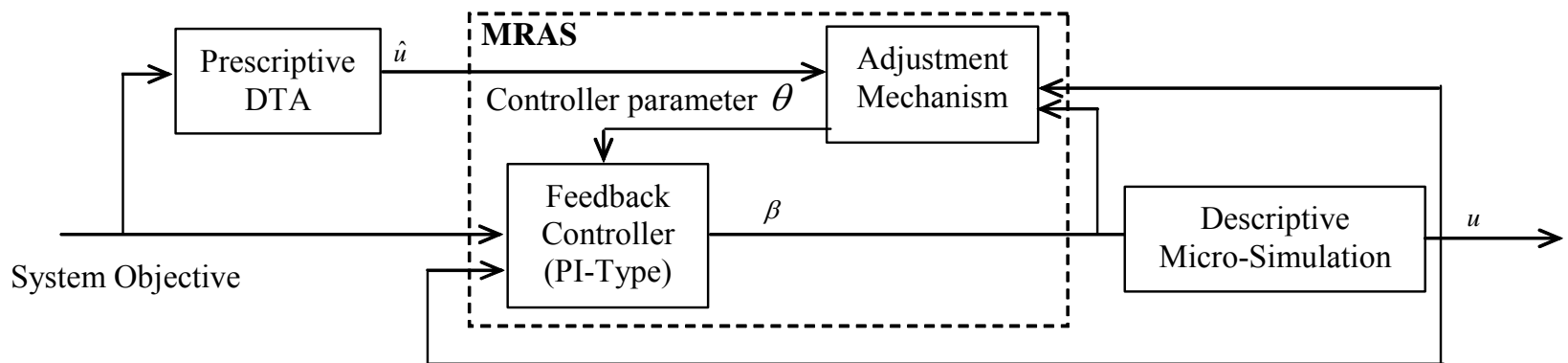
Descriptive Micro-Simulation

- Real World Traffic Evacuation Model
- Controlled by the Splitting Rate Generated by the Controller
- Microscopic Simulation (e.g. Paramics)
- Implementation Issues
 - Volume Splitting Control every two minutes
 - Signal Timing Generation
 - Turning Movement Calculated by Splitting Rate and Total Incoming Flow
 - Fixed-Cycle-Length Signal with Variable Green Splits



MRAS Design

- Adaptive Control
 - Controller with changed control parameters
 - Set point change, dynamics of the system, etc.
- MRAS Design
 - Reference model to predict the desired system states
 - Adjustment mechanism to update controller parameters periodically
 - A traditional controller (e.g. PID) to generate control strategies
- Proposed MRAS Structure





OD Synthesis

- Existing OD Generation Methods for Normal Traffic Scenarios
 - Proportional-assignment methods
 - Equilibrium-assignment methods
 - Path flow estimator (PFE)
- Existing OD Estimation Methods for Evacuation Planning
 - Based on historical data (survey) and behavior analysis
 - Two steps to generate time-dependent OD trips
 - Total OD demand generation (traditional methods)
 - Departure-time and destination choice for dynamic OD
- Online OD Updating for Real Time Traffic Management under Evacuation?
 - Super zone concept



Resource Allocation Problem

- A method to determine optimal allocation of (scarce) resources to different activities to maximize the productivity
- Why Resource Allocation in Our Framework?
 - Control devices may not be able to cover all intersections
 - How to allocate control devices such that certain system optimal objective could be achieved?
 - Traffic data collection devices may not be able to cover all intersections
 - How to allocate sensors such that certain system optimal objective could be achieved?

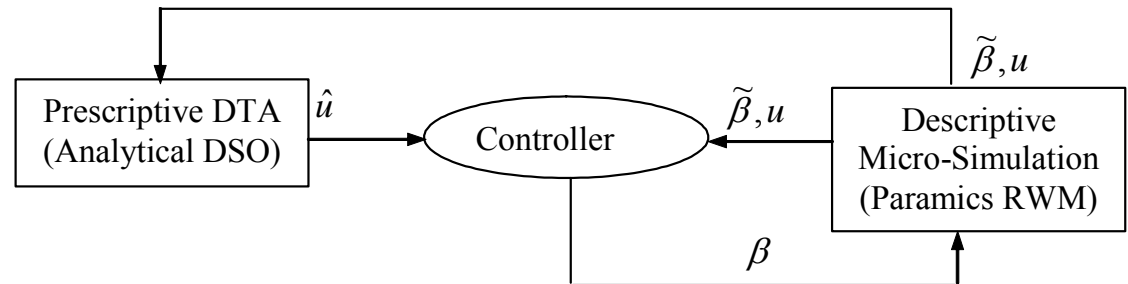
Case Study

- Additional Assumptions and Simplifications

- Perfect Sensing System
 - Perfect Control
 - Dynamic OD Trips Are Given (Ignore OD Synthesis)
- (Ignore Resource Allocation Problem)

- Three Major Components

- Prescriptive DTA
- Descriptive Micro-Simulation
- Controller



$\beta, \tilde{\beta}$: control and actual splitting rate vector, respectively

\hat{u}, u : desired and actual traffic states, respectively

DSO: dynamic system optimal

RWM: real world model



Case Study (Con'd)

- Prescriptive DTA
 - Implemented Using Analytical DSO Model
 - Dynamic System Optimal is Adopted
 - Short Term Implementation – 10 minutes
 - Rolling Horizon Implementation
 - Roll Period: 10 minutes
 - Time Horizon: 1 hour

Prescriptive DTA

- DSO with Minimizing Total Travel Time

$$\min \sum_{k=1}^{K'} \sum_{a \in A} x_a(k) \tau_a(k)$$

$$st. x_{as}(k+1) - x_{as}(k) = u_{as}(k) - v_{as}(k), \quad \forall a, s, k \longleftarrow \text{Mass Balance}$$

$$\sum_{a \in A(j)} u_{as}(k) = d^{js}(k) + \sum_{b \in A(j)} v_{bs}(k), \quad \forall j, s, k; j \neq s \longleftarrow \text{Flow Conservation at Nodes}$$

$$u_{as}(k) = v_{as}(k + \hat{\tau}_a(k)), \quad \forall a, s, k \longleftarrow \text{Flow Propagation}$$

$$u_{as}(k) \geq 0, v_{as}(k) \geq 0, x_{as}(k) \geq 0, \quad \forall a, s, k \longleftarrow \text{Nonnegativity Constraints}$$

$$x_a(k) = \sum_{s \in S} x_{as}(k), u_a(k) = \sum_{s \in S} u_{as}(k), v_a(k) = \sum_{s \in S} v_{as}(k), \quad \forall a, k \longleftarrow \text{Definitional Constraints}$$

$$x_a(1) = 0, \quad \forall a \longleftarrow \text{Boundary Conditions}$$

u : link inflow rate

v : link exit flow rate

x : total number of vehicles

τ : link travel time

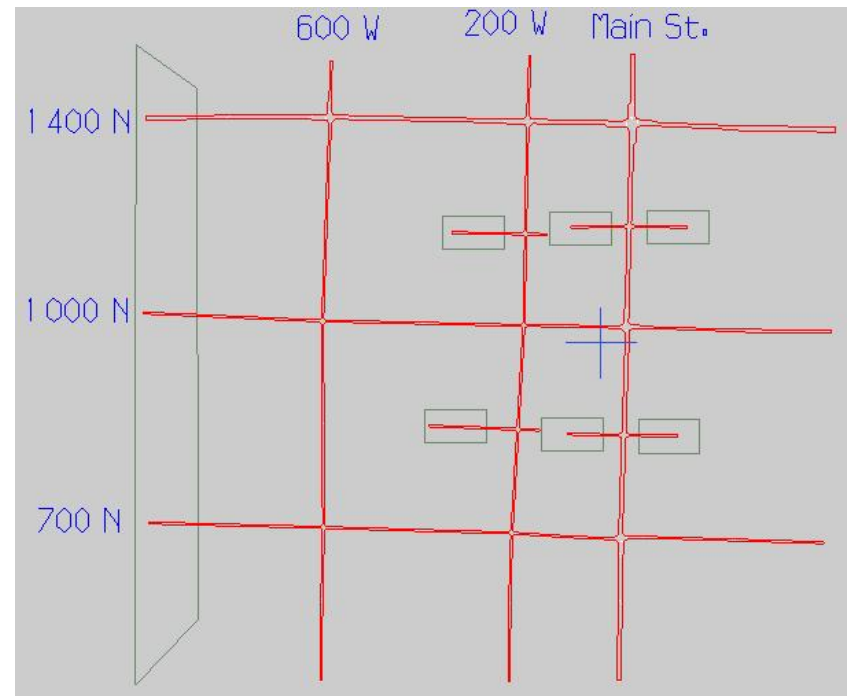


Case Study (Con'd)

- Descriptive Micro-Simulation
 - Paramics Implementation
 - Compliance Rate = 100%
 - Route Choice Determined by Splitting Rate
 - Signal Timing Determined by Splitting Rate
- Controller Design
 - MRAS Design Procedure
 - Discrete-time Controller
 - Incremental Implementation

Data

- Testing Network:
 - Evacuation due to Flooding
 - Origins: 6 zones
 - One Super Destination Zone
 - Intersections:
13 and all actuated signals
 - Time Period: 1 hours



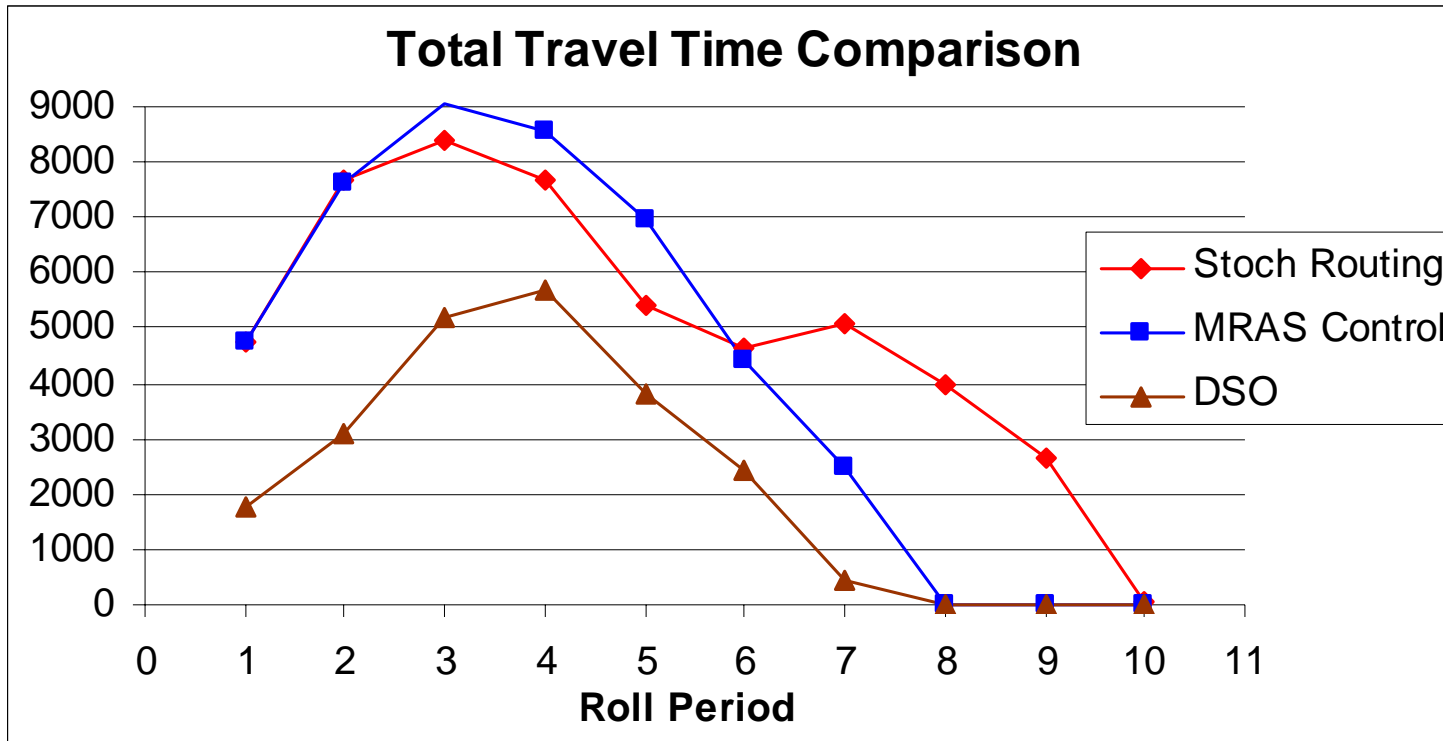


Results

- Performance Measurements
 - Total travel time
 - Clearance time
 - Victim Vehicles
- Comparison Scenarios
 - Dynamic System Optimal (DSO)
 - MRAS Control
 - Stochastic Route Choice (5% perturbation)

Results (Con'd)

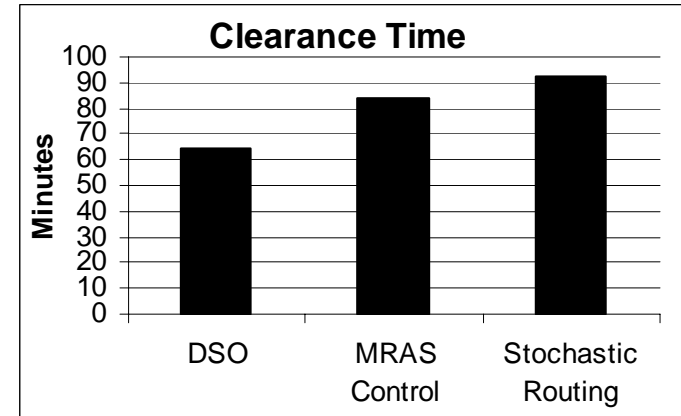
- Total Travel Time



Results (Con'd)

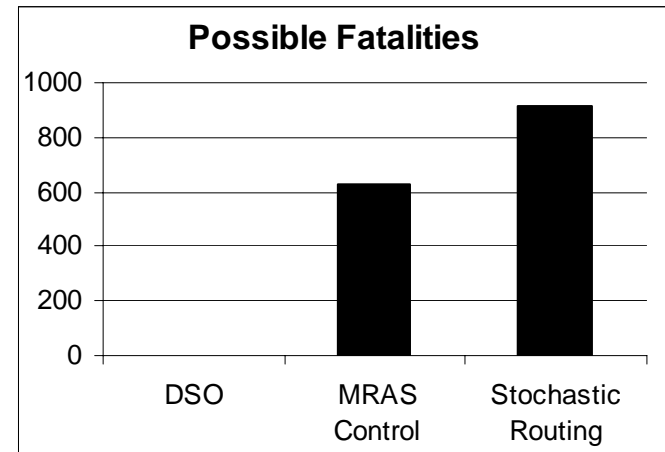
■ Clearance Time

- ❑ DSO: 65 minutes
- ❑ MRAS Control: 84 minutes
- ❑ Stochastic Route Choice: 92 minutes



■ Victim Vehicles

- ❑ Time budget is chosen as the clearance time from DSO, i.e., 65 minutes
- ❑ DSO: 0
- ❑ MRAS Control: 630
- ❑ Stochastic Route Choice: 917





Concluding Remarks

- Proposed a modeling framework for real time traffic management under emergency evacuation
- The framework was designed to guide (control) the traffic under evacuation towards certain system optimal objective
- Integrated both the dynamic network modeling and adaptive control techniques
- Identified and investigated major issues included in the proposed framework



Future Study Directions

- More investigations on resource allocation problem and OD synthesis
- Develop CTM-based or other embedded prescriptive DTA models
- Study on evacuees' route choice behavior and compliance
- More rigorous design procedure for the MRAS controller
- Sensitivity and stability analysis on the designed controller
- Further tailor the proposed framework to better fit into different evacuation scenarios
- More tests on large scale and real world traffic network



Thanks and Questions?