

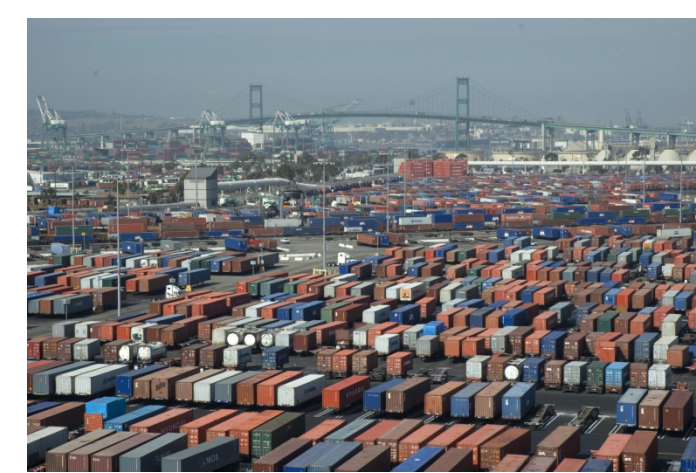
Motivation and Objective

Complex Freight Transportation System

- The same transportation infrastructure are shared for moving people in addition to freight goods which leads to **non-homogeneous traffic**.
- The situation becomes even worse during **incidents and disruptions** that lead to transportation system changes such as road or railway closures that require rapid response and distribution of freight traffic across the multimodal network.
- When it comes to complex networks such as the multimodal transportation network, simple models cannot always capture the **dynamics, interconnections and complexity** involved.



Road



Port

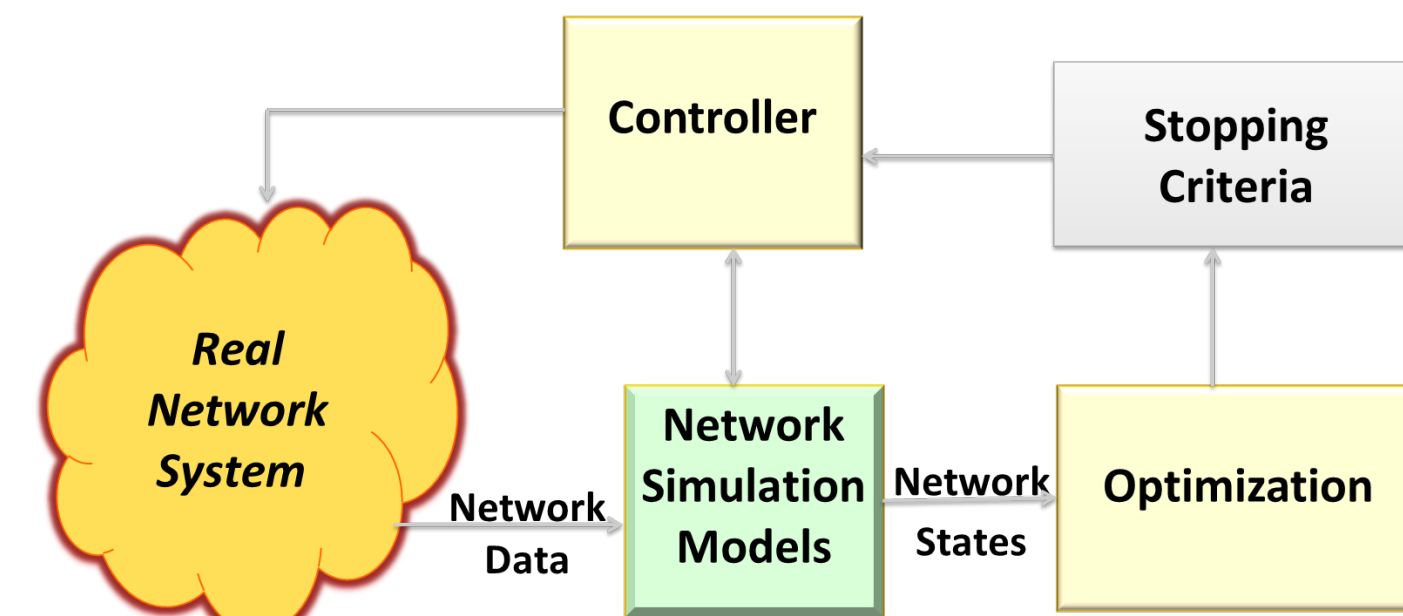


Rail

Project Objectives

- Develop the theoretical foundations of a new control approach referred to as **COSMO (Co-Simulation Optimization)** to balance loads across complex dynamical networks with temporal and spatial characteristics.
- Investigate how identified barriers and policy issues/incentives can be incorporated as mathematical constraints and/or control variables in the optimized dynamic freight load balancing system.
- Use real data to validate the simulation models and generate realistic scenarios for validation and testing using a **testbed** for the Los Angeles/Long Beach area that involves interacting road/rail/port networks.
- Assess the effectiveness and feasibility of implementing freight load balancing strategies to increase **the efficiency and sustainability** of urban freight movements by interacting with participating stakeholders.
- Integrate the research results to the University educational program by training students to new problems both in theory and application to freight transportation.

Proposed COSMO Approach



- Network Simulation Models** describe the dominant characteristics of the real network system and predict states and conditions of real network system.
- Optimization Block** uses the predicted network states to generate optimal solution based on minimizing given cost function.
- Controller Block** generates and applies the control inputs.
- The Stopping Criteria** includes convergence criteria within the allocated time and terminates the iteration process.

COSMO Approach Application

A Freight Routing Problem with Given Demands

$$\min TC(X) = \sum_{k \in K} \sum_{i \in I} \sum_{j \in J} \sum_{p \in P_{i,j}} S_{i,j}^p(k) x_{i,j}^p(k)$$

$$S_{i,j}^p(k) = C_{i,j}^p(k) + K_p T_{i,j}^p(k), \text{ for } \forall i \in I, \forall j \in J, \forall p \in P_{i,j}, \forall k \in K$$

Subject to

$$\sum_{p \in P_{i,j}} x_{i,j}^p(k) = d_{i,j}, \text{ for } \forall i \in I, \forall j \in J$$

$$x_{i,j}^p(k) \geq 0 \text{ for } \forall i \in I, \forall j \in J, \forall p \in P_{i,j}, \forall k \in K$$

$$y_i(k+1) = f_i(y_i(k), a_i(k), X(k), k), \text{ for } \forall i \in I, \forall k \in K$$

$$0 \leq y_i(k) \leq u_i(k) \text{ for } \forall i \in I, \forall k \in K$$

$$W(k) = g(Y(k), k), \text{ for } \forall k \in K$$

$$T_{i,j}^p(k) = \sum_{n_p=1}^{N_p} w_{i,j,p,n_p} (e_{i,j,p,n_p}(k))$$

$$e_{i,j,p,n_p+1}(k) = e_{i,j,p,n_p}(k) + w_{i,j,p,n_p} (e_{i,j,p,n_p}(k)), \text{ for } n_p = 1, \dots, N_p - 1$$

Min Total Cost

Traffic demands

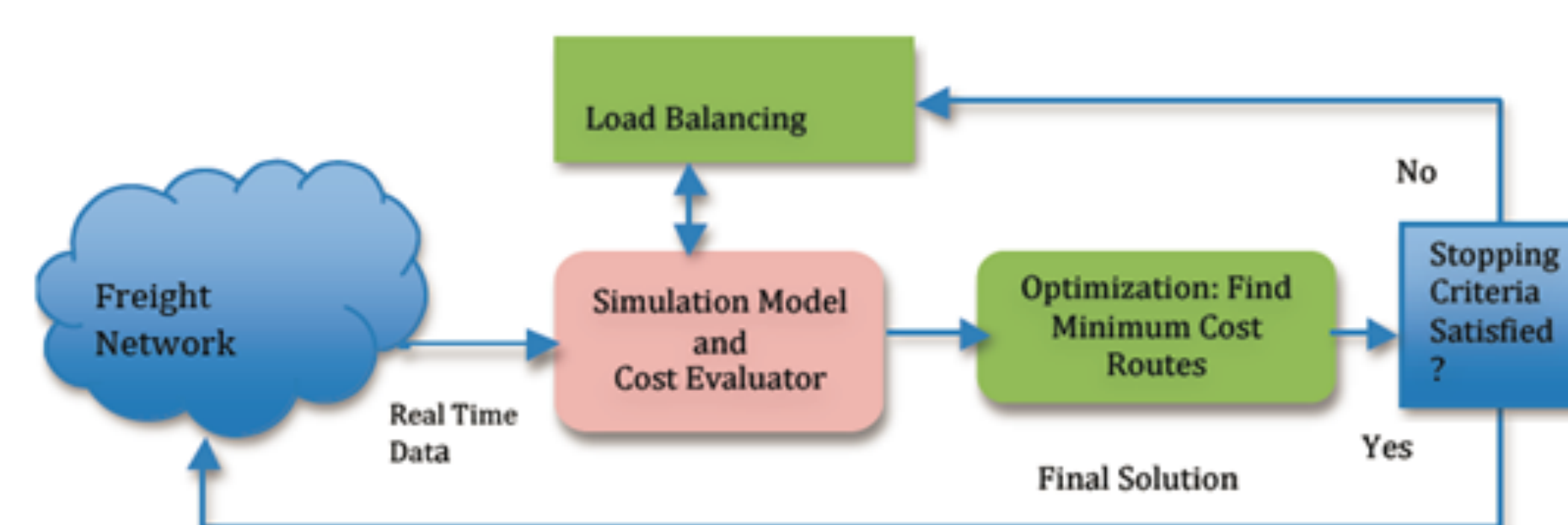
Traffic volume dynamics

Travel time dynamics

i, j – The index of node, k – The time index, p – The route index
 $P_{i,j}$ – The set of routes from i to j $u_i(k)$ – The link i capacity at time k
 $x_{i,j}^p(k)$ – The units of freight traffics on route p from i to j at time k
 $S_{i,j}^p(k)$ – The cost of route p from i to j at time k
 $C_{i,j}^p(k)$ – The distance cost of route p from i to j at time k
 K_p – The unit cost of travel time on route p from i to j at time k
 $T_{i,j}^p(k)$ – The travel time of route p from i to j at time k
 $y_i(k)$ – The traffic volume of link i at time k
 $u_i(k)$ – The capacity of link i at time k
 $w_i(k)$ – The travel time of link i at time k
 $e_i(k)$ – The arrival time of link i with departure time k
 $X(k)$ – The decision vector at time k
 $Y(k)$ – The link traffic volume vector at time k
 $W(k)$ – The link travel volume vector at time k

The explicit forms of the dynamical functions in traffic volume and route costs are difficult to mathematically express directly due to the nonlinearities and complex variable interactions. Therefore, COSMO is used to solve the problem iteratively other than directly.

Solve with COSMO Approach



- Optimization block** estimates the route marginal costs ∇TC based on predicted network states and updates route set by adding new routes with minimum marginal cost into current route set, then solves the linearized approximation problem to obtain an auxiliary optimal solution at iteration m ;

$$\min TC(X_{Aux}^{(m)}) \approx TC(X^{(m)}) + \nabla TC(X_{Aux}^{(m)} - X^{(m)})$$

$$\text{Subject to } X_{Aux}^{(m)} \in \Omega$$

where Ω is the feasible set defined by demands, link capacity and route set.

- Load balancing controller** selects an optimal step size α_m to minimize the total cost, then update the current solution with selected step size;

$$X^{(m+1)} = X^{(m)} + \alpha_m (X_{Aux}^{(m)} - X^{(m)})$$

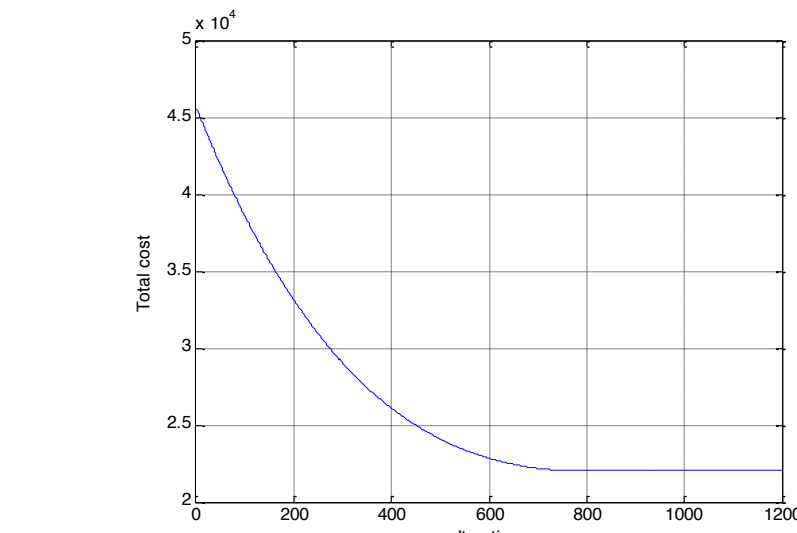
$$\text{where } \alpha_m = \arg \min_{\alpha_m \in [0,1]} TC(X^{(m)} + \alpha_m (X_{Aux}^{(m)} - X^{(m)}))$$

Evaluation

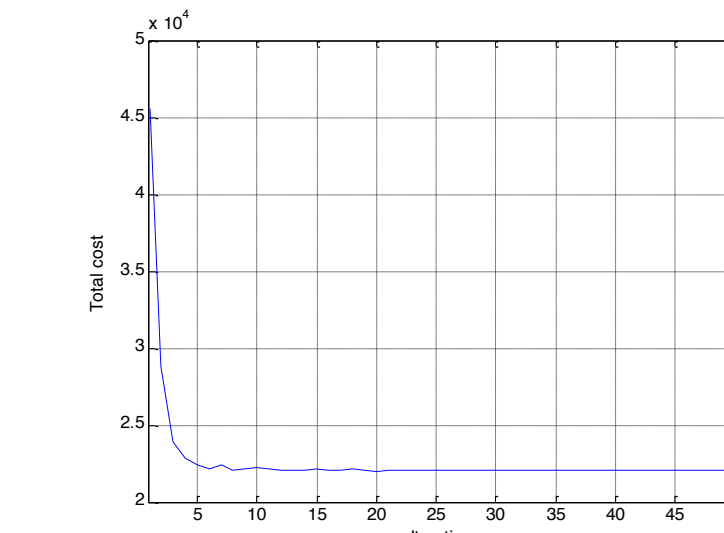
Simple Network

Three routes, three intervals, and 1200 containers between one origin and destination

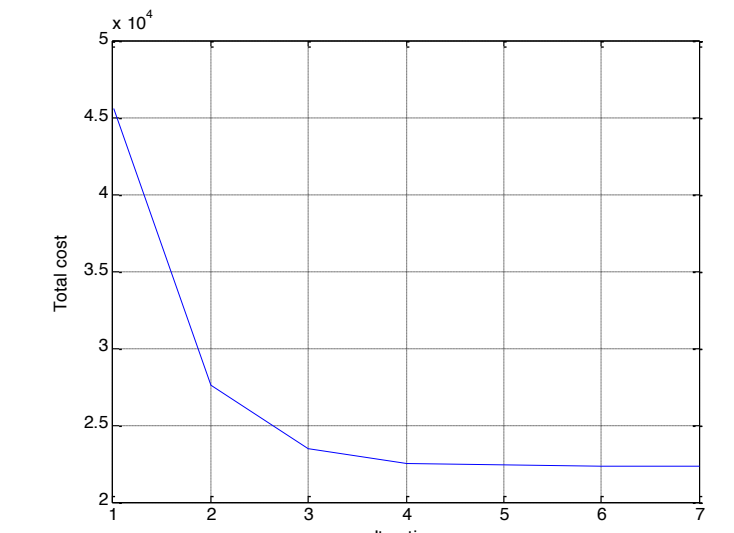
Compared three load balancing methods:



a) Enumeration method in Abadi et al.



b) MSA method;



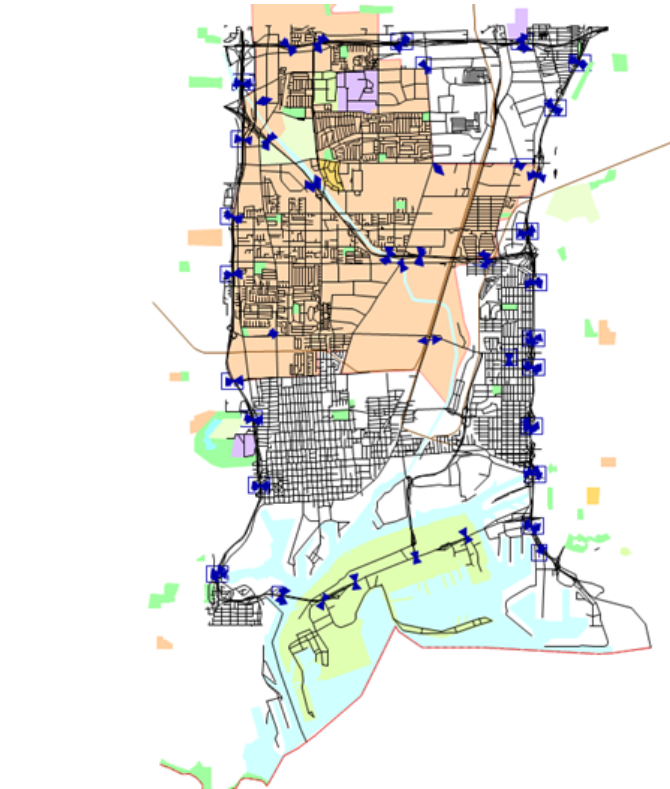
c) Optimal step selection

Cyber Physical Network

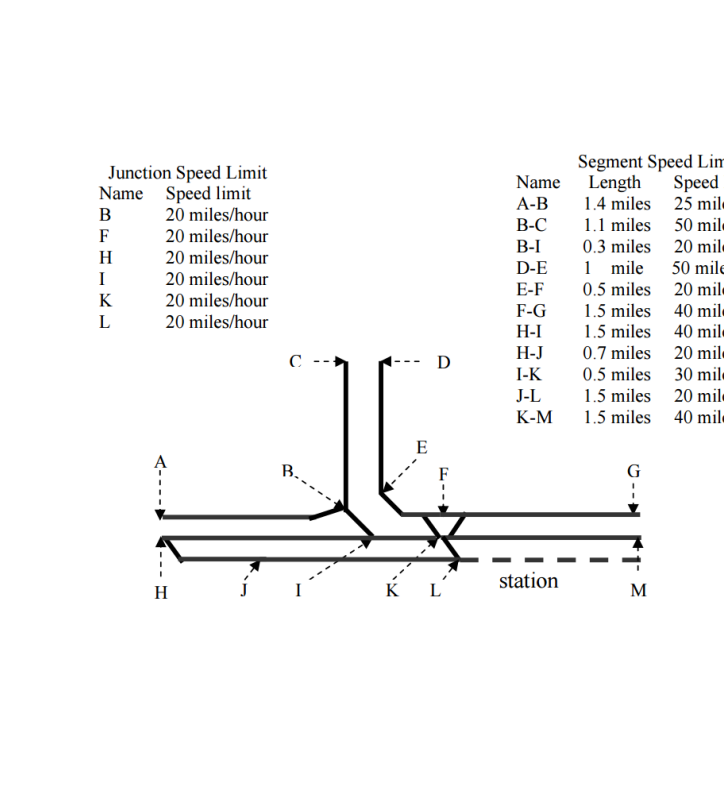
About 80 square miles near the Ports of LA/LB

Simulation Model: Road network simulator with VISUM plus discrete event-based rail simulator with Arena.

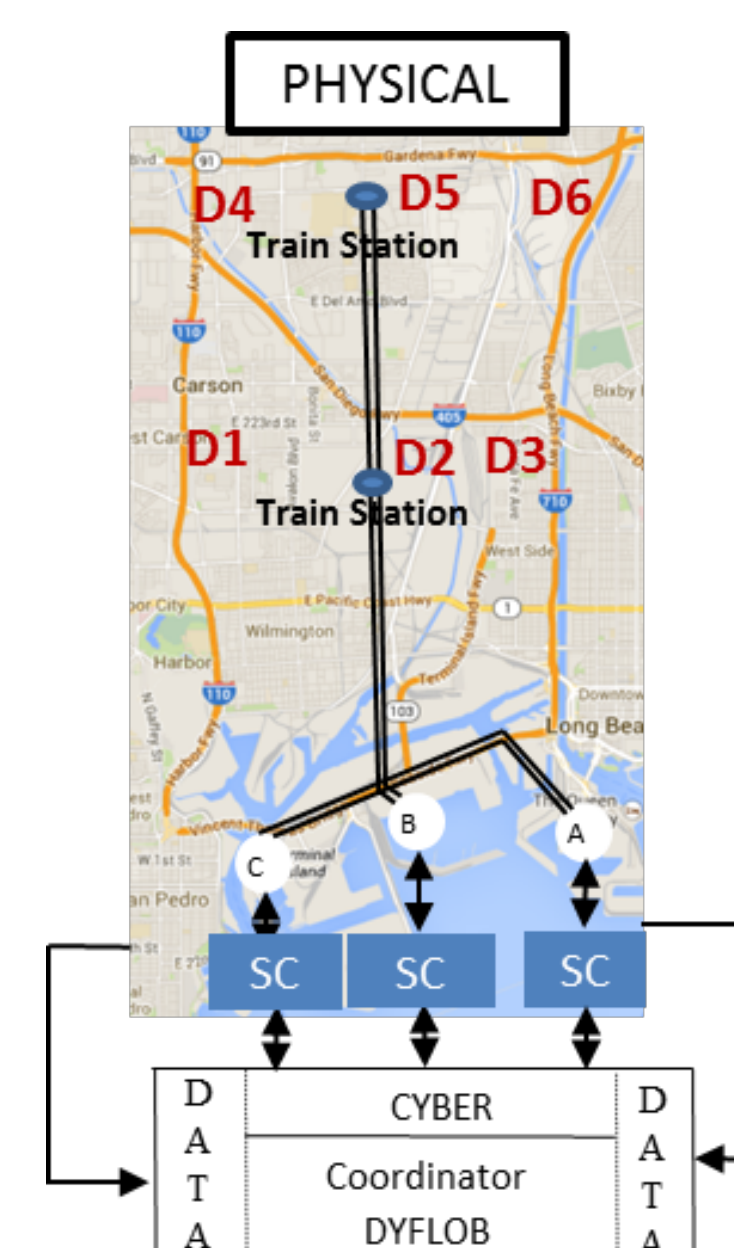
Traffic in road and rail simulators are from the historical data



Road network simulator



Rail network modeling



Evaluation Scenario

Origin suppliers: 3 terminals A (1020), B(1020), C(1020)

Destination demands: D1 (350), D2(450), D3(400), D4(600), D5(700), D6(560)

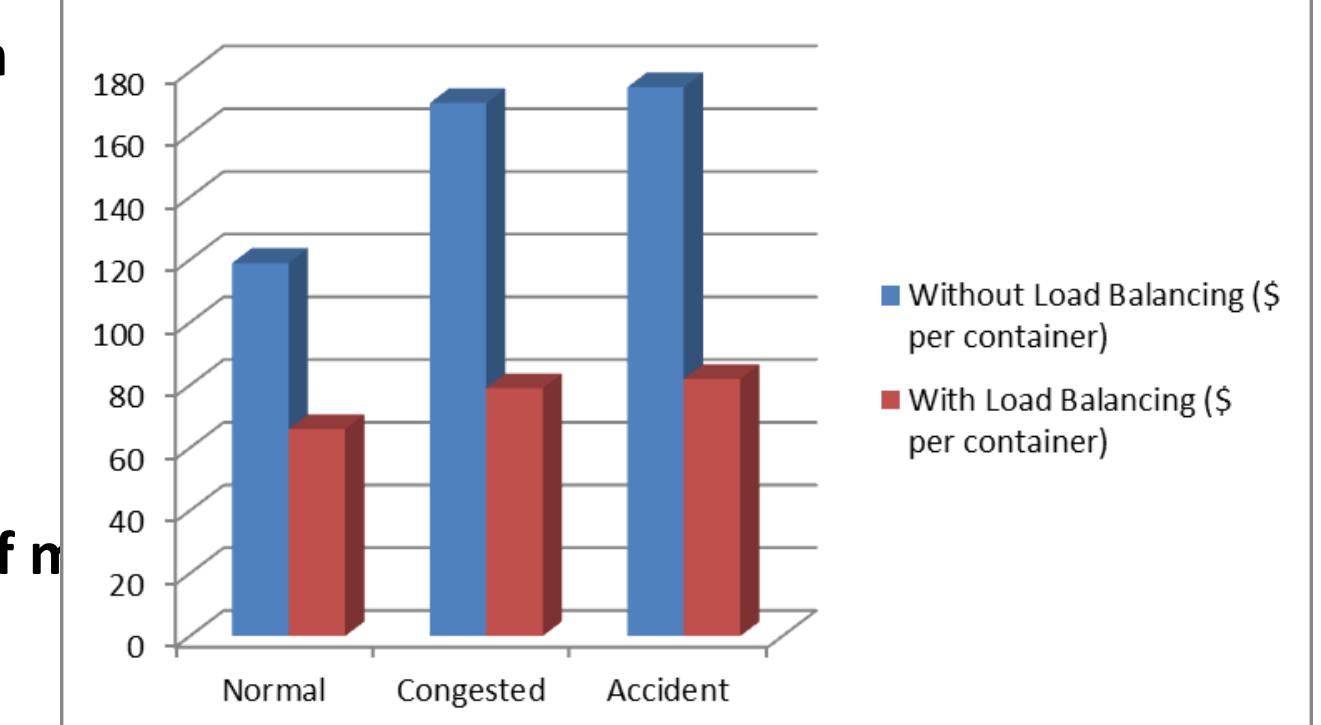
Objective: Minimize total cost which depends on delivery distance, travel time and mode.

Three traffic conditions:

Normal: Average daily traffic

Congested: Increased daily traffic

Lane Closure: Traffic under reduced capacities of n freeways due to incidents



Future Work

- Scalability Issue:** Investigate efficient decomposition methodology that could handle large scale networks, increased demand, etc.
- Time Window:** Add problem constraints of pickup and delivery time windows. The time window constraints will reduce the solution space significantly but increase the problem complexity and require new designed solving techniques.
- Sensitivity Analysis:** Examine the impacts of various factors on system routing performance, such as changed freight demands, dynamical passenger traffic, temporary road/rail capacity changes, etc.
- Game Theory Employment:** Study monetary incentive mechanism and schemes for freight delivery participants to achieve coordinated optimum. A special emphasis will be given on budget balance and voluntary participation considerations.