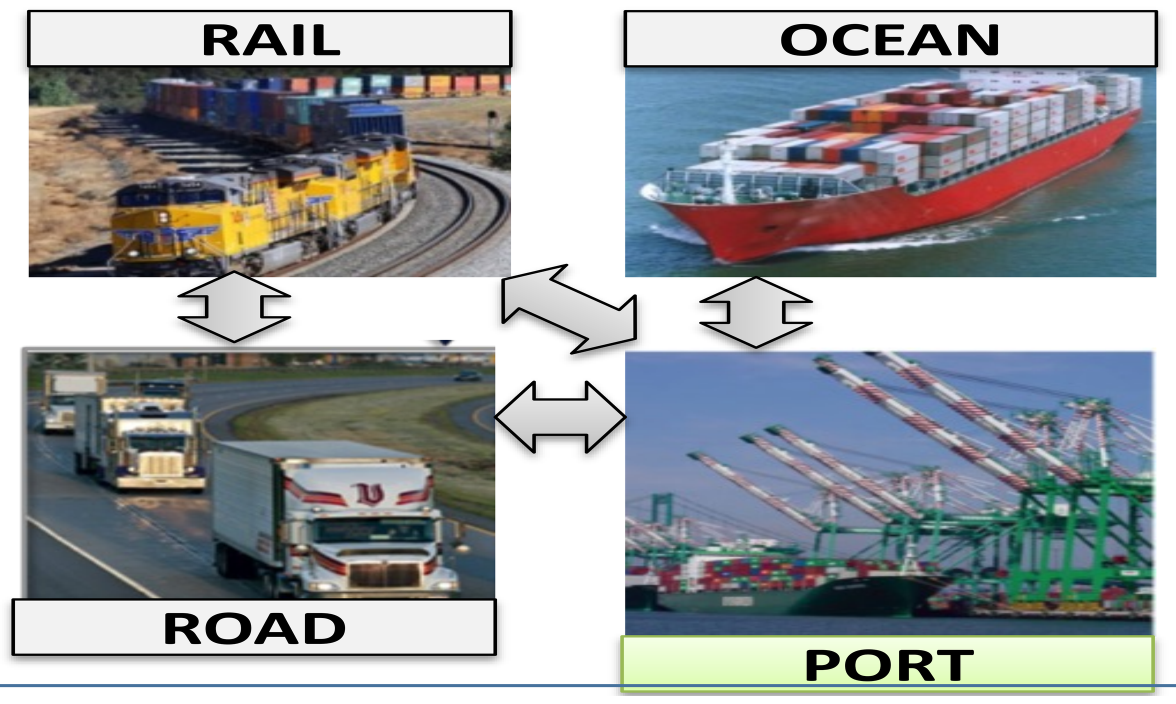
CPS: Synergy: Cyber Physical Regional Freight Transportation

USC University of Southern California

PI: Petros Ioannou, Co-PI: Maged Dessouky, Genevieve Giuliano

Motivation and Objective

Complex Freight Transportation System: How to model, optimize and control



Model Evolution

Analog Years from B.C. to the 60's	Simple Dynamics based on law of physics, conservation laws. Linearity Time Invariance
Digital Years 70's to today	Higher dimensions, nonlinearities, time variations.
Today and Future:fast computations, Software tools, memory	Use on line simulation models, big data to handle far more complex dynamical systems

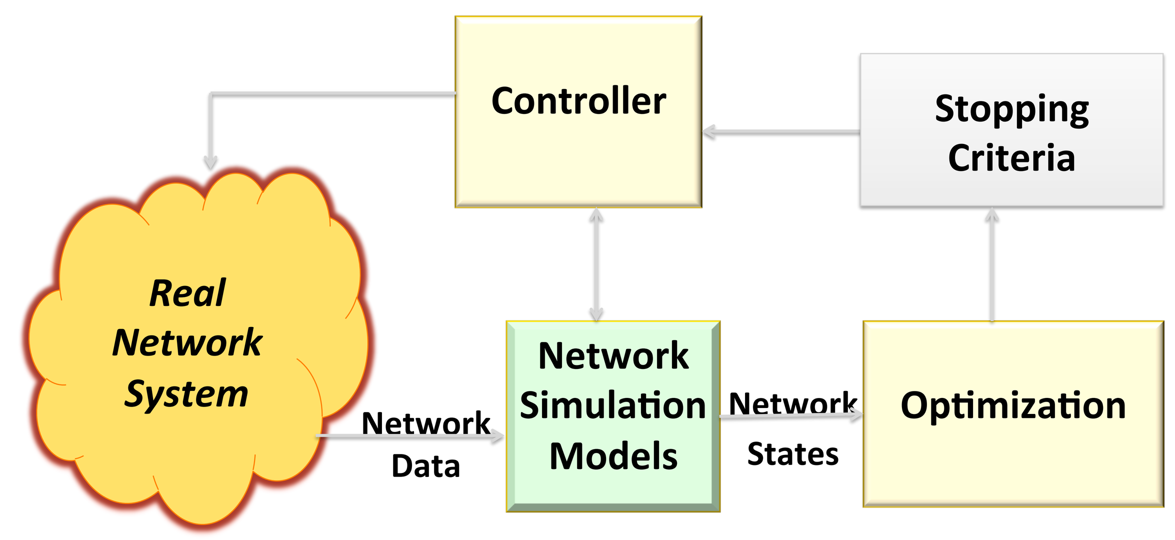
- **Simulation models can be used in real time to predict the states of the network by fast forwarding based on current and expected demand**

Project Objectives

- *Develop the theoretical foundations of a new control approach referred to as COSMO (Co-Simulation Optimization, Control) to optimize and control complex dynamical networks with temporal and spacial characteristics.*
- *Investigate stability, convergence, robustness and scalability issues*
- *Use multimodal freight load balancing as the application area*
- *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*

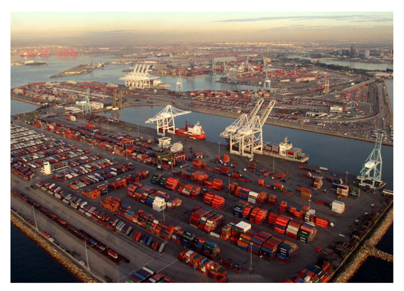
Co-Simulation Optimization (COSMO) Approach

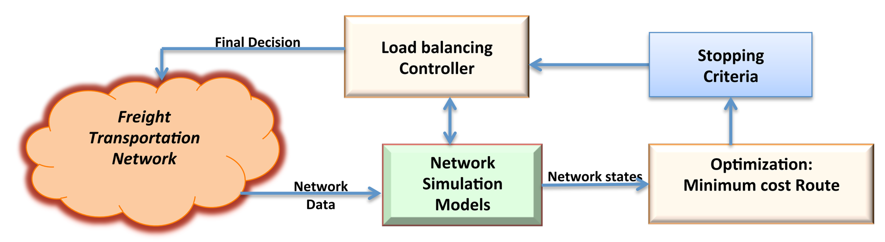
COSMO Approach



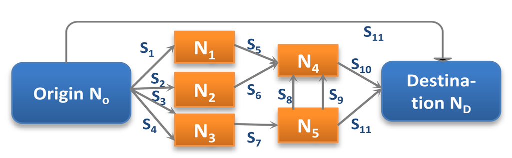
- ***Network Simulation Models*** **describe the dominant characteristics of the real network system**
- ***Optimization Block*** **uses the predicted network states to generate optimal solution based on minimizing given cost function**
- ***Controller Block*** **generates and applies control inputs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

COSMO for Dynamic Freight Load Balancing





- ***Optimization Techniques***



Service Network

Given a network G = (N, S), N – Set of Nodes, S – Set of Links
Objective: Minimize transportation cost of decision
Constraints:
•Demand Satisfaction Requirements
•Link Capacity Restriction
•Variable Selection: Nonnegative and Integer

$$\min \sum_{t\in T}\sum_{(i,j)\in S}\sum_{p\in P} c_{ij}^{p} x_{ijt}^{p} + \sum_{t\in T}\sum_{(i,j)\in S} f_{ijt} y_{ijt}$$

Subject to:

$$\sum_{t\in T}\sum_{j\in N} x_{ijt}^{p} - \sum_{t\in T}\sum_{j\in N} x_{jit}^{p} = d_{it}^{p},\ i\in N,\ \forall p\in P$$
$$\sum_{p\in P} x_{ijt}^{p} \le u_{ij} y_{ijt},\quad (i,j)\in S, \forall t\in T$$
$$x_{ijt}^{p} \ge 0,\quad (i,j)\in S, \forall t\in T, \forall p\in P$$
$$y_{ijt} \in \{0,1,2\ldots\},\quad (i,j)\in S, \forall t\in T$$

f_{ijt} is the cost per service unit incurred by using service (truck or train) on link(i,j) at time t, y_{ijt} is the discrete decision variable which represents number of service units offered on link (i,j) at time $t\in\{1,2,\ldots,T\}$. c_{ij}^{p} is the transportation cost per unit flow of product p on link(i,j). x_{ijt}^{p} is the amount of flow of commodity p using link(i,j), d_{it}^{p} is the demand of product p at node i, and u_{ij} is the capacity of link (i,j).

Optimization Algorithm Candidates

•Decompositions + Branch and Bound Techniques

•Natural heuristics

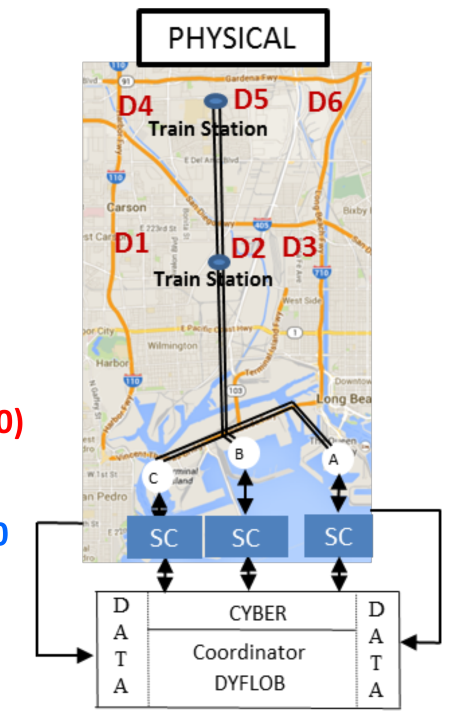
Preliminary Results: Load Balancing Example

- ***Physical Network***

About 80 square miles near the Port of LA/LB

Road network with 12824 links and 4747 nodes plus rail

Traffic and rail data from the Southern California Association of Governments (SCAG)



- ***Evaluation Scenario***

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

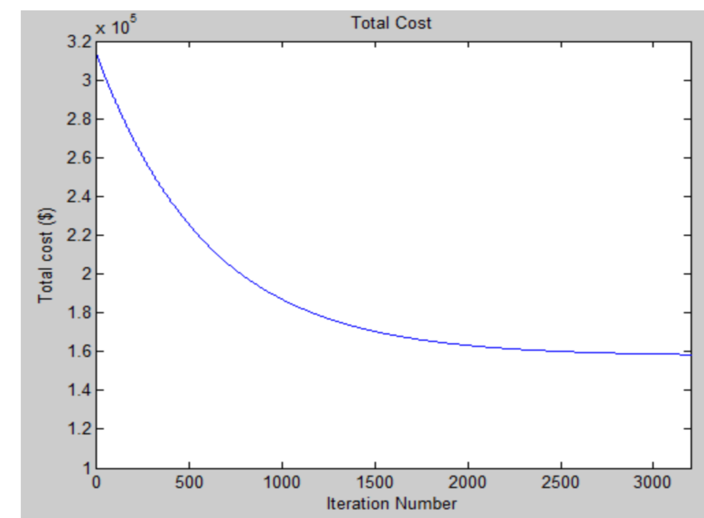
Destinations: D1 (350), D2(450), D3(400), D4(600),D5(700), D6(560)

Shippers: Three, one for each terminal

Routes: Road Network and Partial Rail (5 trains with capacity of 50 containers each)

Simulation Model: Macroscopic based on VISUM. Use historical data and dynamic assignment to tune it.

Cost: Minimize total $ cost based on real data which depends on travel times and mode

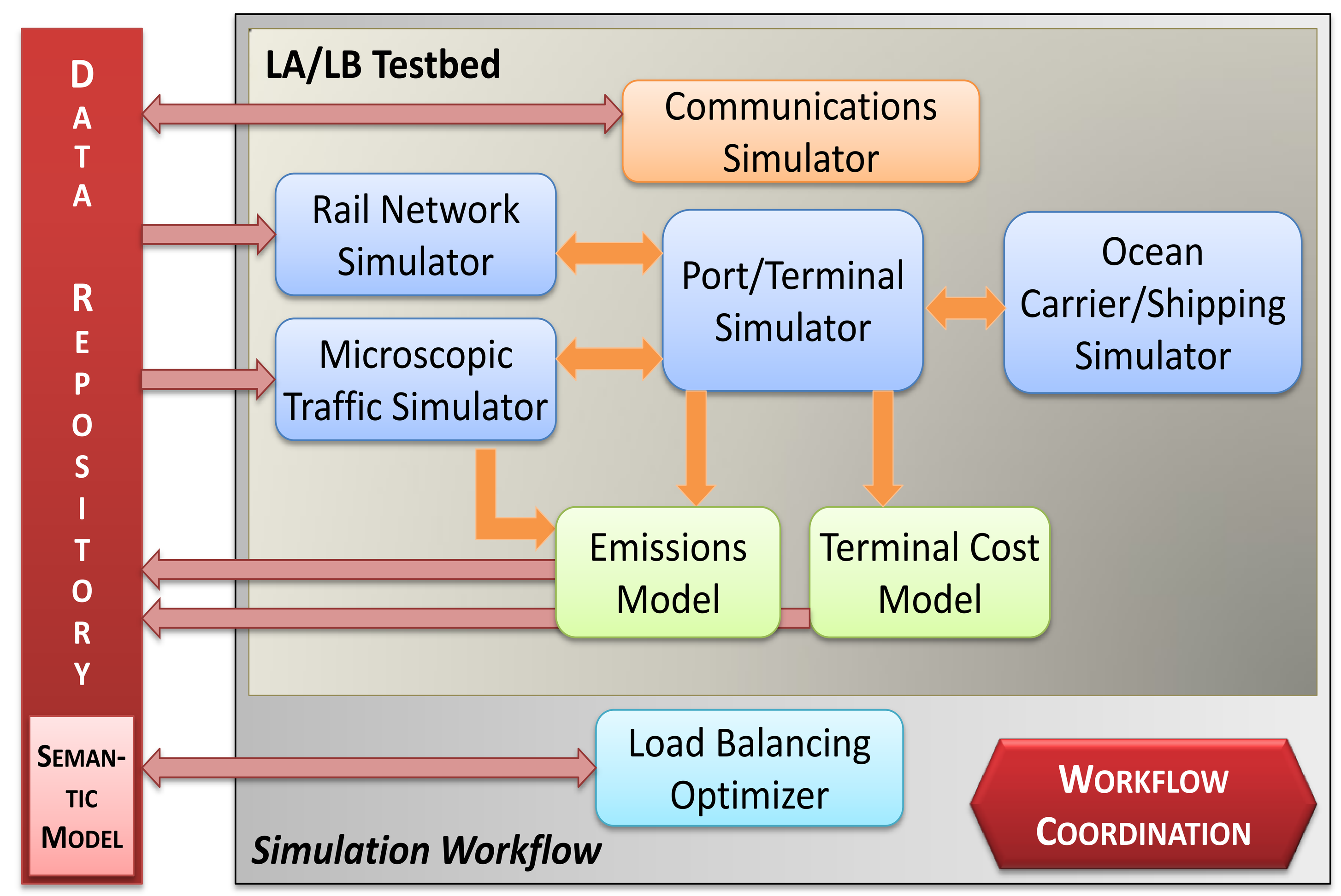


Load balancing Iterations that reduce the overall cost

The experiment was performed on a computer with the Intel 2.3 GHz CPU and a standard routine from Matlab is used to solve the optimization problem at each iteration.

The load balancing control procedure used is rather adhoc and involves shifting loads from previously minimum cost routes to the new minimum cost route generated by the optimizer till all routes have equal cost leading to new states of the network generated by the simulation model which are fed to the optimizer for a solution under the new situation.

Validation using Testbed



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