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SOLVING LARGE-SCALE TRAFFIC ASSIGNMENT PROBLEM

WITH A DISTRIBUTED, SIMULATION-BASED LOAD BALANCING METHOD

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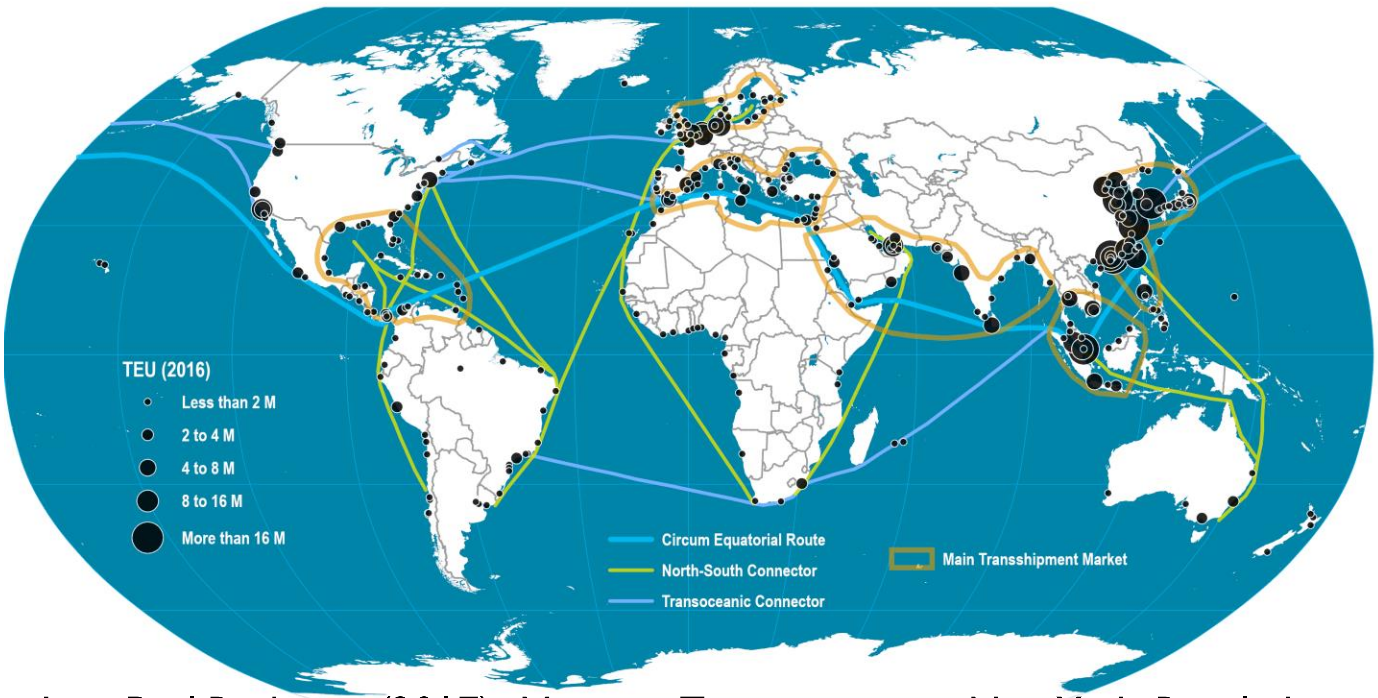
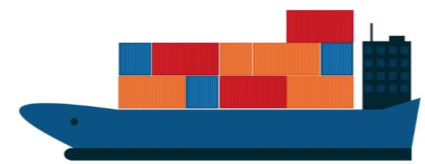
Global Transhipment





Jean-Paul Rodrigue (2017), Maritime Transportation, New York: Routledge

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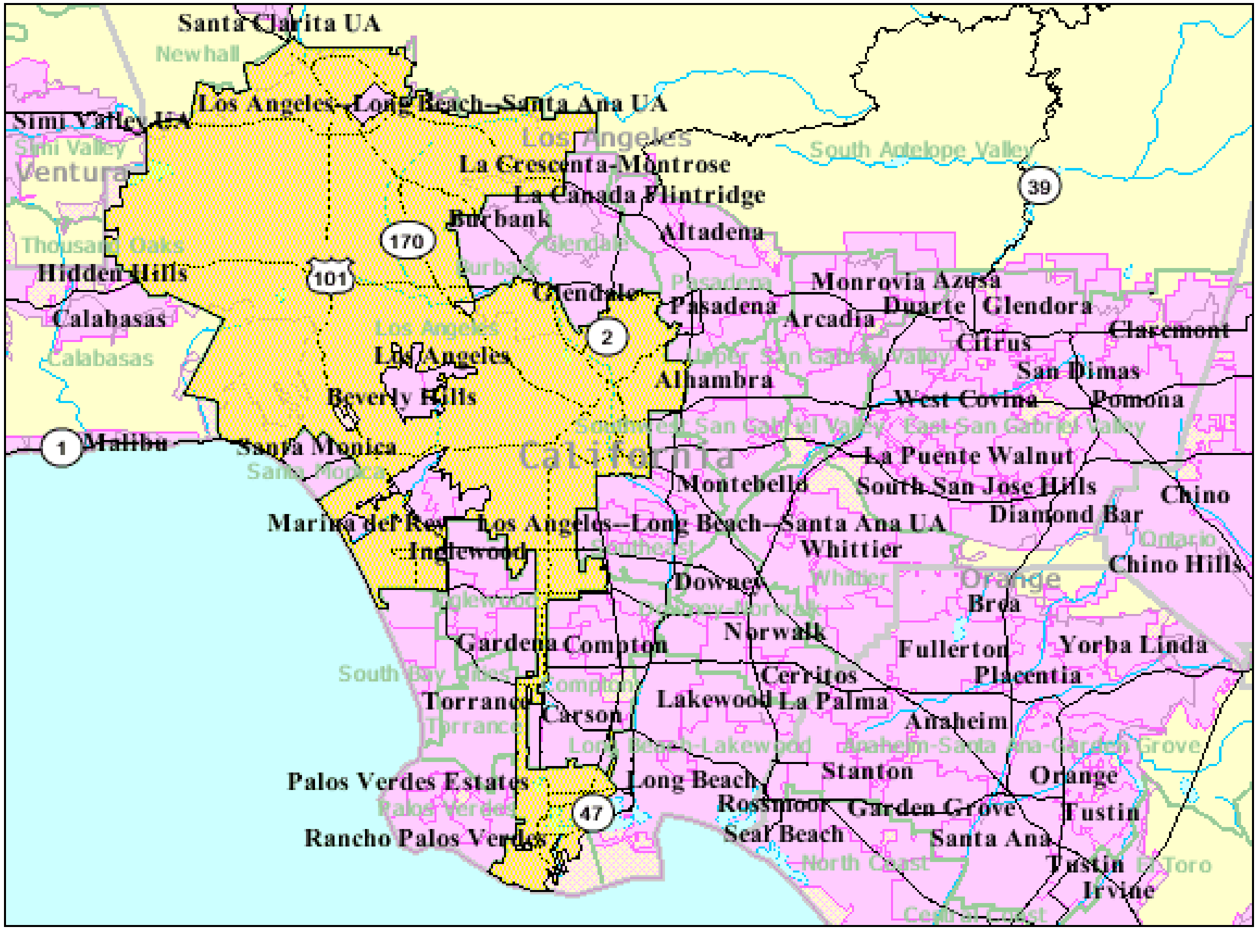
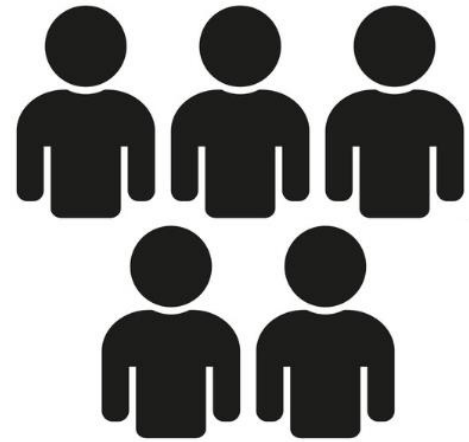
Los Angeles Metropolitan Area



US Federal Gov, Map of Los Angeles, California



Research Problem

To assign a number of demands from origins to destinations with considerations of several factors: *time window*, *road network traffic condition*, *emissions*, etc.

- *Time window*: pick up time window, delivery time window
- *Road network traffic condition*: Vehicle Travel Time
- *Emissions*: $CO_2, PM_{2.5}, NO_x$

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Formulation I

$$\min_x \sum_a \int_0^{v_a} S_a(x)dx$$

subject to:

$$v_a = \sum_i \sum_j \sum_r \alpha_{ij}^{ar} x_{ij}^r$$

$$\sum_r x_{ij}^r = T_{ij}$$

$$v_a \geq 0, x_{ij}^r \geq 0$$

- x_{ij}^r is the number of vehicles on path r from origin i to destination j
- $\alpha_{ij}^{ar} = 1$ if link a is on path r from i to j ; zero otherwise
- $S_a(x)$: volume delay function, stating the relationship between resistance and volume of traffic, usually we use Bureau of Public Roads (BPR) model:

$$S_a(v_a) = t_a(1 + 0.15\left(\frac{v_a}{c_a}\right)^4)$$

t_a: free flow travel time on link a per unit of time
v_a: volume of traffic on link a per unit of time
c_a: capacity of link a per unit of time

The solution to this nonlinear programming problem reaches such condition that travelers will strive to find the shortest path from origin to destination and network equilibrium occurs when no traveler can decrease travel delay/resistance by shifting to a new path.

Formulation 2

$$\min TC(X) = \sum_{k\in K}\sum_{i\in I}\sum_{j\in J}\sum_{r\in R_{i,j}} S_{i,j}^{r}(k)X_{i,j}^{r}(k)$$

$$= \sum_{k\in K}\sum_{i\in I}\sum_{j\in J}\sum_{r\in R_{i,j}} (C_{i,j}^{r}(k) + \theta^{r} T_{i,j}^{r}(k))X_{i,j}^{r}(k)$$

subject to:

$\sum_{k\in K}\sum_{r\in R_{i,j}} X_{i,j}^{r}(k) = d_{i,j}, \forall i \in I, \forall j \in J$ (1)

$\sum_{i\in I}\sum_{j\in J}\sum_{r\in R_{i,j}}\sum_{\tau\le k} X_{i,j}^{r}(\tau)\delta_{l,\tau,k}^{r} = x_l(k), \forall l \in L, \forall k \in K$ (2)

$0 \le x_l(k) \le u_l v_l(k), \forall l \in L^R, \forall k \in K$ (3)

$X_{i,j}^{r}(k) \ge 0, \forall i \in I, \forall j \in J, \forall k \in K$ (4)

$d_{i,j}$: The total demand from an origin i to a destination j;

$X_{i,j}^{r}(k)$: The freight demand in units of containers from an origin i to a destination j using a route r with a departure time k;

$x_l(k)$: The number of containers using edge l at time k;

u_l : The edge capacity in units of vehicles for edge l;

$v_l(k)$: The vehicle capacity in units of containers per freight vehicle for edge l;

$S_{i,j}^{r}(k)$: combination of the non-travel time vehicle cost $C_{i,j}^{r}(k)$ and the cost of the route travel time $T_{i,j}^{r}(k)$;

Methodology: general structure

1. Relaxed Problem

$$\min TC(X) + \sum_{k \in K} \sum_{l} \sigma_l \, \phi(x_l(k), u_l(k), v_l(k))$$

subject to constraints (1), (2), (4)

2. Check convergence, if not convergent, proceed to step 3, otherwise, terminate the algorithm and output X as the optimal solution

$$\phi\big(x_l(k), u_l(k), v_l(k)\big) \leq \eta$$

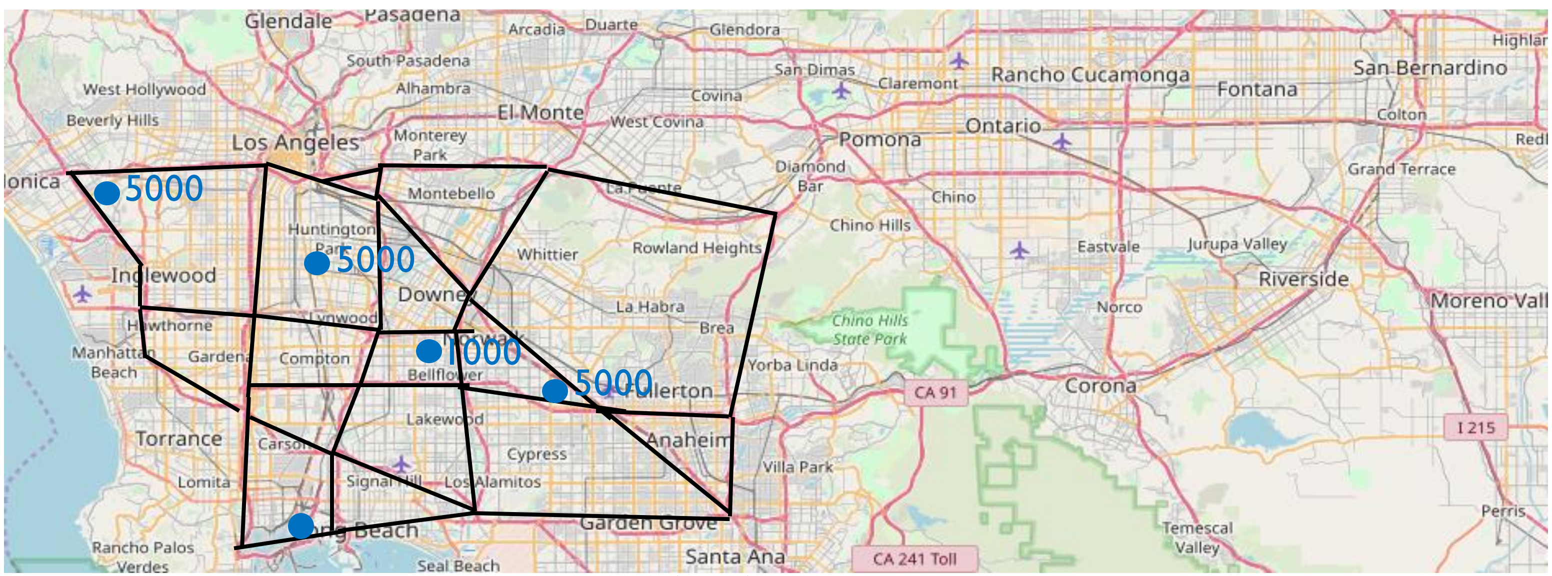
3. Increase penalty factor σ_l, proceed to step 1

Methodology: solving relaxed problem

- Initial feasible solution $X_{ij}^{(0)}$, transfer it into x_l
- Simulate X with road network simulator,
  output simulated results: travel time, emissions, etc.
- Update marginal cost of links and routes in R_{ij} based on simulated
  results: *travel time*, *emissions*, etc.
- Generate one minimum marginal cost route for each R_{ij}
- Generate augmented X_{aug} based on R_{ij} in the previous step
- Set new X as $X^{(m+1)} = X^{(m)} + \beta(X_{aug} - X^{(m)})$
- Check convergence, if convergent, output X as the solution of relaxed problem,
  else, proceed to step 2.

Methodology: service network

- Iterate every edge in the network takes computational time and memory
- 2-layer: service network + road network
- Global optimum to local optimum
- Denote l to service link , a road arc



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Methodology: marginal cost

- Marginal cost : the change in total cost if we add one truck at time instance k on service link l

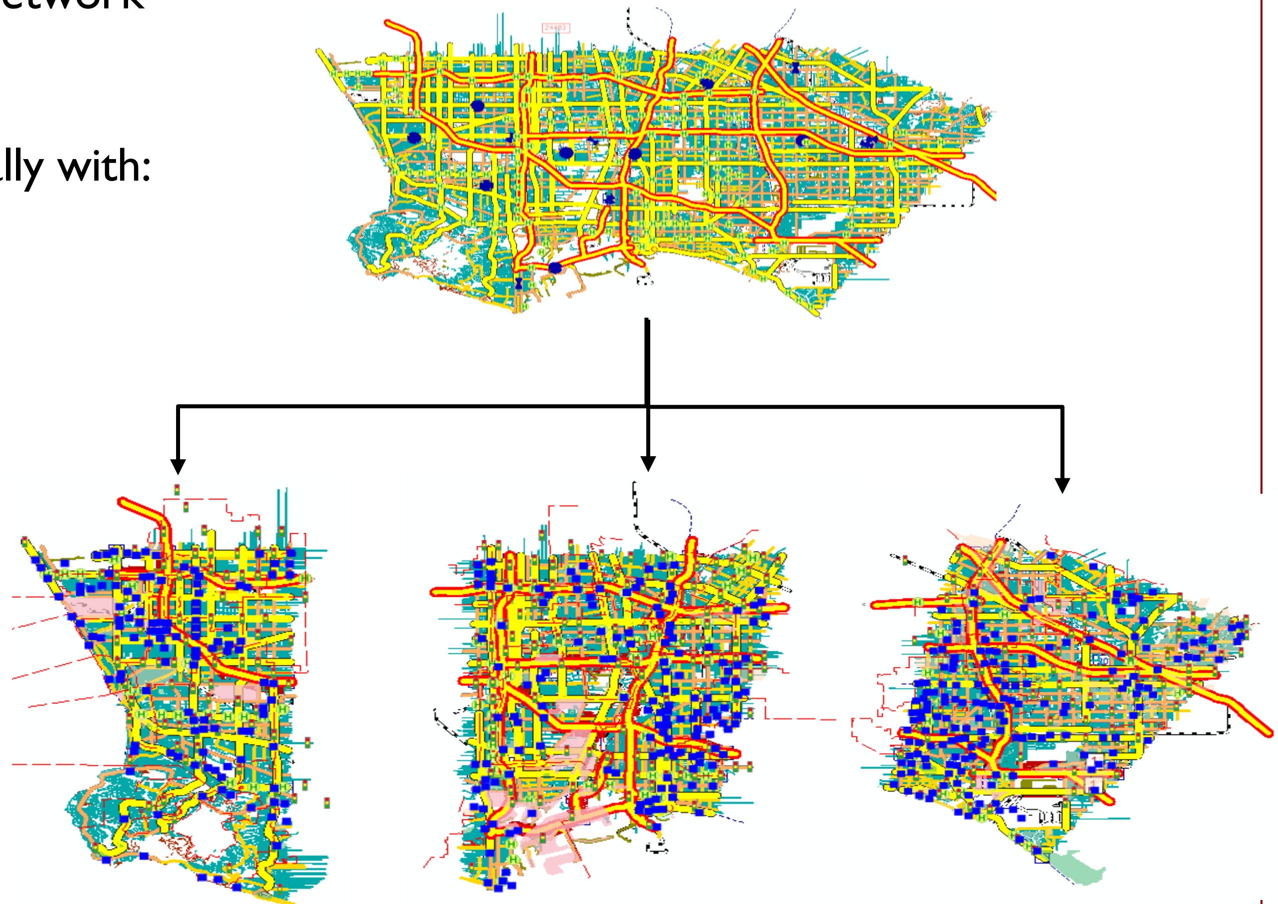
$$MCP_{l'}^{p'}(k') \approx c_{l'}^{p'} + \sigma_{l'}^{p'} t_{l'}^{p'}(k)$$
$$+ \sum_{n_{p'}=1}^{N_{p'}} \left(\sigma_{l'}^{p'} y_{l'}^{p'}(e_{a_{p',n_{p'}}}(k')) \frac{1}{v_{l'}\left(e_{a_{p',n_{p'}}}(k')\right)\Delta t} \frac{\partial w_{a_{p',n_{p'}}}}{\partial z_{a_{p',n_{p'}}}}(e_{a_{p',n_{p'}}}(k')) \right)$$

$e_{a_{p',n_{p'}}}(k')$: entering time at arc $a_{p',n_{p'}}$ for a freight vehicle using path p' with a departure time of k' from the origin.
$w_{a_{p',n_{p'}}}(k')$: the travel time of arc $a_{p',n_{p'}}$ at time k'
$z_{a_{p',n_{p'}}}(k')$: the traffic volume on road network arc $a_{p',n_{p'}}$ at time k'

Methodology: tackle scalability issue

Marginal cost update depends on simulated results from road network simulator.
However, the time and space complexity grows exponentially with:

- the number of demands
- the scale of road network



Solution:

- Distributed network
- Parallel computing

Methodology : with distributed subnetwork

- Initial feasible solution $X^{(0)}$
- Simulate input to subnetwork $X_1, X_2, \dots$ with road network simulator $S_1, S_2, \dots$, output simulated results: travel time, emissions, etc.
- Update marginal cost of links and routes in R_{ij} based on simulated results: *travel time*, *emissions*, etc.
- Generate one minimum marginal cost route for each R_{ij}
- Generate augmented X_{aug} based on R_{ij} in the previous step
- Set new X as $X^{(m+1)} = X^{(m)} + \beta(X_{aug} - X^{(m)})$
- Check convergence, if convergent, output X as the solution of relaxed problem, else, proceed to step 2.

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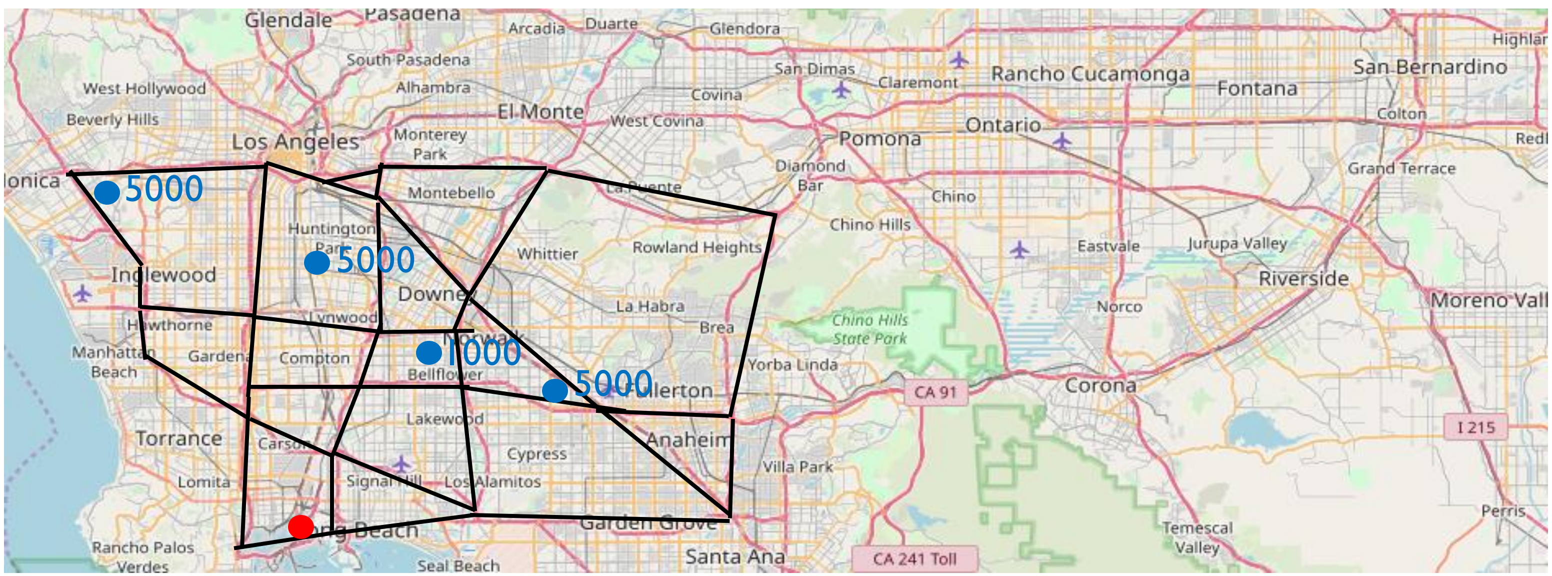
Numerical Results

- **Baseline Scenario (Long Beach Area)**
  - Terminal, Destinations with demand label
  - Routes: Road Network
- **Evaluation Scenarios**
  - Centralized method
  - Distributed-COSMO



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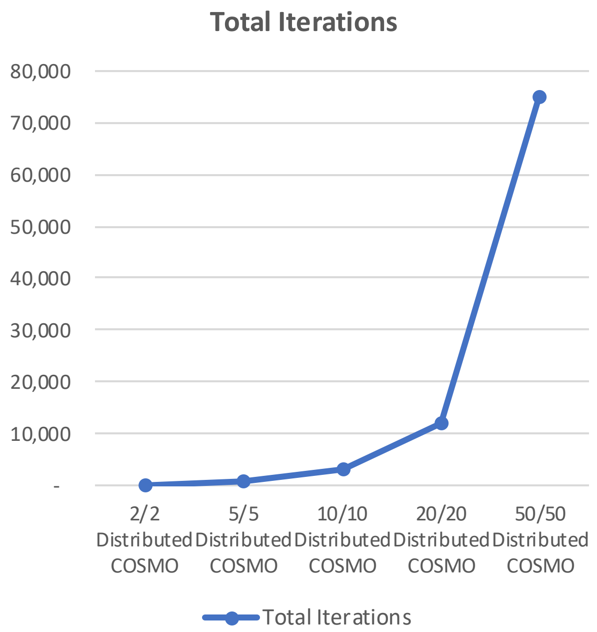
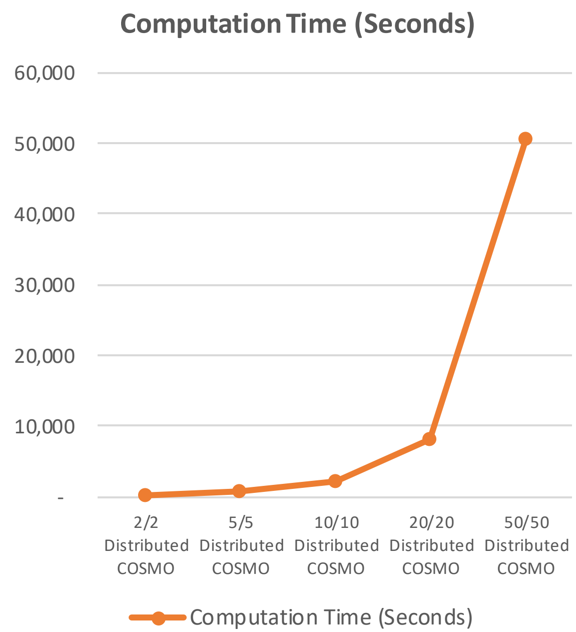
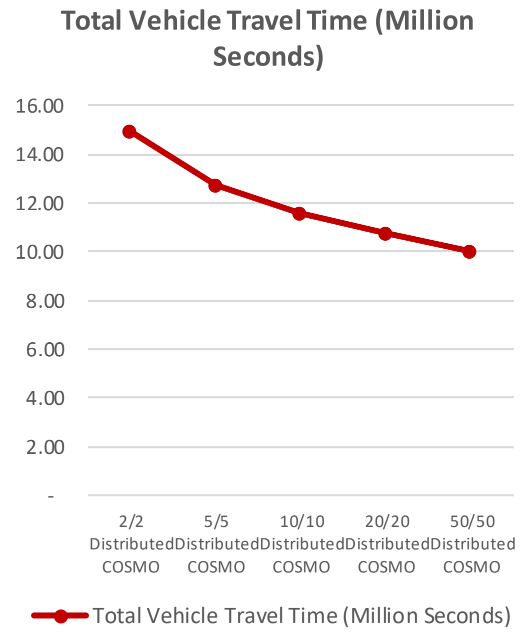
Numerical Results

	Total Iterations	Computation Time (Seconds)	Total Vehicle Travel Time (Million Seconds)
Centralized Method	3,600	16,240	6.73
Centralized Method	400	464	9.34
2/2 Distributed COSMO	120	160	14.96
5/5 Distributed COSMO	750	600	12.73
10/10 Distributed COSMO	3,000	2,093	11.60
20/20 Distributed COSMO	12,000	8,169	10.80
50/50 Distributed COSMO	75,000	50,632	10.06







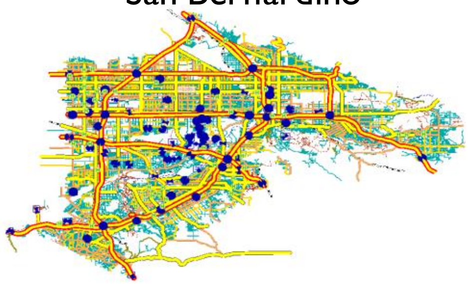
Numerical Results

- **Baseline Scenario (the Greater Los Angeles Area)**
  - Terminal, Destinations with demand label
  - Routes: Road Network
  - 5 Sub-level service network

Santa Monica-Downtown LA

Covena

San Bernardino



Long Beach

Irvine

Numerical Results

Data Source

- Southern California Association of Governments (SCAG)
- Warehouse data: Longitudinal Employer-Household Dynamics datasets, 2003 and 2015
- Customer data: Longitudinal Employer-Household Dynamics datasets, 2003 and 2015

Evaluation Scenarios

- Centralized method: too much computational load, cannot accomplish outputting an assignment for freight transportation system
- Distributed-COSMO(Co-Simulation Optimization) with warehouse/customer datasets (2002/2003, 2003/2015, 2015/2003, 2015/2015) and different outbound rates(0, 20%, 40%, 60%, 80%, 100%), to east through San Bernardino

Numerical Results

	0	0.2	0.4	0.6	0.8	1
2003warehouse2003customer	2.92E+12	4.36E+12	6.21E+12	7.95E+12	9.83E+12	1.16E+13
2015warehouse2003customer	3.04E+12	4.51E+12	6.56E+12	8.38E+12	1.02E+13	1.2E+13
2015warehouse2015customer	2.83E+12	4.27E+12	6.25E+12	7.94E+12	9.67E+12	1.14E+13
2003warehouse2015customer	2.68E+12	3.99E+12	5.82E+12	7.48E+12	9.23E+12	1.09E+13

2015 customer demand:1667070

2003 customer demand:1755545

- With increasing outbound demand, decentralized distribution of warehouses tend to have a lower cost on vehicle travel time

Conclusions

- We solved a large-scale traffic assignment problem with a distributed, simulation-based load balancing method
- The system incorporates road network, service networks and load balancing algorithm
- The method is experimentally presented to provide a local optimal solution for a large-scale traffic assignment problem

Future work

- Subnetworks: optimal partioning of road network based on multiple factors
- Load balancing strategy: reinforcement learning
- New technologies on freight vehicle industries: electric, hybrid, hydrogen, etc.
- Real-time assignment and much demanding time window

Thank you!