CPS: Medium Collaborative Research: Smart Freight Transport Using Behavioral Incentives

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Motivation

- Modeling based on pure mathematical formulations cannot accurately capture the interactions of passenger and truck flows.
- Therefore, traffic simulation models are introduced into a mathematical optimization model to help estimate the transportation network states.
- Better truck routing solutions can be generated by balancing non-homogeneous traffic flows in both time and space.
- The computational complexity of a centralized CO-SiMulation Optimization (COSMO) method increases exponentially with the size of the targeted network. A distributed version is necessary to achieve the benefits of algorithmic performance and computational speed.
- It is essential to improve the reliability of the pickup and delivery service in an urban setting where travel times are stochastic and time dependent.

Proposed SCOBE Approach

- Simulation models are used to generate/predict the dependencies of link states on time, space and added loads.
- Utility functions for each user or class of users are established and updated based on new data.
- Utility function information and payment incentives are used by the cost minimizer and load-balancing controller in an iterative procedure that leads to a lower cost at each iteration until the procedure converges or a stopping criterion is satisfied.
- The aim of the central coordinator is to achieve system optimality while providing user benefits which are attractive enough to attract participation.

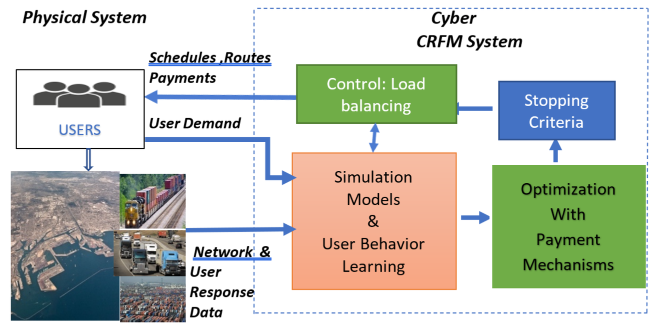


Figure 1 SCOBE Approach for Cyber CRFM System

Personalized Route Recommendations with System Optimality Considerations

- Step 1: Cluster the drivers into distinct groups
- Step 2: Learn the utility function of each cluster
- Step 3: Solve the optimum routing problem that provides behavioral incentives

Utility learning $\quad \text{minimize} \quad \mathcal{L}(\theta_i, x, y)$

where
$$\mathcal{L}(\theta_i, x, y) = -\frac{1}{M}\sum^{M} y_m log(s(\theta_i, x_m)) + (1-y_m)log(1-s(\theta_i, x_m))$$
$$s(\theta_i, x_m) = \frac{1}{1+\exp(J_i(\theta_i, x_{m1}) - J_i(\theta_i, x_{m2}))}$$

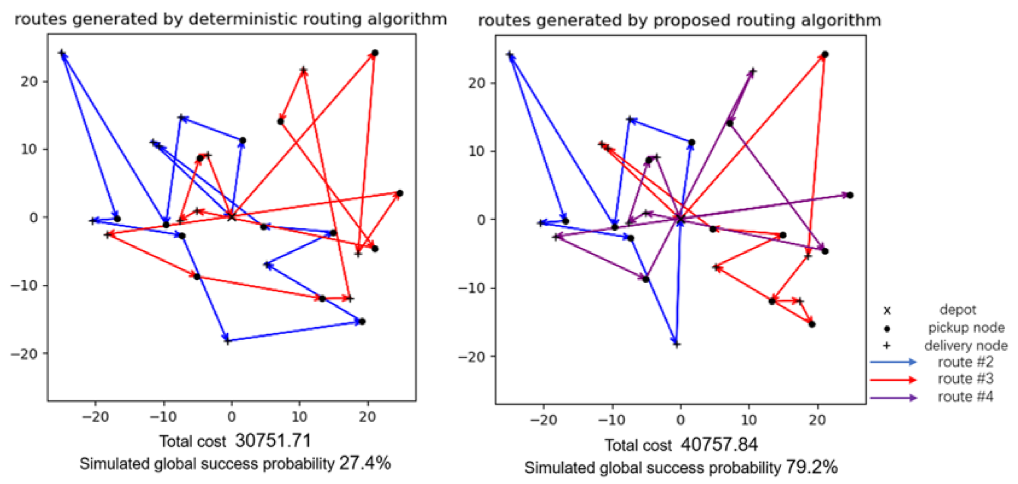
Optimum Routing with Behavioral Incentives

$$\underset{\alpha(\cdot),\pi(\cdot)}{\text{minimize}} \quad \lambda(\mu E[T_{tr}(\alpha)] + (1-\mu)E[T_p(\alpha)]) - (1-\lambda)E[U_{tr}(\alpha)]$$
$$\text{subject to} \quad \sum_c \sum_{r\in R_w} p_c \alpha_{i,r}^{c,w}\left(J_{i,r}^{c,w}(\theta, x_r(\alpha)) + \pi_r^{c,w}\right) \geq \max_{r\in R_w} \sum_c p_c J_{i,r}^{c,w}(\theta, x_r(\alpha)),\ \forall w, i$$
$$\sum_c \sum_{w=1}^{v} \sum_i \sum_{r\in R_w} p_c d_i^{c,w} \alpha_{i,r}^{c,w} \pi_r^{c,w} = 0$$
$$\sum_{r\in R_w} \alpha_{i,r}^{c,w} = 1,\ \forall c, w, i$$
$$\alpha_{i,r}^{c,w} \geq 0,\ \forall c, w, i, r$$

Pickup and delivery problem with stochastic and time-dependent travel times

- The model was formulated as a chance-constrained integer optimization problem with a set-partitioning formulation.
- An exact algorithm based on a branch-cut-and-price was proposed to solve the problem. In the pricing problem, a new labeling algorithm and dominance rules are designed to deal with stochastic travel times and probabilistic information.

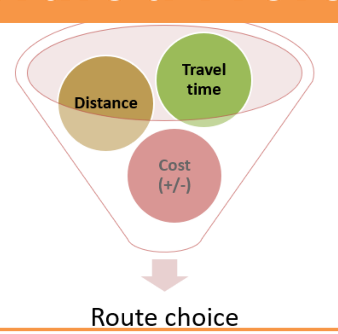
$$\begin{aligned} \textit{minimize} \quad & \sum_{r\in R} c_r x_r \\ \textit{s.t} \quad & \sum_{r\in R} a_{ir} x_r = 1 \qquad \forall i \in N_p \\ & \sum_{r\in R} x_r\, ln(P^r) \geq ln(\Theta) \\ & x_r \in \{0,1\} \qquad \forall r \in \mathcal{R} \end{aligned}$$



Driver Stated Preference Survey

Objectives: Obtain data from short-haul drayage truck drivers on behaviors and preferences in choosing delivery routes

Develop incentives for alternative trip route/time of day from estimated utility functions and value of time



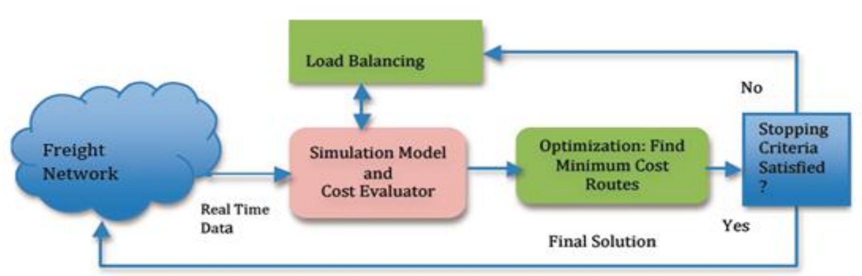
- Step 1: Develop stated preference SP survey using D-efficient design with attributes of distance, usual travel time, maximum travel time, and toll $
- Step 2: Use Sawtooth Software by Lighthouse Studio to construct SP question blocks based on fractional factorials (orthogonal design)
- Step 3: Conduct survey at ports and fleets over a 3-month time frame
- Step 4: Develop utility functions using logit modeling in STATA for main and interaction effects comparing driver type (fleet employee versus owner operator), length of trip, and other dimensions

Project Objectives

- Develop the theoretical foundations of a new approach referred to as SCOBE (co-Simulation Control and Optimization with BEhavioral incentives) for a Coordinated Regional Freight Management (CRFM) system which generates schedules, routes and payments for freight by minimizing a social cost function that takes into account the user response described by estimated utility functions.
- Develop a complete solution framework that enables truck reuse with the COSMO approach in the daily freight movements, providing complete routing and touring solutions for truck drivers.
- Develop a distributed COSMO method that is applicable to large-scale road networks with an efficient network decomposition scheme.
- Find a routing solution with minimum operational cost that guarantees a certain success rate for each customer node and for the overall solution.
- Propose a chance-constrained model for the pickup and delivery problem with hard time windows considering stochastic and time-dependent travel times, and develop an exact solution method based on branch-cut-and-price.
- Collect real world data by building a survey whose respondents are truck drivers in Southern California.
- Integrate the research results to the University educational program.

CO-SiMulation Optimization (COSMO) Approach

- Traffic Simulation models are used to estimate the load-dependent transportation network states.
- A Load Balancing Algorithm is designed to balance truck flows over time and space to avoid traffic congestions.
- The aim of the procedure is to minimize system costs and provide the best routing solution for truck drivers given the daily demand.



Freight Routing and Touring with COSMO

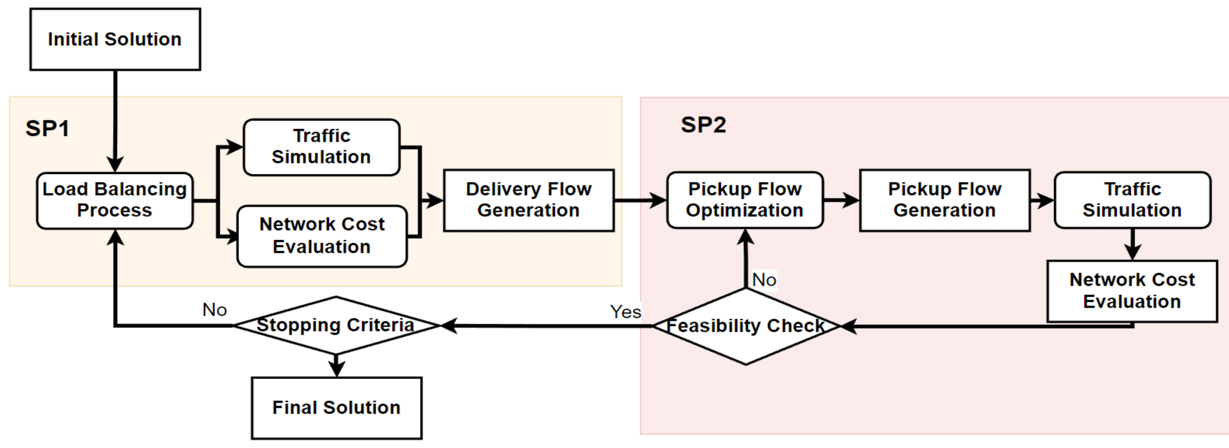
Iteratively solve the following two subproblems and update traffic assignments in the simulation model until stopping criteria reached:

(1) Delivery flow optimization (SP1)

The problem is a load balancing problem which can be solved by the COSMO approach.

(2) Pickup flow optimization (SP2)

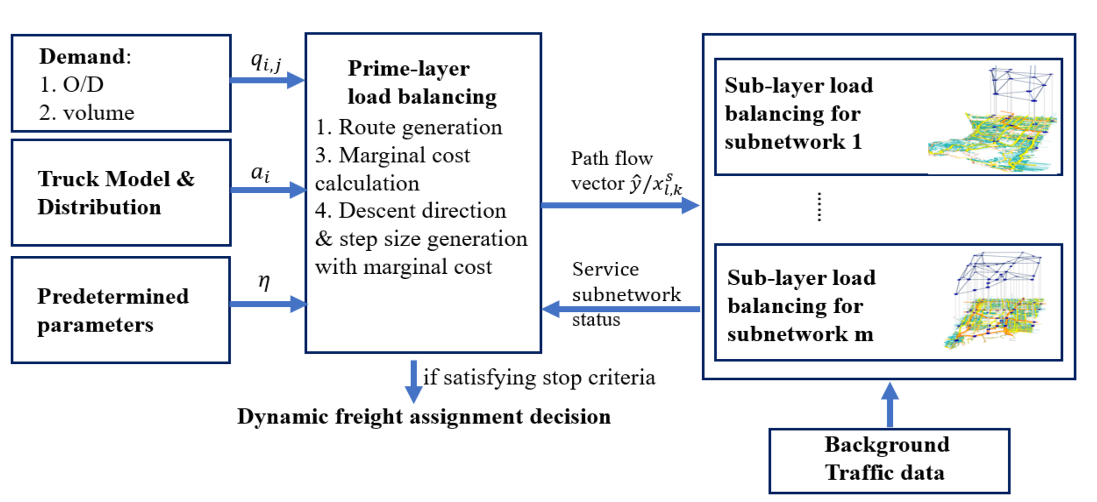
Using the solution and network states from (1), find the next pickup location for idle trucks that minimizes the fleet size and travel costs. The optimal solution can be found using a linear programming relaxation.



Distributed COSMO for Freight Routing

Problem:	Dynamically route freight trucks across the large-scale transportation network with a load balancing scheme
Objective:	Minimize total cost consisting of vehicle usage costs and travel time values
Constraints:	Demand conservation; Vehicle availability among service nodes
Algorithm:	Decompose the problem into a prime problem and several subproblems; Load balancing scheme solves the prime-layer problem and the COSMO method solves the subproblems

- Step 1: Divide the road network into subnetworks
- Step 2: For each subnetwork, create an associated service subnetwork. Create an abstracted service network.
- Step 3: Solving the prime problem based on abstracted service network and service subnetworks using load balancing scheme. Output the solution to each subproblems.
- Step 4: Solving the subproblems based on service subnetwork and road subnetwork using COSMO method and updating the dynamics of a road network backward.



Futures in Transportation (FIT) Education for Local High Schools

Objectives:	Expose local high school students from under-represented groups in engineering to transportation/ STEM-related fields and research, with an emphasis on freight. Involve USC undergraduate and graduate students in developing content and leading exercises	**Topics/activities:**	Supply chain management Lean manufacturing exercise Autonomous vehicles Routing Clean fuels Fieldtrip to Foothill Transit Guest speakers including Port of Long Beach Attend several in-person classes	**Spring 2022 (2nd offering)**	On campus at USC Total hours = 25 38 students from Hybrid High
				Spring 2023 (3rd offering)	Planned

2022 NSF Cyber-Physical Systems Principal Investigator's Meeting
Nov. 2022

Award ID#: 1932615