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Inventory and Fleet Purchase Decisions under a Sustainable Regulatory Environment

International Urban Freight (I-NUF) Conference
Long Beach, CA

Miguel Jaller

Associate Professor, Civil & Environmental Engineering,
Co-Director, Sustainable Freight Research Center,
Institute of Transportation Studies (ITS),
University of California, Davis

Carlos Otero

Rubén Yie

Background

Freight system in California

Economy and Employment

- $650-740 billion
- 32% of the California economy
- ~5 million jobs in freight-related industries
- 33% of California jobs

Freight Transported

- 2/3 Within California

Freight Transport Produced

- 50% of diesel PM
- 45% of the nitrogen oxide
- 24.2% of GHGs

Projections 2025

- 25% increase in volume
- 70% increase in commodity value

Sources: Freight Analysis Framework Data by U.S. Department of Transportation 2012

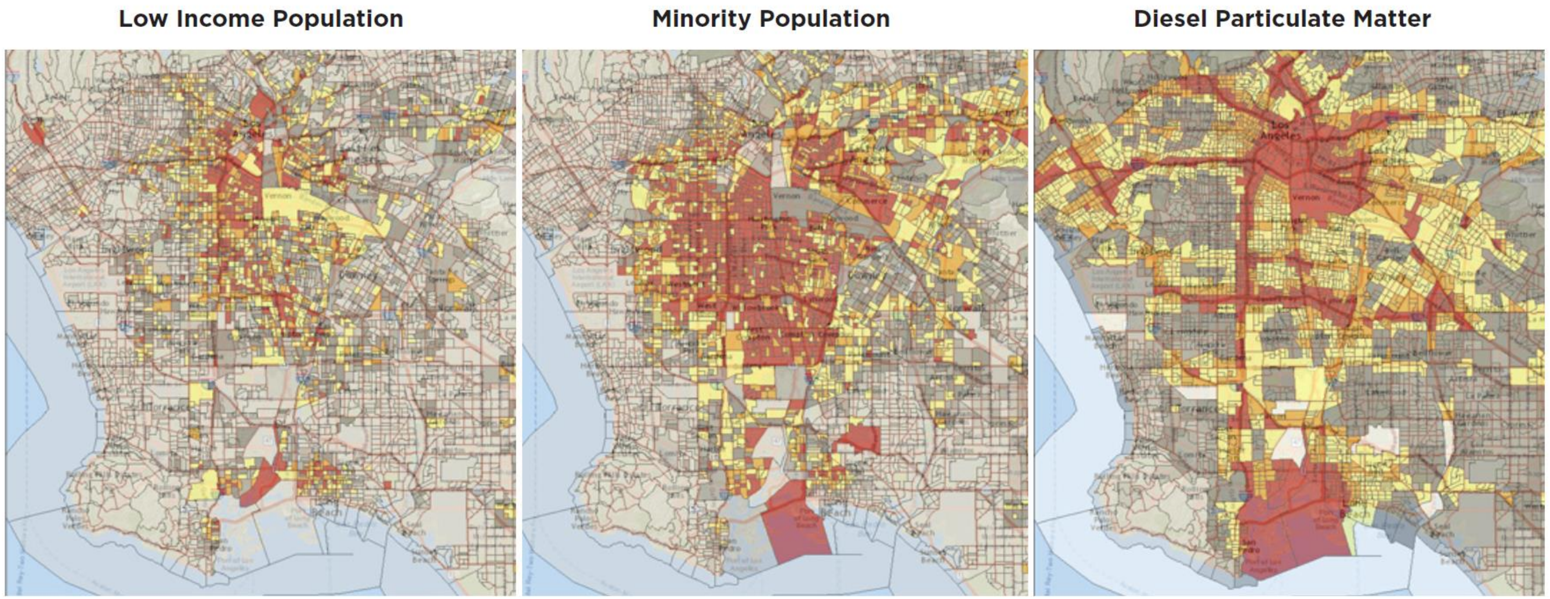
EDD, Labor Market Information Division, 2014

Background

Major environmental, social and equity issues in the State

Freight transportation, a major source of environmental impacts

Several non-attainment zones



Maps of the Los Angeles area suggest the correlation of air pollution (diesel particulate matter in this example) to income and race.

Notes: "Minority population" refers to the fraction of California's population that is all but non-Hispanic white. "Diesel particulate matter" represents the amount of this pollution in a given area relative to other areas in California. "Low income population" refers to the percent of Californians whose household income was less than two times the poverty level in the past 12 months. Percentiles are as follows: yellow: 80–90 percent; orange: 90–95 percent; red: 95–100 percent. Percentiles are relative to California's population.

SOURCE: EPA 2016B.

http://www.ucsusa.org/clean-vehicles/electric-vehicles/freight-electrification

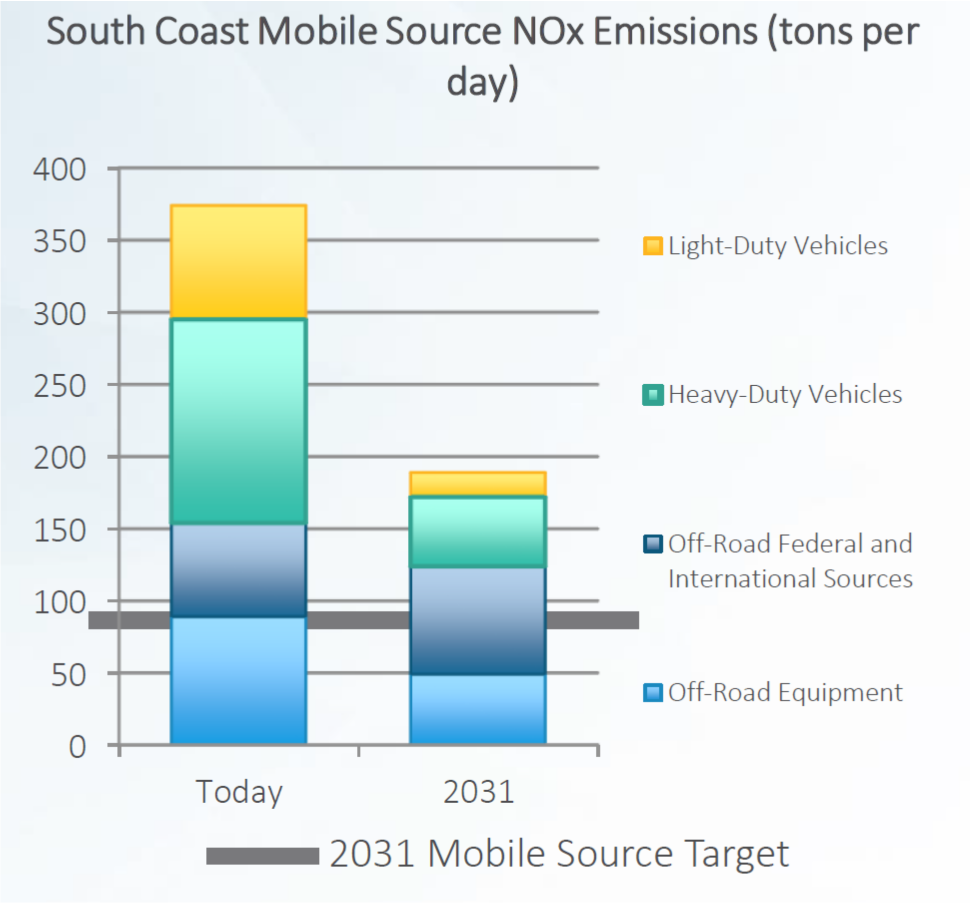
Major Improvements Needed

From GHGs to criteria pollutant reductions

Example: NOx emissions

Nearly all trucks to have 2010 model year engines by 2023

- Mobile source emissions reduced more than 50%
- Trucks and bus emissions reduced by nearly 70%



Source: CARB

The Role of Zero and Near Zero Emission Vehicles

Trucks are a major source of emissions

There are many programs and regulations in place or imminent fostering the use of ZEVs in the State

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Examples of 2030 targets:

California Sustainable Freight Action Plan (CSFAP)

- Improve freight system efficiency by 25%
- Deploy over 100,000 freight vehicles and equipment capable of zero emission operation; and
- Foster future economic growth within the freight and goods movement industry

Advanced Clean Truck (ACT) Program

- Manufacturer sales requirement (ZEVs as a percentage of sales)
- Large company and fleet reporting requirements (2021)

Senate Bill 44 'Medium-duty and Heavy-duty Vehicles: Comprehensive Strategy'

Assembly Bill 1411 'Integrated Action Plan for Sustainable Freight'

- Deploy 200,000 zero-emission vehicles and equipment

ACT

2024 – 2030 requirements

Manufacturer sales

Post 2030?

Zero Emission Fleet Directive

Fleet purchase requirements

Model Year (MY)	Class 2B-3[1]	Class 4-8	Class 7-8 Tractors
2024	3%	7%	3%
2025	5%	9%	5%
2026	7%	11%	7%
2027	9%	13%	9%
2028	11%	24%	11%
2029	13%	37%	13%
2030[2]	15%	50%	15%

1. Excludes pickups until 2027 MY
2. 2030 MY requirements continue after 2030

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Today

Many incentive programs

HVIP
Low NO_x engines, ZEVs plus infrastructure, advanced technology
FY 18-19
$125 M

VW
Zero-emission truck and bus replacements
$423 M

Carl Moyer
Cleaner engines & ZEVs plus fueling infrastructure
FY 18-19
$79 M

AB 617
Engine replacement & infrastructure in DAC
FY 18-19
$245 M

Truck Loans
Helps small businesses with 10 or fewer trucks upgrade to newer trucks

Utility Programs
Charging infrastructure service upgrades and electricity rates (SB350)
>$579 M

LCFS
Credits for using low carbon transportation fuels
Offsets Most/All Electricity Costs for Trucks and Buses

Once purchase requirements kick in…”no more” purchase incentives

Major Questions

What are the impacts of these types of regulations on logistics operations?

What are the costs?

How will these affect the very large number of very small operators?

What we are Doing…

Evaluating the potential impacts of some of these regulations:

- Reduction of the overall fleet emissions
- Fleet mix to include zero and near-zero emission vehicle technologies

Concentrating on logistics decisions:

- Changes in inventory
- Fleet composition and use

How?

We introduce a constrained Stochastic Multi-objective Joint Replenishment Problem (S-MJRP) model

We solve it with a hybrid solution algorithm based on:

- GRASP and GAs metaheuristics

S-MJRP

Traditionally, companies seek to reduce their logistics costs

e.g., to transport, to order and to hold inventories.

Reducing emissions by minimizing the transport or using more expensive vehicles may affect the frequency and shipment sizes

So… What is the trade-off between the different costs?

S-MJRP stands for Stochastic Multi-Objective (Minimizing logistics costs and CO2 emissions) Joint Replenishment Problem.

It is an extension of the classic Joint Replenishment Problem (JRP) introduced by Starr, M. K., & Miller (1962)

JRP deals with the problem of coordinating the replenishment of multiple items to a customer

By coordinating orders, the JRP reduces both ordering and holding costs

Joint inventory disaggregates at the end

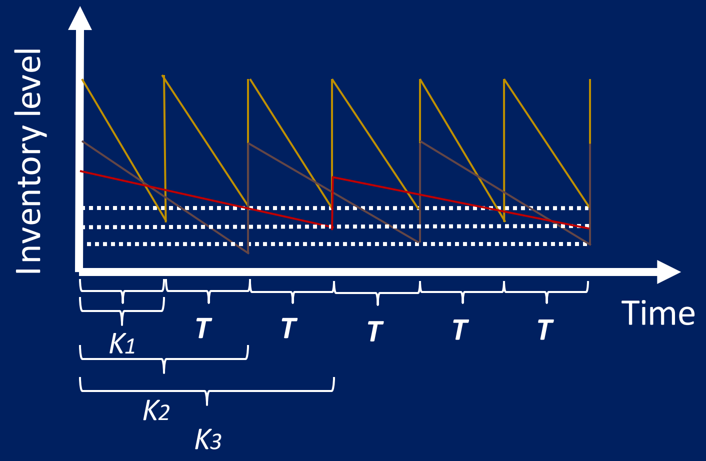
Increased cargo volume allows for reduced transport fees

JRP has high potential application in real settings

However…Even the simplest form of JRP is very computationally complex

S-MJRP

How to transport and inventory different products



Ordering Cost

Holding Cost

Transport & Fleet Cost

$Minimize: \; TC(T, k_i, x_j, F_{jm})$

$$= \left(S + \sum_{i\in I} \frac{s_i}{k_i}\right)/T + \left(\frac{T}{2}\sum_{i\in I} D_i k_i h_i + \sum_{i\in I} Z_{\alpha i}\sigma_i h_i(\sqrt{L_i + Tk_i})\right) + \left(\frac{\left(365\frac{r}{c}T\sum_{m\in\{1-H\}}\sum_{j\in J} F_{jm}x_j a_j\right)}{TH} + \sum_{j\in J} A_j x_j\right) \quad (1)$$

Warehouse cap. cons.

$Minimize: \; EI(T, k_i, x_j, F_{jm})$

$$= \sum_{m\in\{1-H\}} 365\frac{r}{c}T\sum_{j\in J} F_{jm}x_j e_j \Big/ TH \quad (2)$$

$Subject\ to:$

$$\sum_{i\in I} D_i w_i T k_i + \sum_{i\in I} Z_{\alpha i}\sigma_i w_i(\sqrt{L_i + Tk_i}) \le K \quad (3)$$

Total generated emissions

$$\left(\sum_{j\in J} A_j x_j\right) \le B$$

Budget cons.

$$\sum_{i\in I}\left(\left(1 - min\,[1,\; m - (\lfloor m/k_i \rfloor k_i)]\right) * (D_i T k_i w_i)\right) \le 365\frac{r}{c}T\sum_{j\in J} F_{jm}x_j W_j \quad \forall m \in \{1 \dots H\} \quad (5)$$

$$0 < T < 1;\; 0 \le F_{jm} \le 1;\;\; k_i, x_i: integer$$

Worse case fleet requirement cons.

Enforcing Regulatory Constraints

Reduction of the overall fleet emissions

Fleet mix to include zero and near-zero emission vehicle technologies

$$\frac{\sum_{m\in\{1-H\}} 365\,\frac{r}{c}\,T \sum_{j\in J} F_{jm} x_j e_j}{TH} \le \varepsilon E \qquad (6)$$

Requiring a reduction of the overall fleet emissions

$$\frac{\sum_{j\in J^v} x_j}{\sum_{j\in J} x_j} \ge \gamma^v, \qquad \forall\, v \qquad (7)$$

Requiring a fleet mix to include zero and near-zero emission vehicle

Solution Method

Random Evolutionary three-level meta-heuristic (MH3)

- Exponential number of feasible solutions
- Non-linear non-continuous nature

Problem decomposition:

1. Solutions for T and K's
2. Solutions for X's for given T and K's

Based on:

- Genetic Algorithms
- Greedy Randomized Adaptive Search Procedure (GRASP)

GA (Level 1)

- **Step 1:** Generate initial population of $(T, K\text{'}s)$.
- **Step 2:** For each chromosome:

GRASP (Level 2)

- **Step 1:** for a given $(T, K\text{'}s)$, generate a random set of possible (X's).
- **Step 2:** create a Pareto front base on a relaxed fitness function.

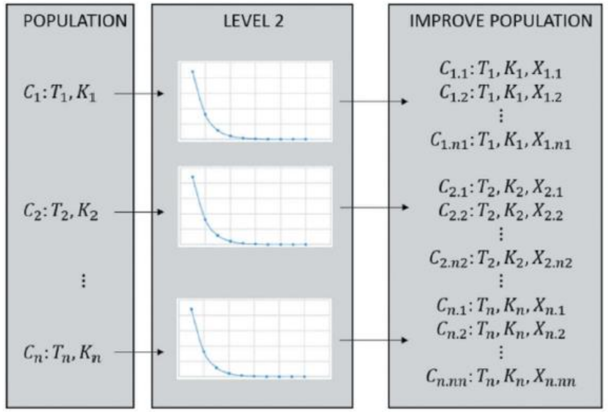
- **Step 3:** Apply GA functions.
- **Step 4:** If last Generation go to step 6, otherwise go to step 5.
- **Step 5:** Create new population, then go to Step 2

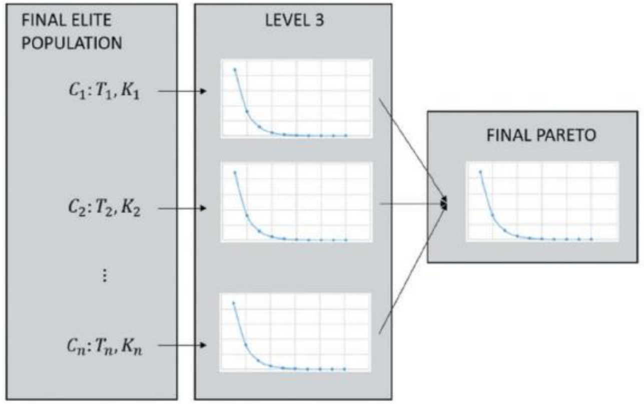
- **Step 6:** Drop the (X's) genes from the chromosomes on the elite population.
- **Step 7:** For each $(T, K\text{'}s)$ in the elite population:

GA (Level 3)

- **Step 1**: Run A complete GA to generate stronger solutions based on a given $(T, K\text{'}s)$.
- **Step 2**: cumulate the solutions on a general solution set.

- **Step 8:** Apply elitism function for the general solution set, this result is our Solution Pareto front .





Empirical Analyses

Integrated supplier-retailer operations

Single echelon distribution

Families of homogeneous products

Normally distributed demands

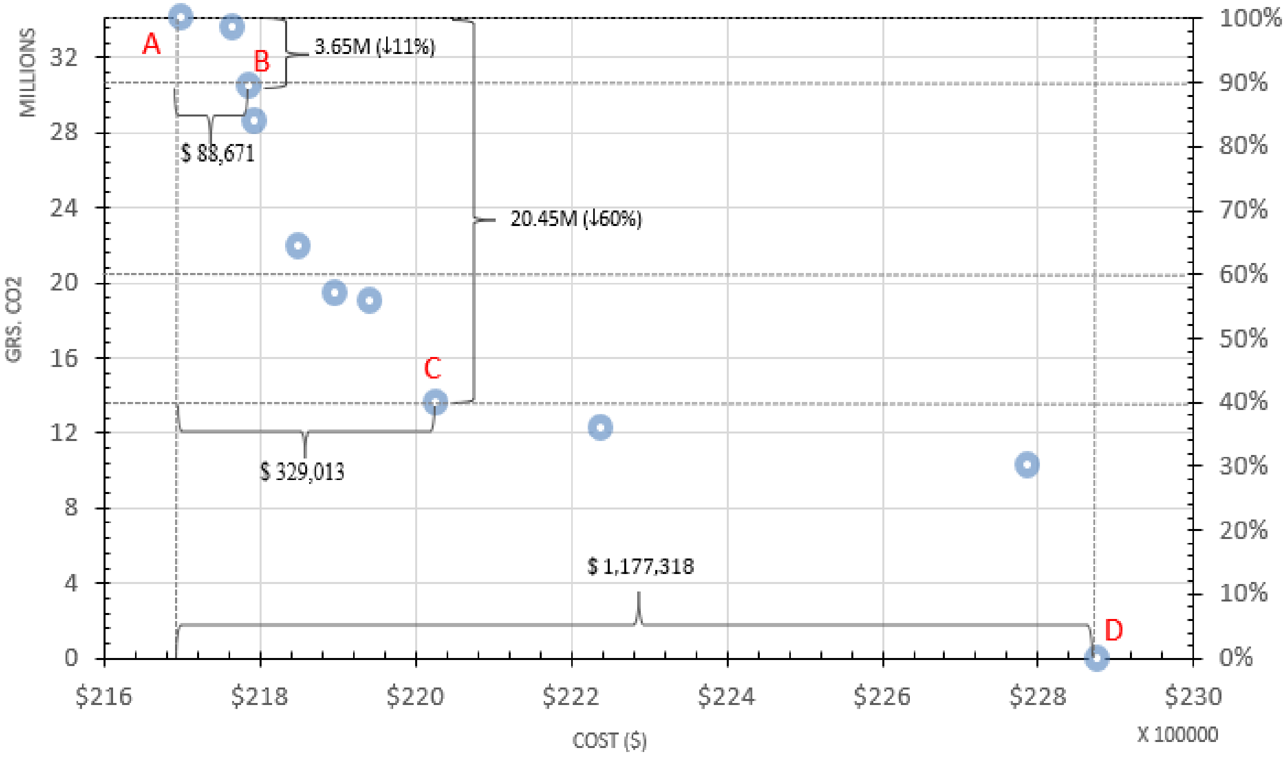
We consider:

- Diesel, Battery Electric, Hybrid Electric
- And for-hire diesel trucks at a flat rate

	Diesel	Rented	Hybrid	EV
Operational cost $/mile	0.71	10	0.63	0.44
Purchase cost $/vehicle ($A_i$)	160,000	0	250,000	290,000
Vehicle cap. mts3/unit (W_i)	75	75	63.75	52.5
Emissions grs/shipment (e_i)	1667.32	1667.32	1167.12	0

Parameter	1	2	3	4	5	6	7	8	9	10
Annual demand (D_i)	700,000	500,000	400,000	55,000	40,000	600,000	450,000	500	450	400
Minor cost $/shipment ($s_i$)	90	100	135	400	475	80	130	1000	1000	1500
Holding cost $/unit ($h_i$)	10	12	12	12	12	10	10	15	15	15
Unit weight mts3 (w_i)	0.25	0.75	0.5	2	4	0.25	0.75	4	4	4
$Z_{\alpha i}$	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64
Standard deviation (σ_i)	35,000	65,000	25,000	4,000	4,500	65,000	70,000	50	60	20
Lead time yrs./shipment (L_i)	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03

Results



Solution	% EV in fleet	% Emission reduction	% Incr. transportation cost	% Incr. replenishment cost	Required fleet invest.
1 (A)	0.0%	0.0%	0.00%	0.00%	$ -
2	0.0%	1.0%	32.87%	0.31%	$ 1,480,000
3 (B)	6.7%	11%	43.38%	0.41%	$ 1,700,000
4	18.8%	16%	46.25%	0.44%	$ 1,850,000
5	43.8%	36%	74.15%	0.70%	$ 3,150,000
6	52.9%	43%	97.20%	0.92%	$ 3,890,000
7	50.0%	44%	119.34%	1.12%	$ 3,930,000
8 (C)	57.9%	60%	160.97%	1.52%	$ 5,190,000
9	76.9%	64%	264.19%	2.49%	$ 7,300,000
10	61.9%	70%	189.07%	5.01%	$ 5,770,000
11 (D)	100%	100%	232.71%	5.43%	$ 6,670,000

Solution	Diesel		For-Hire		Hybrid		EV	
1 (A)	-	-	14	1.00	-	-	-	-
2	3	1.0	8	1.00	4	1.00	-	-
3 (B)	1	1.0	8	1.00	5	1.00	1	1.00
4	3	1.0	8	0.92	2	1.00	3	1.00
5	7	1.0	2	1.00	-	-	7	1.00
6	8	1.0	-	-	-	-	9	1.00
7	2	1.0	3	1.00	4	1.00	9	1.00
8 (C)	-	-	-	-	8	1.00	11	1.00
9	-	-	-	-	6	0.65	20	0.79
10	-	-	-	-	8	0.75	13	1.00
11 (D)	-	-	-	-	0	-	23	0.88

Each Colum: Number / Use rate

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Conclusions and Insights

New SB1 Project

"Development of a Logistics Decision Support Tool for Small and Medium Companies to Evaluate the Impacts of Environmental Regulations in California"

The ratio emission reductions/investment is not linear.

E.g.,

reducing emissions by 60% increases:

- Replenishment costs by 1.52%,
- Transportation costs by 160.97%.

To reduce the remaining 40% of emissions, increases

- Replenishment costs by 5.43%
- Transportation by 232.71%.

Understanding of the impacts of environmental policies on logistics operations, can inform and help design more appropriate support programs

Given that different companies have different logistics dynamics, we need to consider the allocation of benefits

Questions!

- Contact info:

  mjaller@ucdavis.edu