Department of Civil and Materials Engineering
COLLEGE OF ENGINEERING

Green Urban Freight Strategies in the New Mobility Era

Jane Lin, Ph.D.
janelin@uic.edu

Northwestern University
May 14, 2015

Urban Freight Challenges

- **Urban mobility is one of the toughest challenges cities face.**
  - By 2050, 70% of the population (6.3 billion people) live in urban areas
- **Environmental and energy concerns are taking center stage.**
  - Transportation accounts for 29% of total GHG emissions in US (within which, 19% is from freight trucks)
  - Freight trucks are the primary contributor of $PM_{2.5}$ emissions
    - Diesel-powered trucks emit $PM_{2.5}$ 40 times higher than gasoline vehicles
  - Freight transport accounts for 74% of total transportation energy consumption
  - Fuel cost contributes 39% of the operating cost in the trucking industry
- **E-commerce industry is demanding faster and cheaper urban delivery service.**
  - Increasing volume of goods transportation, especially in smaller packages
  - Increasing demand for just-in-time (same day) and reliable delivery.

Urban Freight Opportunities

- **Large amount of under- or un-utilized vehicle capacity**
  - According to the Texas Commercial Vehicle Survey data, about 28% of all goods trips on a given day were empty and less than 20% were fully loaded during the 2005-2006 survey period
  - Trucks in Japan operated with an average load factor around 30%-40%, and downward between 1970-1997 (Taniguchi and Thompson, 2003)
  - In Europe, truck load factors were found generally under 50% (by weight) and declined between 1997 and 2008 (European Environment Agency 2010)
  - Vast number of passenger vehicles with empty trunk space

- **New and emerging urban mobility technologies enabled by**
  - Rapid advances in wireless communication and ubiquitous mobile computing
  - New vehicle technologies

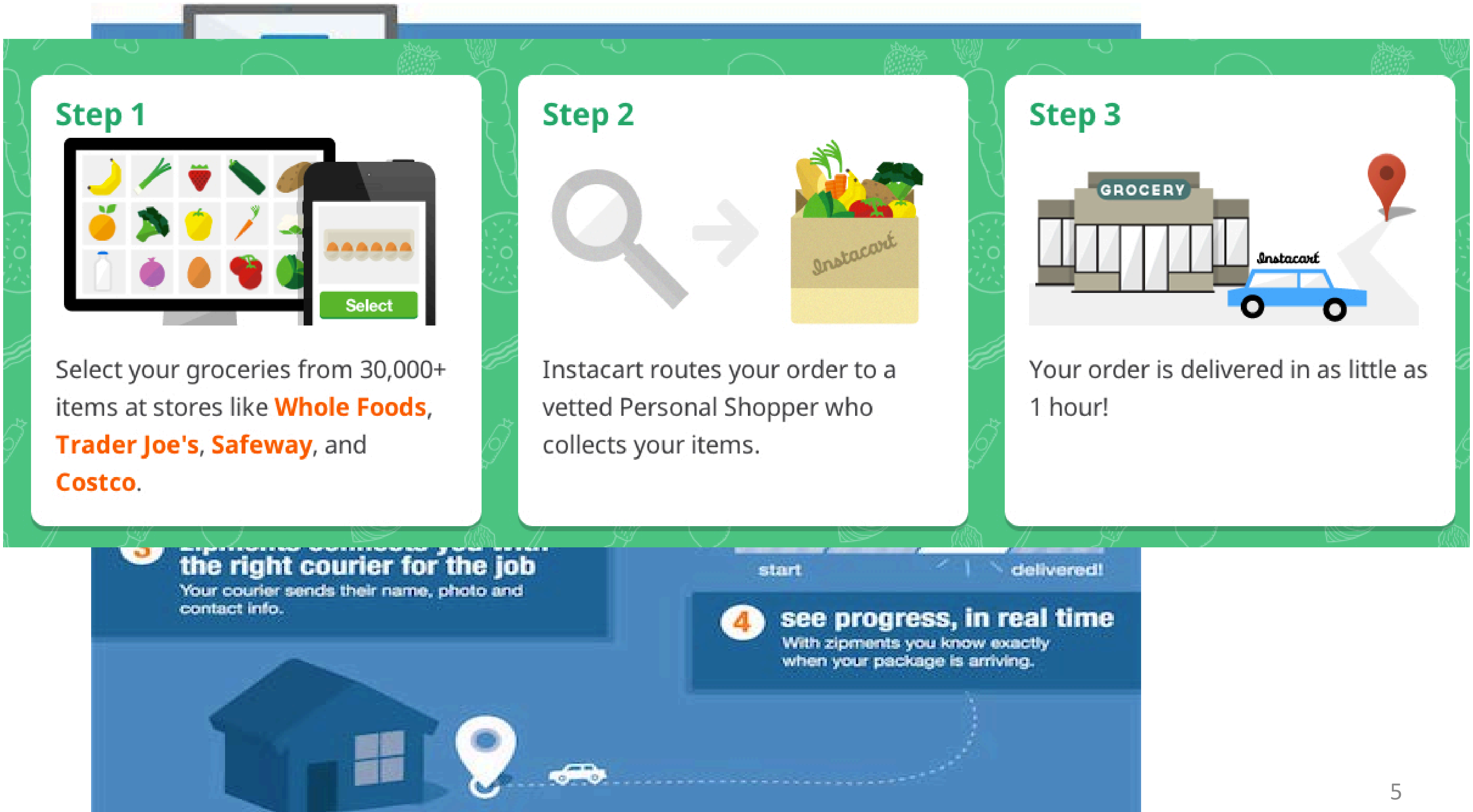
New/Emerging Urban Mobility Technologies

- Ridesharing and Cargo sharing

Coyote Logistics Carriers Mobile App

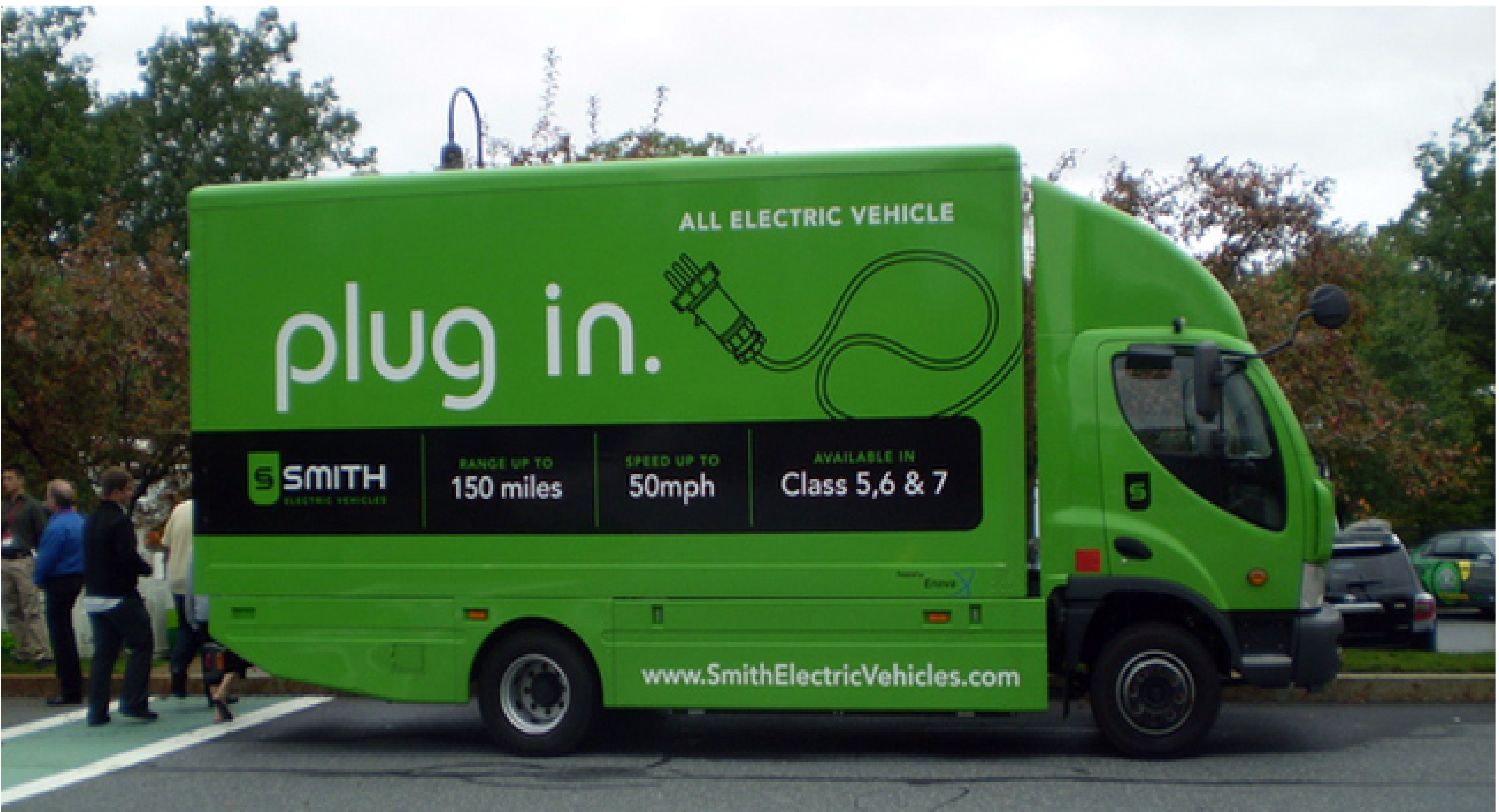
New/Emerging Urban Mobility Technologies

- Crowd-sourced Mobility Service



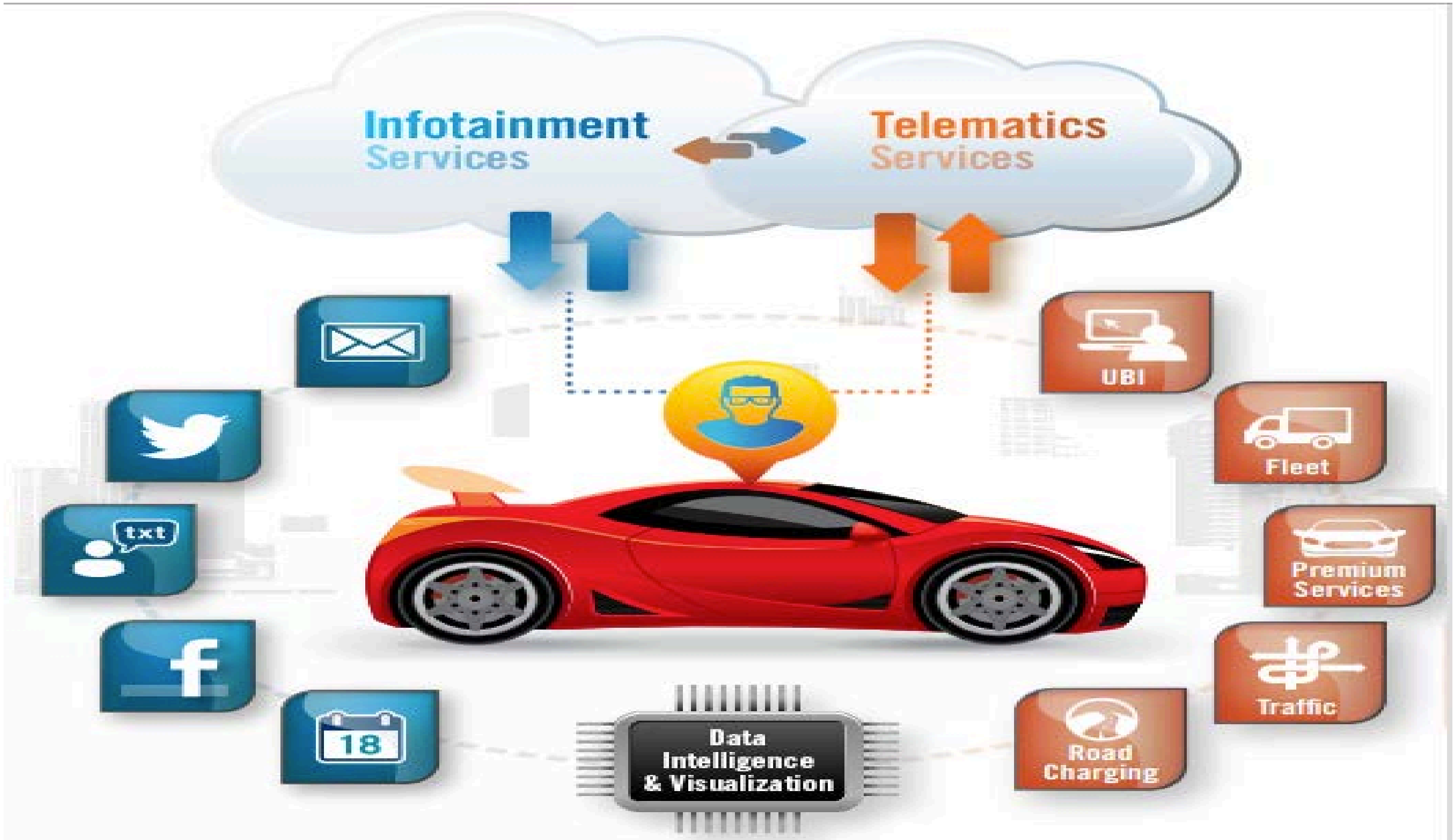
New/Emerging Urban Mobility Technologies

- New Vehicle Technology
  - ➢Electric Vehicle



New/Emerging Urban Mobility Technologies

- New Vehicle Technology
  - ➢Connected Vehicle



New/Emerging Urban Mobility Technologies

- New Vehicle Technology
  - ➢Autonomous Vehicle (drone)

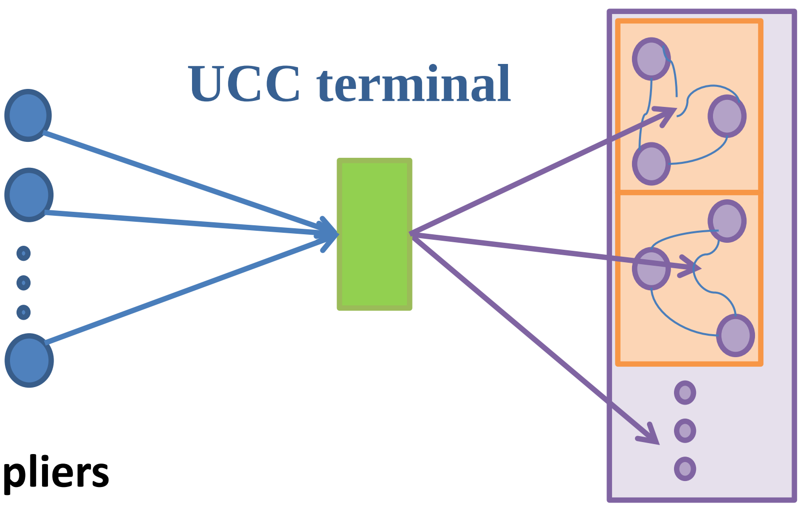
Urban Freight Consolidation Strategies

- **Urban Consolidation Center (UCC)**
  - “a logistics facility that is situated in relatively close proximity to the geographic area that it serves be that a city centre, an entire town or a specific site (e.g. shopping centre), from which consolidated deliveries are carried out within that area” (Browne et al., 2005)

- **Dynamic En-route Cargo Consolidation (DECC)**
  - a strategy that allows truckers to effectively manage and utilize on-board spare cargo space in response to real time demand

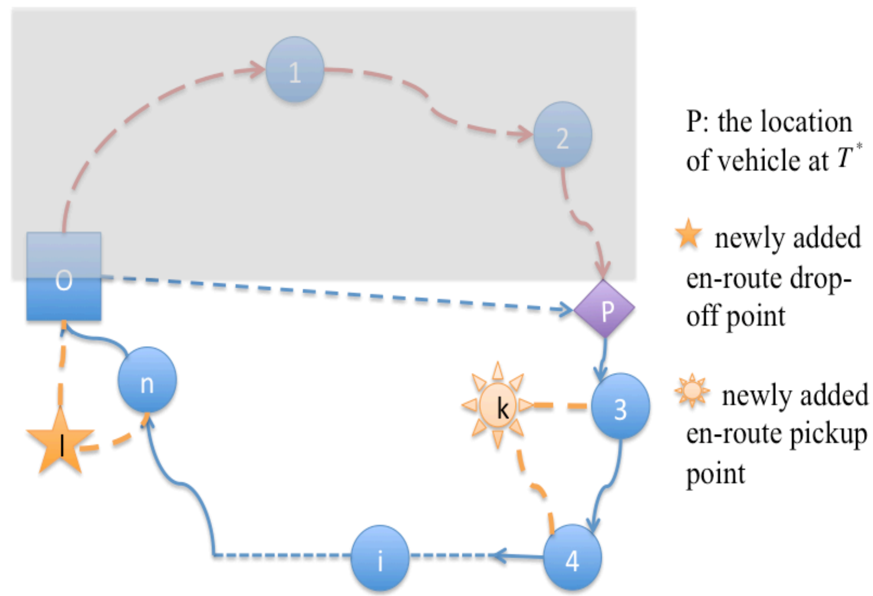
Graphic Representation of Consolidation Strategies

- **Urban Consolidation Center**



Lin et al. (2014) *Networks and Spatial Economics*, online first, DOI 10.1007/s11067-014-9235-9

- **Dynamic En-route Cargo Consolidation**



Zhou et al. (under review) *Transportation Research Part B*

(I) Evolution of UCC

Country	Total	Research / Feasibility	Pilot / Trial	Operational
Austria	1	1	-	-
Belgium	1	1	-	-
Canada	1	1	-	-
France	8	5	2	1
Germany	14	1	2	11
Italy	5	-	2	3
Japan	3	-	2	1
Monaco	1	-	-	1
Netherlands	7	3	-	4
Portugal	1	-	1	-
Spain	1	-	-	1
Sweden	4	1	1	2
Switzerland	2	-	2	-
United Kingdom	17	12	1	4
U.S.A.	1	1	-	-
Total	67	26	13	28

Source: Browne et al. (2005)

Evolution of UCC (cont'd)

- Business models of UCC
  - Carrier-oriented – heavily subsidized by government to provide incentives to attract carriers to participate
    - Most of them failed after a few years of operation due to high cost and reluctant participation from carriers for fear of loss of brand name, visibility, and customer connection
  - Receiver-oriented – business owners in central business district or residents in city center form UCC, which provides basic free last-mile delivery service and optional paid value-added services (e.g., storage rental, home delivery) to the member receivers/customers
    - Successful examples: Binnenstadservice.nl (BSS) in 2010, at Motomachi, Yokohama for shopping streets in 2004, and at Tokyo sky tree town (Soramachi) in 2012

Research Questions on UCC

- Is it cost effective to apply cooperative delivery strategy esp. in the US context?

- What the factors affect the strategy effectiveness?

- What about environmental benefits?

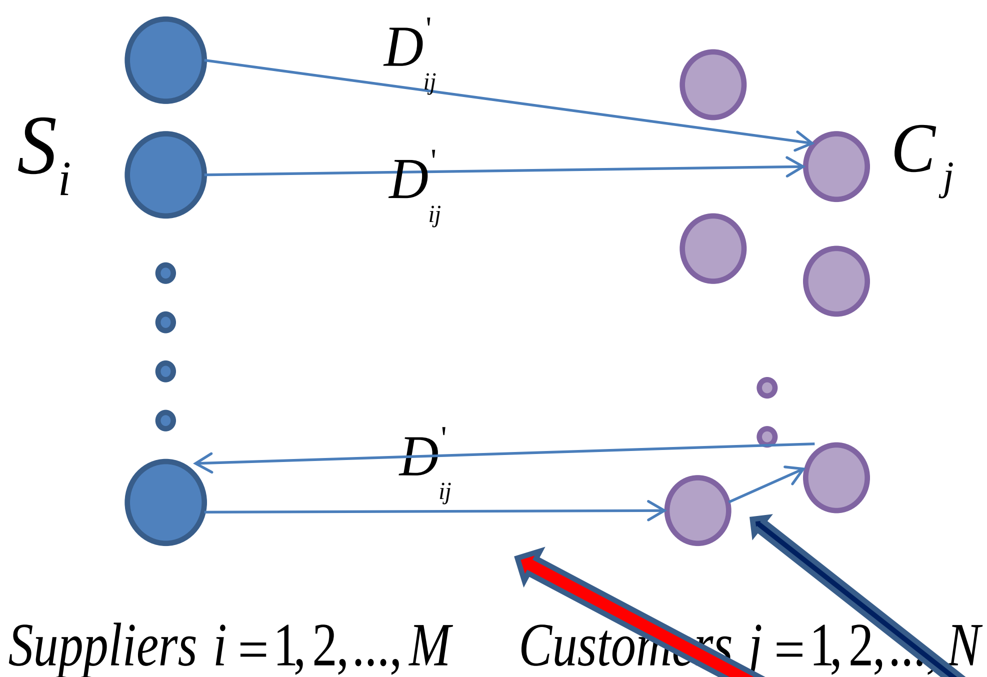
UCC Study Approach

1. Consider two urban delivery strategies:
    A. Direct delivery (without UCC) as the baseline
    B. Cooperative delivery with UCC

2. Investigate the effects of key factors on the logistics cost, energy consumption and PM2.5 emissions via a two-step model:
   (i) Distribution network model to find the optimal delivery plan and the optimal logistics cost: tactical level model using Continuous Approximation (CA) method (Daganzo, 2005)
   (ii) Environmental impact model to evaluate the vehicle energy consumption and emissions (PM2.5) from the above optimal delivery plan: MOVES (US EPA, 2010)

3. Conduct sensitivity analyses over selected factors on cost, emission and energy consumption

UCC Logistics Cost Components



Logistics cost components

Stationary Cost
(at supplier/ customer/UCC's)

- ❖Rent/Storage cost
- ❖Inventory cost
- ❖Operating cost
- ❖Loading/unloading (stop) cost

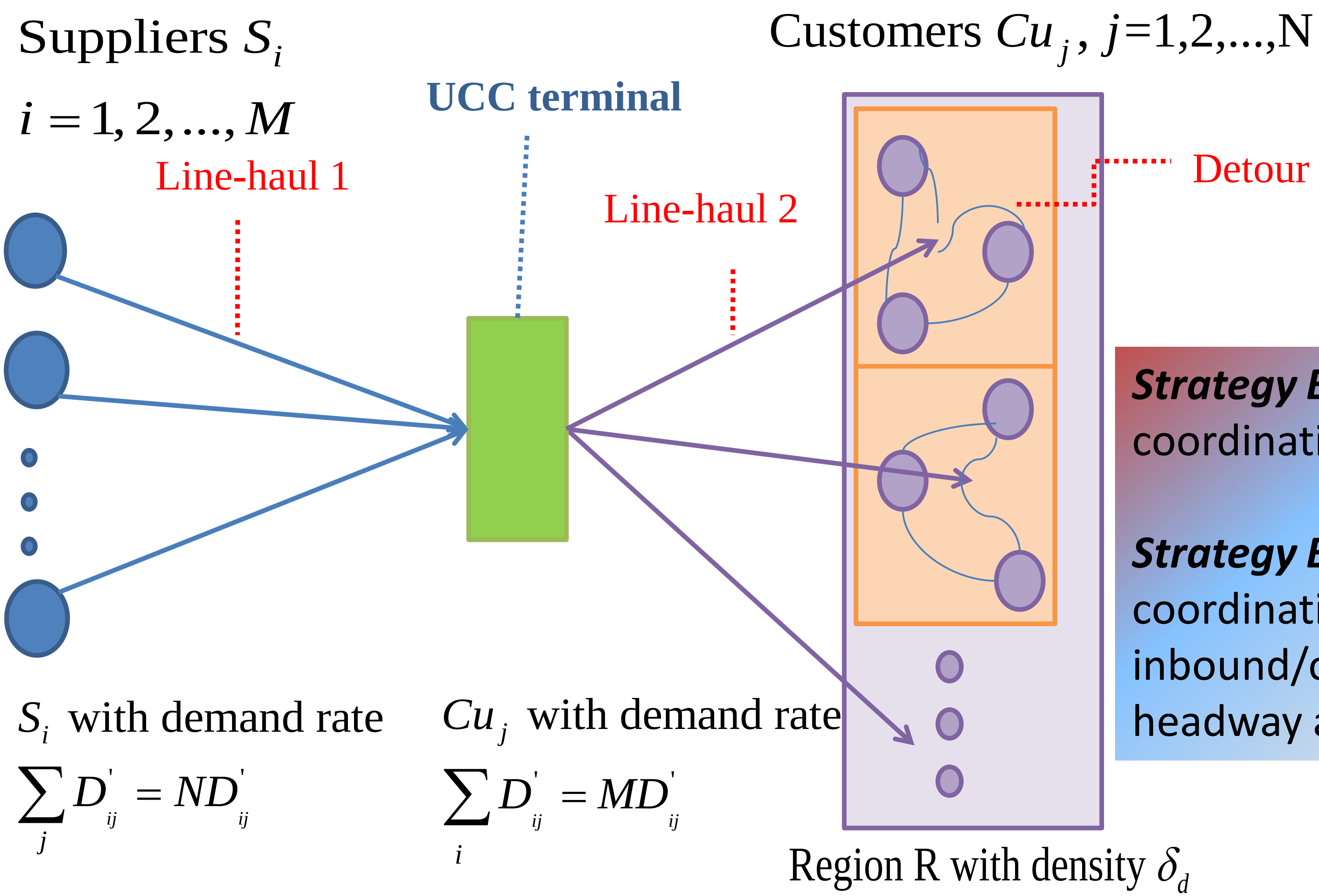
Motion Cost
(during transportation)

- ❖Detour motion cost
- ❖Line-haul motion cost

UCC Model Assumptions

- The UCC facility location is outside the urban center, fixed and known;
- The customers are **homogeneous** and **uniformly** distributed in the study with the **same demand rate** for each supplier;
- The number of customers is relatively large so multiple delivery tours are needed;
- Each supplier serves all the customers in the study area (**no discrimination**);
- Shipped goods have negligible inventory costs;
- Vehicles have a capacity constraints;
- **No reverse flow**, which means the vehicle does not collect items at the customers' and bring them back to the base;
- There is **no tour length restriction.**

UCC Model Setup



Strategy B1: without coordination at UCC

Strategy B2: with coordination of the inbound/outbound headway at UCC

UCC Model Formulation

Total Logistics Cost/unit $Z_B = Z_{Bi} + Z_{Bo} + Z_{Bt}$

$St.$

$$v_i \le V_{max}$$

$$v_o n_s \le V_{max}$$

$$n_s \ge 1$$

Capacity constraint;

At least one customer per tour.

$$Z_{Bi} = C_s^{'} + \alpha_{1Bi} / v_i$$

Inbound: transportation and loading/unloading costs

$$Z_{Bo} = C_s^{'} + \alpha_{1Bo} / n_s v_o + \alpha_{2Bo} / v_o + \alpha_{4Bo} v_o$$

Outbound: line-haul, detour, and storage costs at customer end

$$Z_{Bt} = C_r^t(\max[H_i, H_o] + H_t) + \alpha_5 / ND^{'} + \alpha_6$$

Terminal: transshipment processing time and terminal operating costs

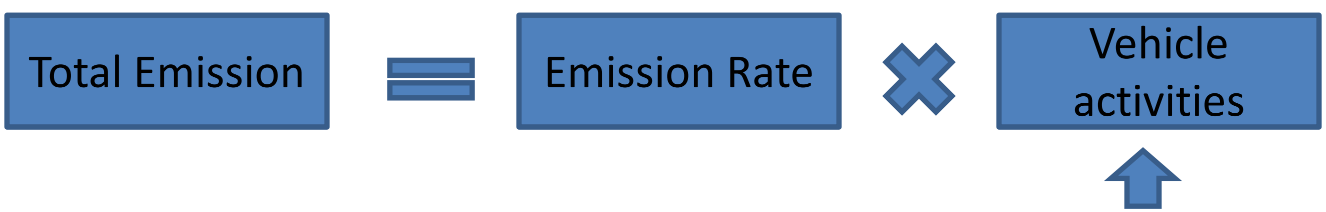
Solution B1: Solve Inbound and Outbound problem separately without coordination at UCC

Solution B2: Solve the total cost jointly with coordination of the inbound/outbound headway at UCC

Environmental Impact Model Estimation

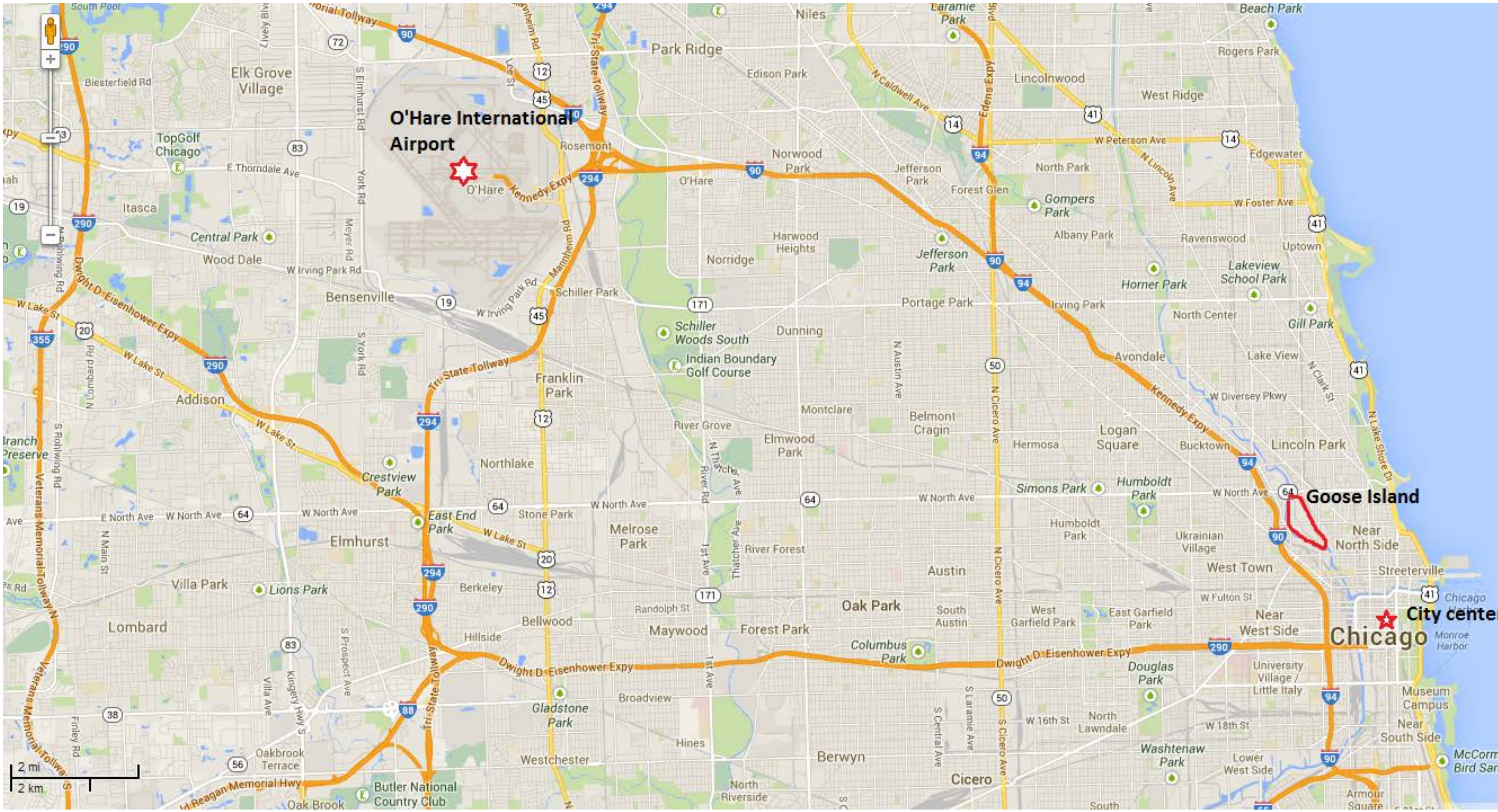
PM2.5 emission rates and energy consumption rates for diesel trucks

Pollutant	**Vehicle type**	**EF at Speed=19.36mph (grams or 10^6 joules/mile)**	**EF at Speed=44mph (grams or 10^3 joules/mile)**
PM2.5	Single unit truck	0.5899	0.1367
	Combination truck	1.5140	0.9376
Energy Consumption	Single unit truck	24.4	15.5
	Combination truck	34.3	25.0



Result from distribution network model

Hypothetical Case Study



Model Inputs

Data Source	**Data field**	**Data year**	**Variable estimated**	**Adopted value (lower/upper bound)**
D&B survey (via SimplyMap)	Number of convenient stores per zip code	2010	**Customer density** δ_d (# conv. stores/sq mi)	1.93 (0.44/24.85)
D&B survey (via SimplyMap)	Prepared food sales volume by store type (supermarket and convenient) ($/year)	2010	**Convenient store market share**	0.14 (0.01/0.65)
Census 2010 (via SimplyMap)	Zip code area (sq miles)	2010		
Census2010 (via SimplyMap)	Population per zip code	2010		
Food Environmental Altas	Prepared food demand rate (lbs/capita-year)	2006	**Customer demand rate** D' (lbs/store-day)	956.43 (31/3518)

Model Input (cont'd)

Truck type	**FHWA truck classification**	**Truck payload V_{max} (lbs)**	**Line-haul transportation cost C_{d1} (\$/mile)**	**Detour transportation cost C_{d2} (\$/mile)**
LDT	Class1	9895	0.91	2.07
HDT	Class 3	37097	1.41	3.20

Cost category	**Cost elements**	**Unit**	**Value**
Operating cost (UCC)	Fixed terminal operating cost	$/day	3460.87
	Variable terminal operating cost	$/lbs	0.059
Rent cost(UCC)	Terminal rent cost	$/lbs-day	0.022
Storage cost (customer)	Customer storage cost C_h	$/lbs-day	0.067

Model Input (cont'd)

Notation	Explanation	Unit	Adopted Value[1]
r	Line-haul distance in direct delivery	Miles	25.00
$r1$	Supplier-UCC line-haul distance	Miles	20.00
$r2$	UCC-customer line-haul distance	Miles	5.00
K	Dimension less parameter[1]		0.82
M	Number of suppliers	/	5.00
N	Number of customers	/	375.00
C_s	Fixed stop cost (invariant to shipped volume)	\$/stop	10.32
$C_s^{'}$	Variable stop cost (depending on shipped volume)	\$/lbs	0.002
H^t	Fixed terminal process time	Days	0.083
n_s	Number of stops in a delivery tour	(decision variable)	
v	Delivery lot size from one supplier to one customer	(decision variable)	

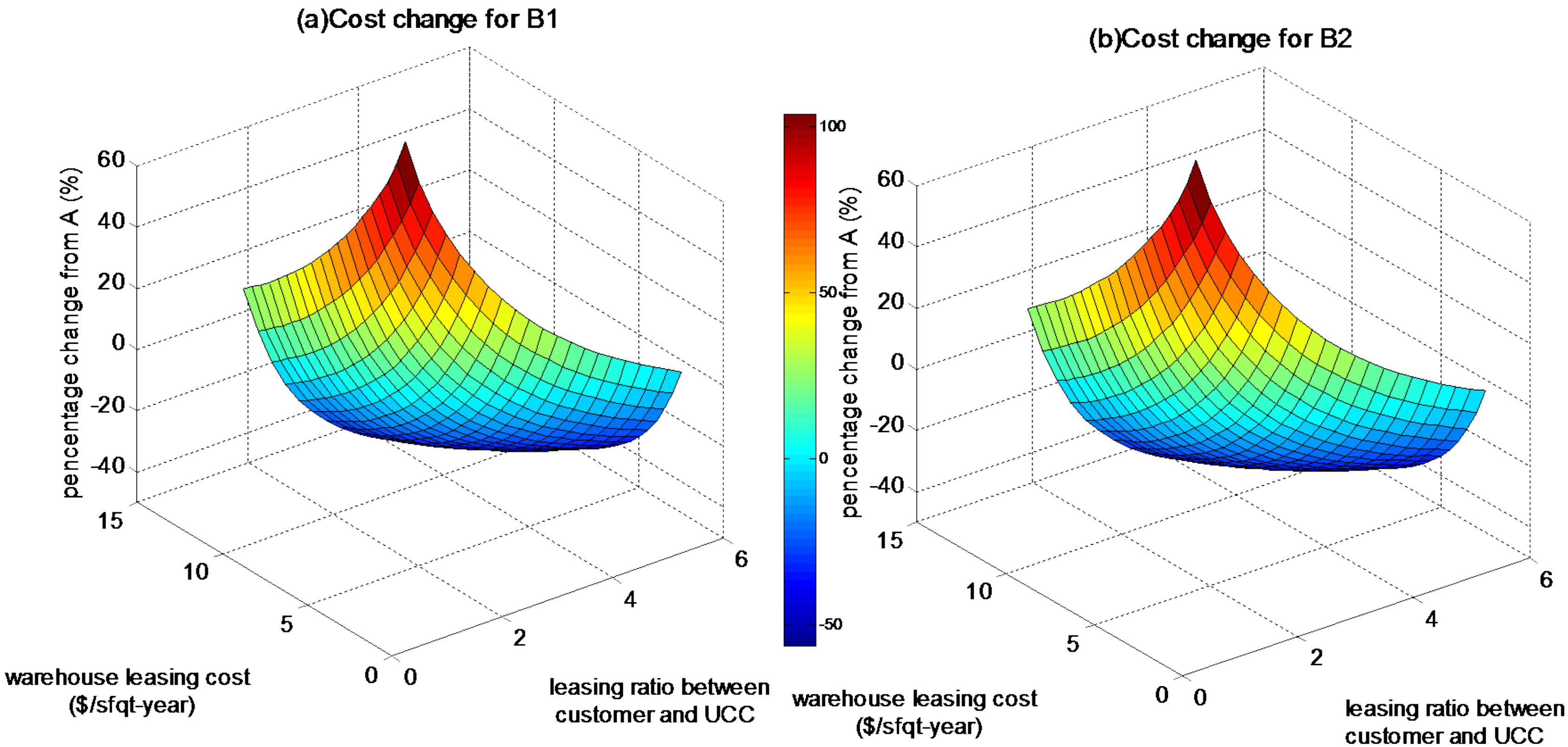
Results: (1) Vehicle Size Restrictions

Scenarios ID	Strategy A	Strategy B		Vehicle load factor in Strategy A	Size restriction applied?
		In-bound	Out-bound		
S1	HDT	HDT	HDT	1.00	N
S2	LDT	HDT	LDT	1.00	Y
S3	LDT	LDT	LDT	1.00	Y
S4	LDT	LDT	LDT	0.40	Y

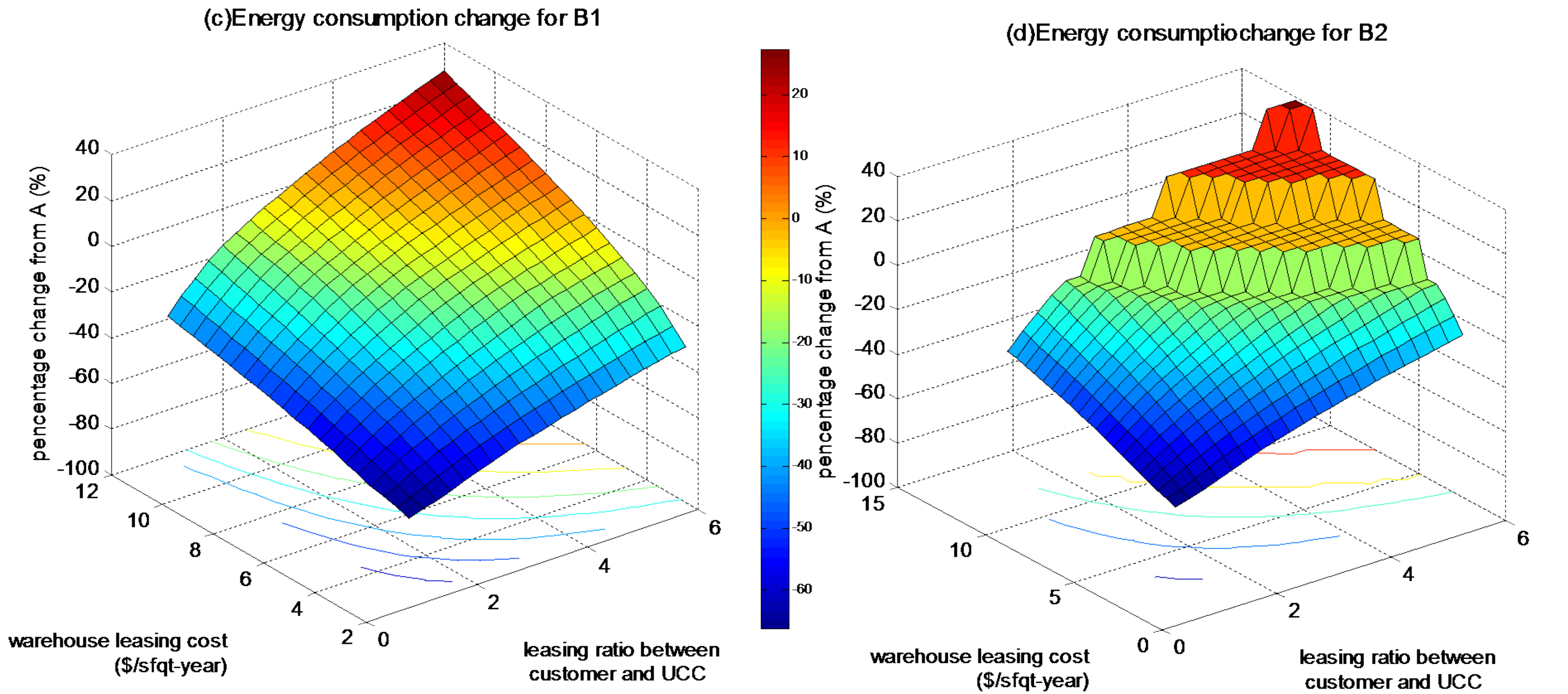
Scenario ID	Logistics cost (%)		Truck VMT (%)		Energy (%)		$PM_{2.5}$ (%)	
	B1-A	B2-A	B1-A	B2-A	B1-A	B2-A	B1-A	B2-A
S1	-17.36	-17.36	21.12	21.38	19.54	19.77	18.63	18.85
S2	-9.13	-9.08	-19.76	-17.74	-26.17	-20.28	36.02	38.05
S3	-10.61	-10.52	2.38	3.78	2.06	3.29	12.01	19.92
S4	-18.76	-18.86	-48.85	-43.1	-49.53	-44.39	-51.45	-48.02

Results: (2) Effect of Rent/Storage Cost

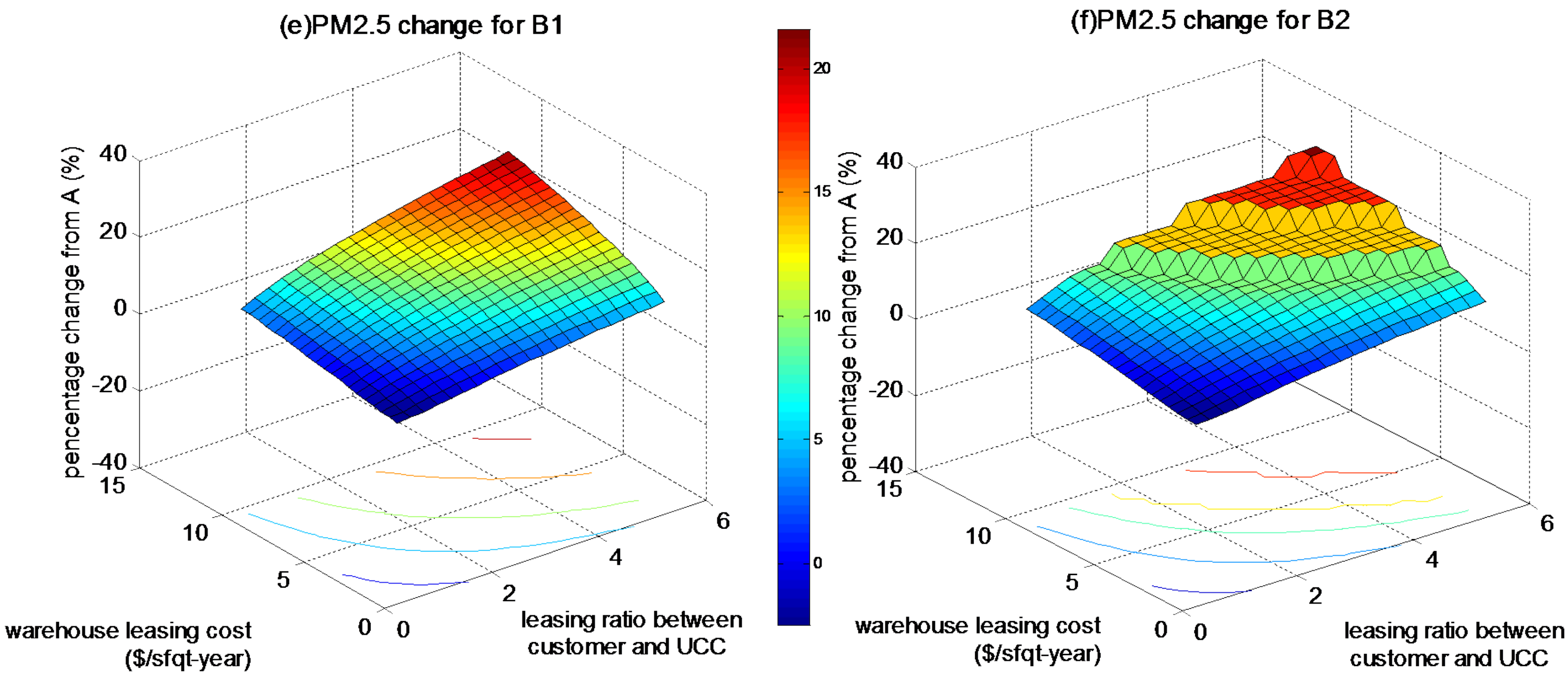
Strategy A using LDT (FTL); Strategy B using HDT inbound and LDT outbound



Results: (2) Effect of Rent/Storage Cost

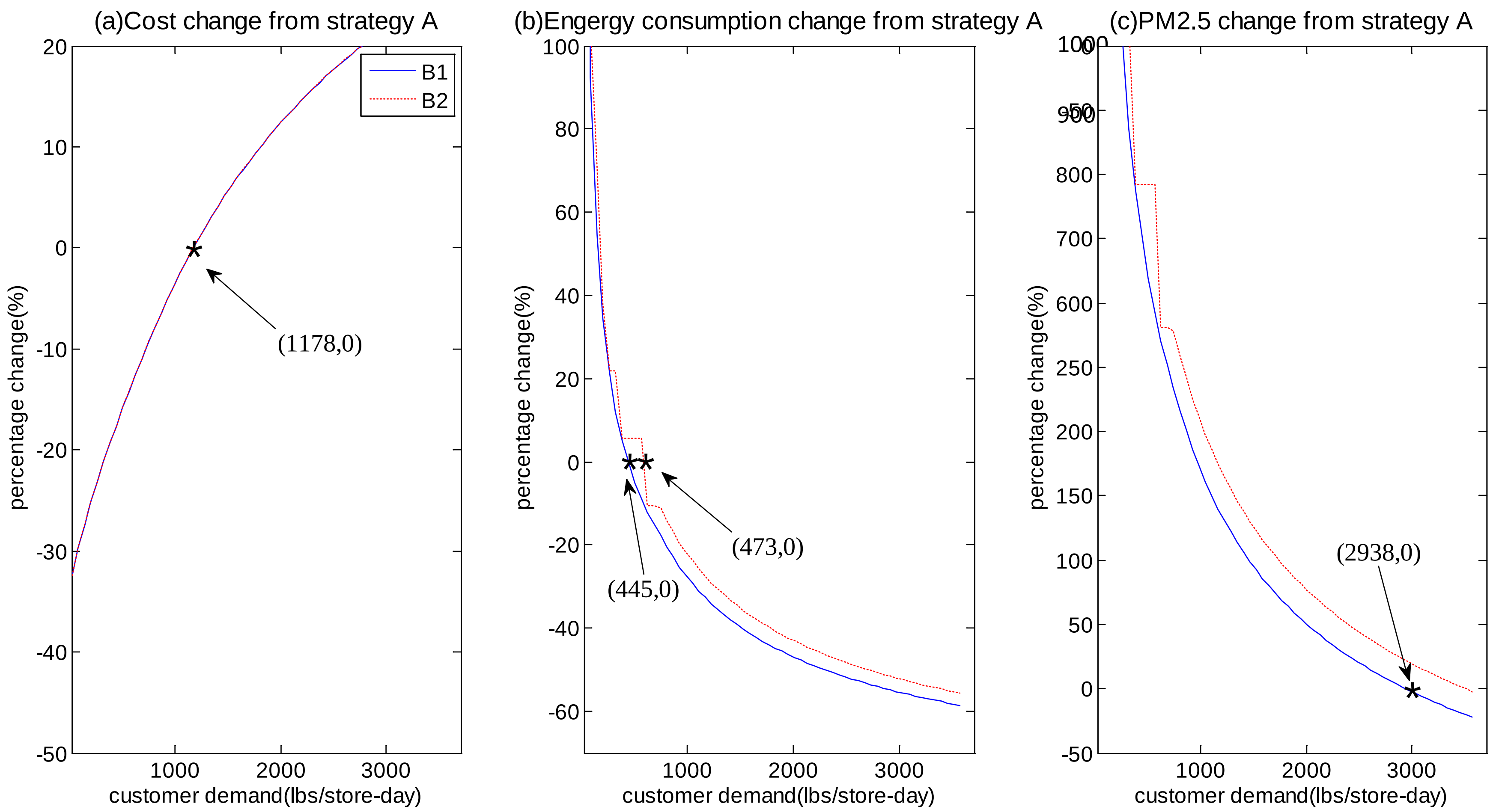


Results: (2) Effect of Rent/Storage Cost



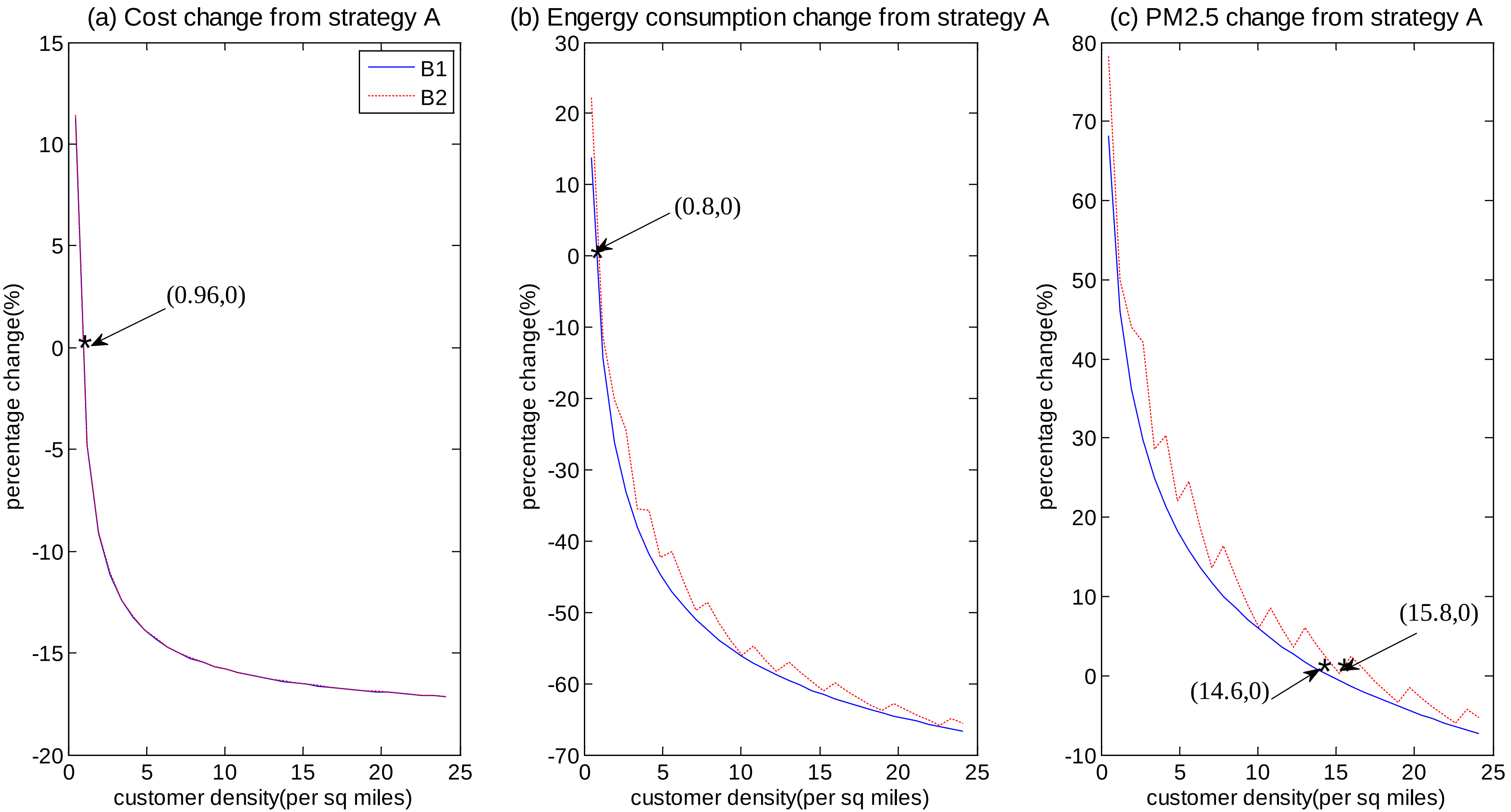
Results: (3) Effect of Customer Demand

Strategy A using LDT (FTL); Strategy B using HDT inbound and LDT outbound



Results: (4) Effect of Customer Density

Strategy A using LDT (FTL); Strategy B using HDT inbound and LDT outbound



Conclusion on UCC Study

- **Potential monetary and environmental benefits of UCC could come from**
  - maximizing the utilization of the vehicle capacity by consolidation, or
  - providing cheaper storage space at the UCC for its customers
- **Logistics cost and the environmental impact (energy consumption and $PM_{2.5}$ emission) of UCC do not always trend in the same direction**
  - UCC could achieve both monetary and environmental benefits only under certain conditions, e.g., when there is a high customer density.
- **UCC can perform the "break-bulk" function**
  - so that the outbound shipments can be carried out by smaller and cleaner commercial vehicles (e.g., electrical trucks)
- **UCC could provide value added service**
  - such as electrical vehicle charging stations at the UCC, cheap storage space for its customers, etc.

(II) Dynamic En-Route Cargo Consolidation

- Consider the following urban delivery scenario:
  - At any time during a daily operation, a new customer request involving a pair of pickup and delivery tasks arrives at random;
  - All vehicles have wireless mobile communication at all time and are informed of new customer requests in real time;
  - All vehicles in the service area are engaged in their respective pre-scheduled deliveries/pickups when a new request arrives;
  - Arc travel time is time dependent.

- Dynamic En-Route Cargo Consolidation (DERCC) determines
  - which vehicle currently in service should be re-routed
  - how it should be re-routed to perform this newly-arrived request
  - the total fleet cost, as a sum of the travel time cost, the fuel cost, and the vehicular emission cost, is minimized,
  - all vehicles retain their service obligations to their pre-scheduled customers after re-routing

Dynamic En-Route Cargo Consolidation

❑ Conventional DVRP

- ❖ Vehicle assignment (re-assignment) problem
- ❖ May not retain a vehicle's pre-scheduled customer commitment after re-assignment.

❑ DERCC

- ❖ Vehicle selection + re-routing problem
- ❖ Vehicles are committed to their pre-scheduled customers even after re-routing due to the pre-loaded cargos to be delivered and customer relationship consideration etc.

Model Assumptions

1. Vehicle fleet is homogeneous；
2. All vehicles start their routes at the depot (O) at time zero;
3. The total work hour limit for each vehicle is 8 hours;
4. A new customer request always comes in as a pair of pick-up and drop-off orders at $T^{*}>0$. That is, goods are transported from one customer location to the other. And only one new request is considered at a time.
5. No idling is allowed at stops and thus no idling fuel consumption and emissions are considered;
6. There is no extended waiting time on an arc or at a customer stop;
7. No time window constraint is considered for any existing or new customer demand.

Model Assumptions (cont'd)

8. Vehicle travel time is time dependent, and approximated with a step function of departure time at the starting node *i* of arc (*i,j*).

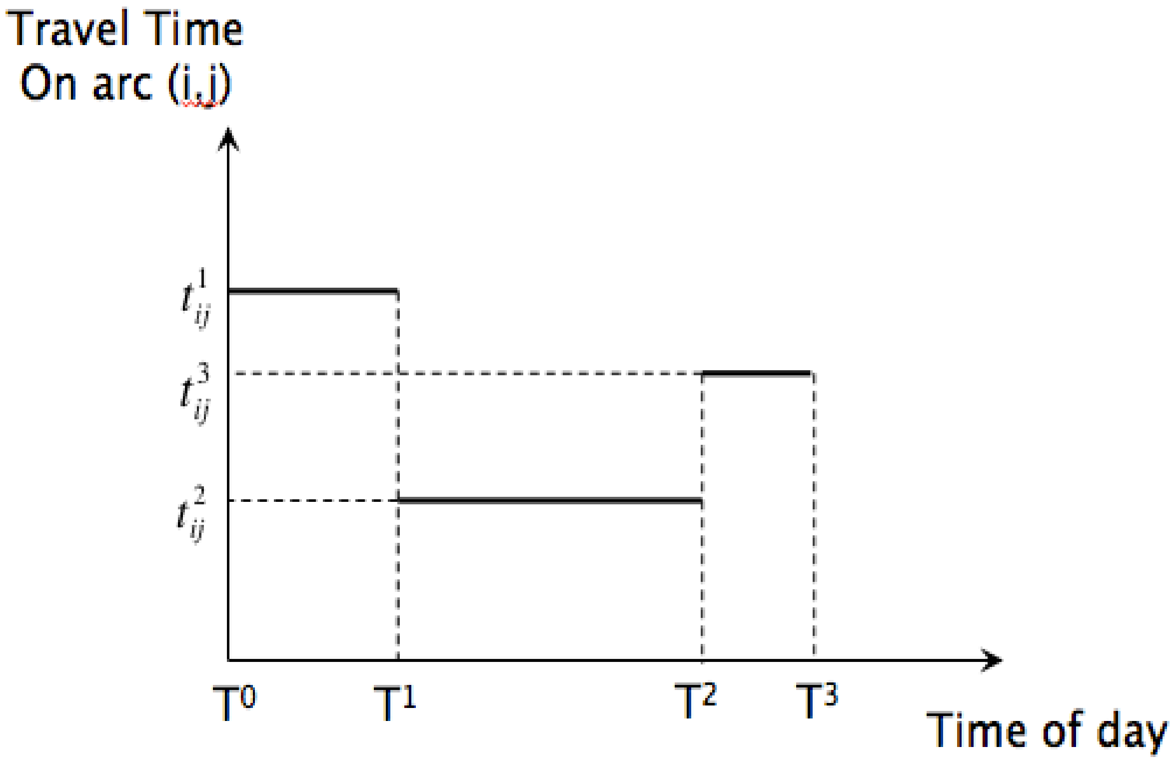


Fig: Arc (i,j) travel time as a step function of departure time at node i.

Model Notations

Z_{tt}: arc travel time cost.

Z_f : arc fuel cost for vehicle m.
Z_{pm}: arc emission cost for vehicle m.
$\mathbf{N_0}$ = $\{1,2,...,i,...,j,...,k,...,l,...N\}$: set of unvisited customer nodes at a given T^* including the new customer nodes k and l.
O: Depot.

$\mathbf{N} = \mathbf{N_0} \cup \{O\}$.

$\mathbf{A} = \{(i,j)\}, \forall i,j \in \mathbf{N}$.
$\mathbf{M} = \{1,2,...,M\}$: a total of M assigned vehicles for the pre-scheduled daily operation.
$\mathbf{S} = \{s\} = \{1,2,...,S\}$: set of time periods of the day, $s \in \mathbf{S}$.

T^{s-1} : start time of time period $s \in \mathbf{S}$.

d_{ij} : travel distance (miles) on arc (i,j), $\forall i,j \in \mathbf{N}$.
t_{ij}^s : travel time (hours) on arc (i,j) in time interval s, $\forall s \in \mathbf{S}$, $\forall i,j \in \mathbf{N}$.

v_{ij}^s : travel speed (mph) on arc (i,j) in time interval s, $\forall s \in \mathbf{S}$, $\forall i,j \in \mathbf{N}$.

D_i : demand (tons) of customer i, $\forall i \in \mathbf{N}$.
u_i : service type at node i, $\forall i \in \mathbf{N}$. u_i=1 for pick-up; u_i= -1 for delivery.
h_i : handling time (hours) at node i, $\forall i \in \mathbf{N}$.
Q: vehicle capacity (tons).
H: Daily work hour limit. In this study H is set to 8 hours, i.e., H=8.

Model Notations (cont'd)

- Three decision variables:

x_{ijm}^{s} : binary decision variable representing vehicle flow on arc (i,j), $\forall i,j \in \mathbf{N}$. If vehicle m leaves node i for j during time period s, $x_{ij}^{s}=1$; otherwise, $x_{ij}^{s}=0$.

l_{ij} : decision variable representing vehicle load (tons) on arc (i,j), $\forall i,j \in \mathbf{N}$.

τ_i : decision variable representing vehicle departure time at node i, $\forall i \in \mathbf{N}$.

Model Formulation

$$Min\ Z = \sum_{(i,j)\in A}\sum_{m\in M}\sum_{s\in S} Z_f x^s_{ijm} + \sum_{(i,j)\in A}\sum_{m\in M}\sum_{s\in S} Z_{pm} x^s_{ijm} + \sum_{(i,j)\in A}\sum_{m\in M}\sum_{s\in S} Z_{tt} x^s_{ijm} \quad (1)$$

Subject to:

$$\sum_{j\in \mathbf{N}}\sum_{s\in S} x^s_{0jm} = 1, \forall m \in \mathbf{M} \quad (2)$$

No. of vehicles: M

$$\sum_{j\in \mathbf{N}}\sum_{s\in S}\sum_{m\in \mathbf{M}} x^s_{ijm} = 1, \forall i \in \mathbf{N}_0 \quad (3)$$

No. of customer visits: 1

$$\sum_{i\in \mathbf{N}}\sum_{s\in S} x^s_{ijm} = \sum_{i\in \mathbf{N}}\sum_{s\in S} x^s_{jim}, \forall j \in \mathbf{N}, \forall m \in \mathbf{M} \quad (4)$$

Arc flow balance

$$\sum_{j\in \mathbf{N}} l_{ji} - \sum_{j\in \mathbf{N}} l_{ij} = D_i u_i, \forall i \in \mathbf{N} \quad (5)$$

Vehicle load balance

$$\mathrm{H}(\sum_{s\in S} x^s_{ijm} - 1) \le \tau_i + \sum_{s\in S} x^s_{ijm} t^s_{ij} + h_j - \tau_j \le \mathrm{H}(1 - \sum_{s\in S} x^s_{ijm}),\ \forall i \in \mathbf{N}, \forall j \in \mathbf{N}, \forall m \in \mathbf{M} \quad (6)$$

Departure time balance

$$\sum_{s\in S} \frac{1}{2}(u_j - 1) D_j u_j x^s_{ijm} \le l_{ij} \le Q - \sum_{s\in S} \frac{1}{2}(u_j + 1) D_j u_j x^s_{ijm},\ \forall i \in \mathbf{N}, \forall j \in \mathbf{N}, \forall m \in \mathbf{M} \quad (7)$$

$$0 \le l_{ij} \le \mathrm{Q} - \frac{1}{2}(u_i - 1) D_i u_i,\ \forall i \in \mathbf{N}, \forall j \in \mathbf{N} \quad (8)$$

Vehicle load constraint

$$\sum_{(i,j)\in A}\sum_{s\in S} t_{ij} x^s_{ijm} + \sum_{(i,j)\in A}\sum_{s\in S} h_i x^s_{ijm} \le \mathrm{H}\text{-}\mathrm{T}^*, \forall m \in \mathbf{M} \quad (9)$$

Work hour limit

$$\mathbf{T}^{s-1}\sum_{j\in \mathbf{N}} x^s_{ijm} \le \tau_i \le \mathbf{T}^s \sum_{j\in \mathbf{N}} x^s_{ijm} + \mathrm{H}(1 - \sum_{j\in \mathbf{N}} x^s_{ijm}),\ \forall i \in \mathbf{N}, \forall s \in \mathbf{S}, \forall m \in \mathbf{M} \quad (10)$$

Time interval selection

$$\tau_k \le \tau_l \quad (11)$$

$$\tau_0 = 0 \quad (12)$$

$$d_{ij} = v^s_{ij} t^s_{ij}, \forall i, j \in \mathbf{N}, \forall s \in \mathbf{S} \quad (13)$$

$$x^s_{ijm} = \begin{cases} 1, & T^{s-1} \le \tau_i \le T^s \\ 0, & Otherwise \end{cases}, \forall i, j \in \mathbf{N}, \forall m \in \mathbf{M}, \forall s \in \mathbf{S} \quad (14)$$

Cost Components

1. Travel time cost

$$Z_{tt} = pt_{ij}$$

where p is the driver's wage (\$/hr) and t_{ij} is the travel time on arc (i,j).

2. Fuel cost

$$Z_f = C_f P_{ij}$$

where C_f is the fuel price and P_{ij} is the fuel consumption:

$$P_{ij} = \alpha_{ij} (w+l_{ij}) d_{ij} + \beta(v_{ij})^2 d_{ij}$$

where α is an arc specific constant, β is a vehicle specific constant and *w* is the vehicle curb weight (tons). (Adopted from Bektas and Laporte, 2011)

3. $PM_{2.5}$ Emission Cost

$$Z_{pm} = C_e E_f d_{ij}$$

where C_e is the unit cost of $PM_{2.5}$; E_f is the arc $PM_{2.5}$ emission rate (g/mi) estimated by vehicle speed and weight using the U.S. Environmental Protection Agency's Motor Vehicle Emission Simulator (MOVES) (EPA, 2012).

Cost Components (cont'd)

- $PM_{2.5}$ Emission Factor E_f

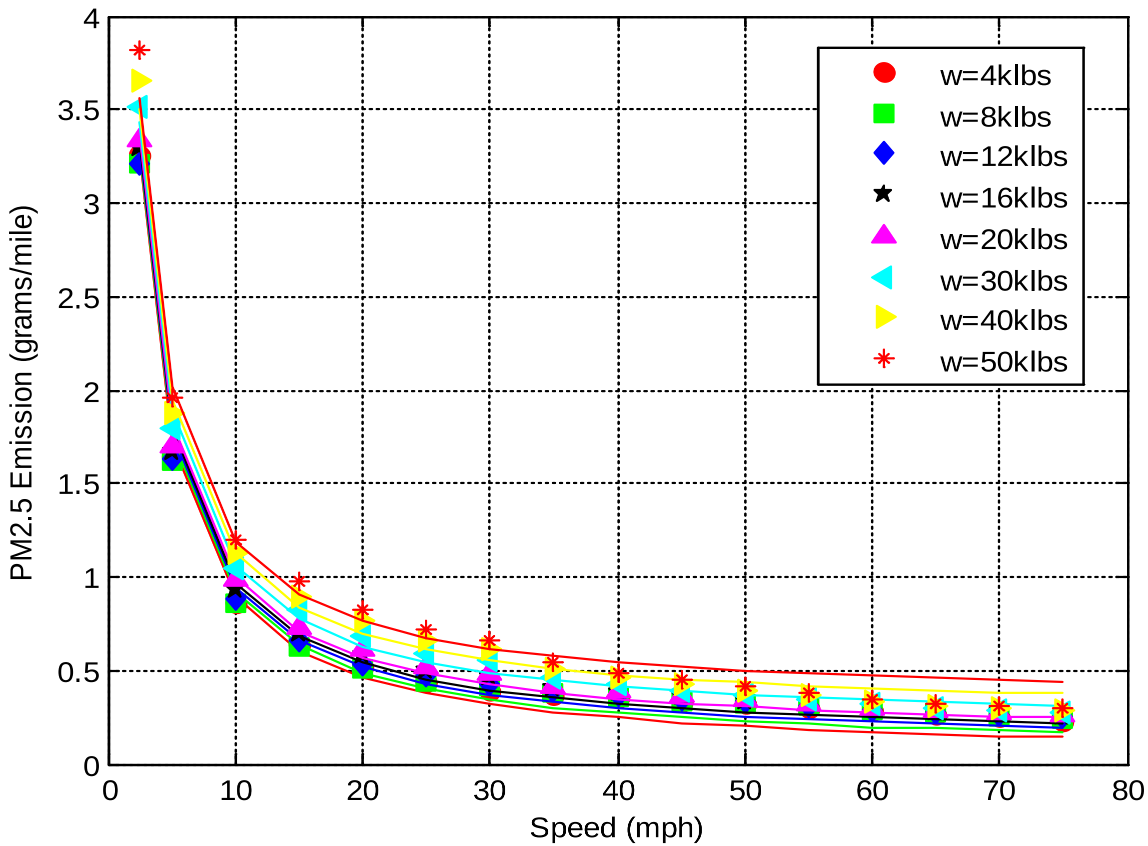


Fig: $PM_{2.5}$ Emission Factor Curve

$E_f = \Upsilon/(v_{ij}+\eta) + \sigma(w+l_{ij})$.

The model coefficients:
Υ = 8.853, η=0.2323, σ=0.006462.

The model goodness of fit indicator adj-R^2 is 0.99.

Visual Examination of the Cost Functions

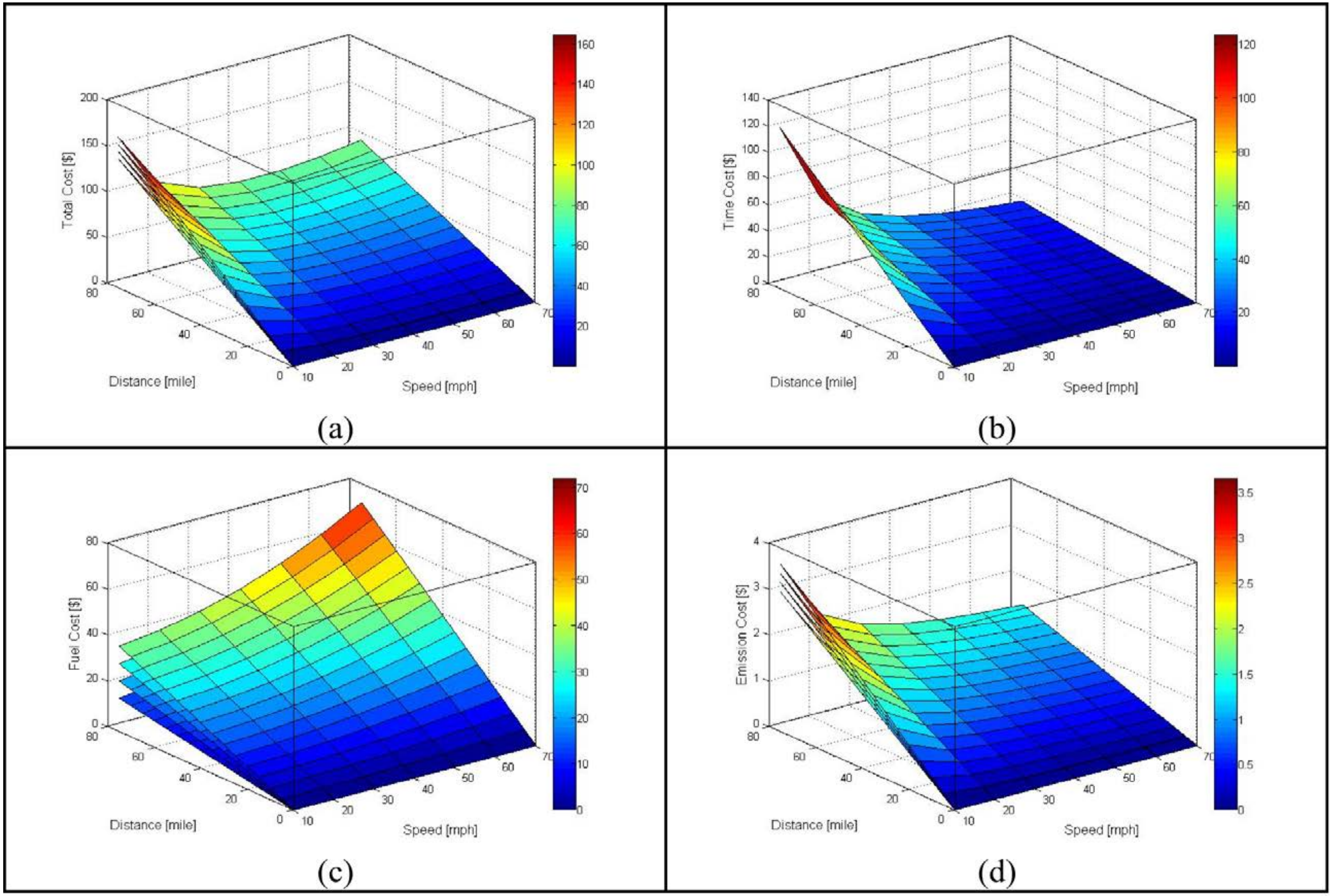


Fig: Cost function plots by gross vehicle weight: (a) total cost, (b) travel time, (c) fuel and (d) $PM_{2.5}$ (from bottom to top layer: 20,000lbs, 40,000lbs, 60,000lbs, 80,000lbs respectively).

Visual Examination of the Cost Functions (Cont'd)

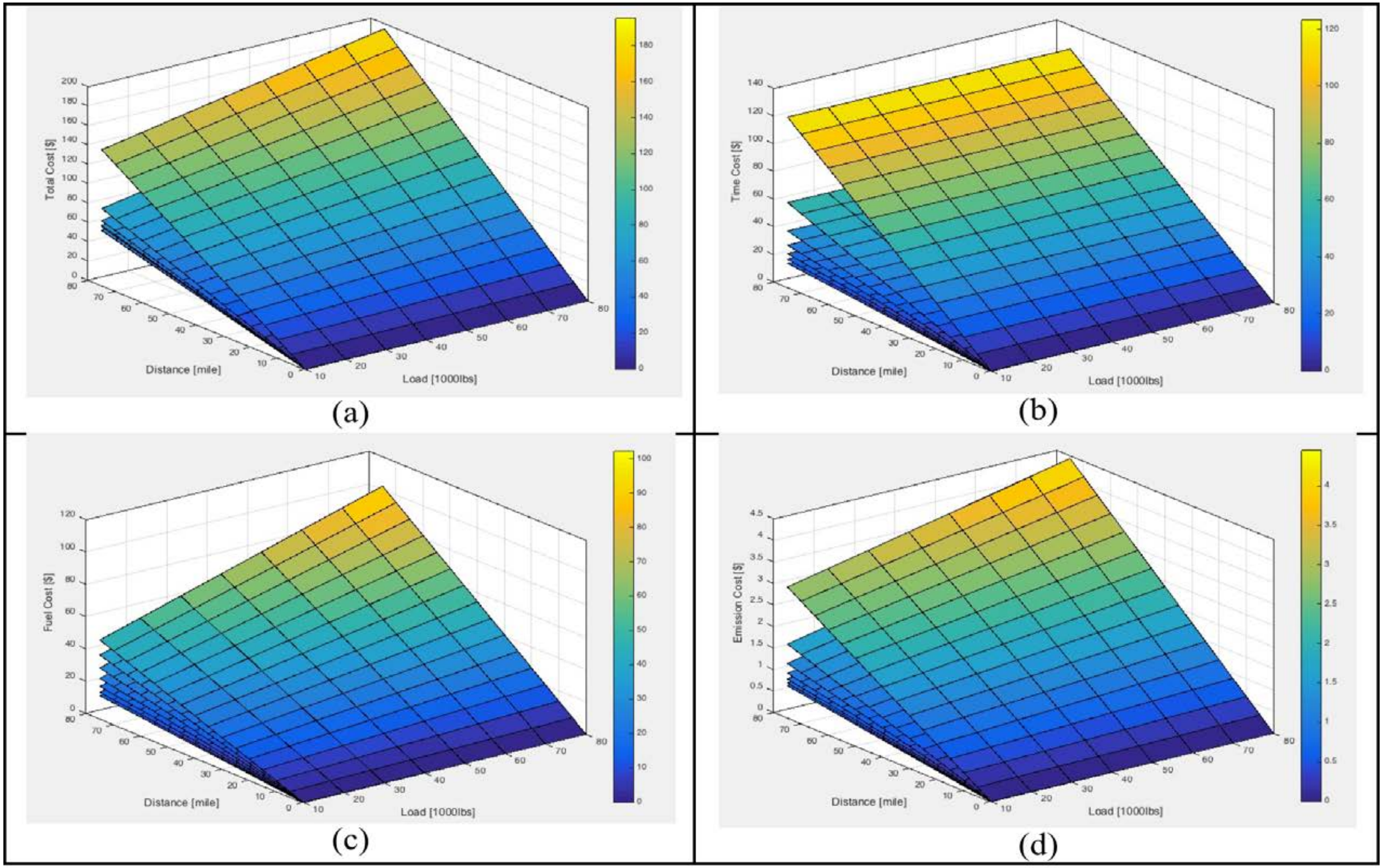
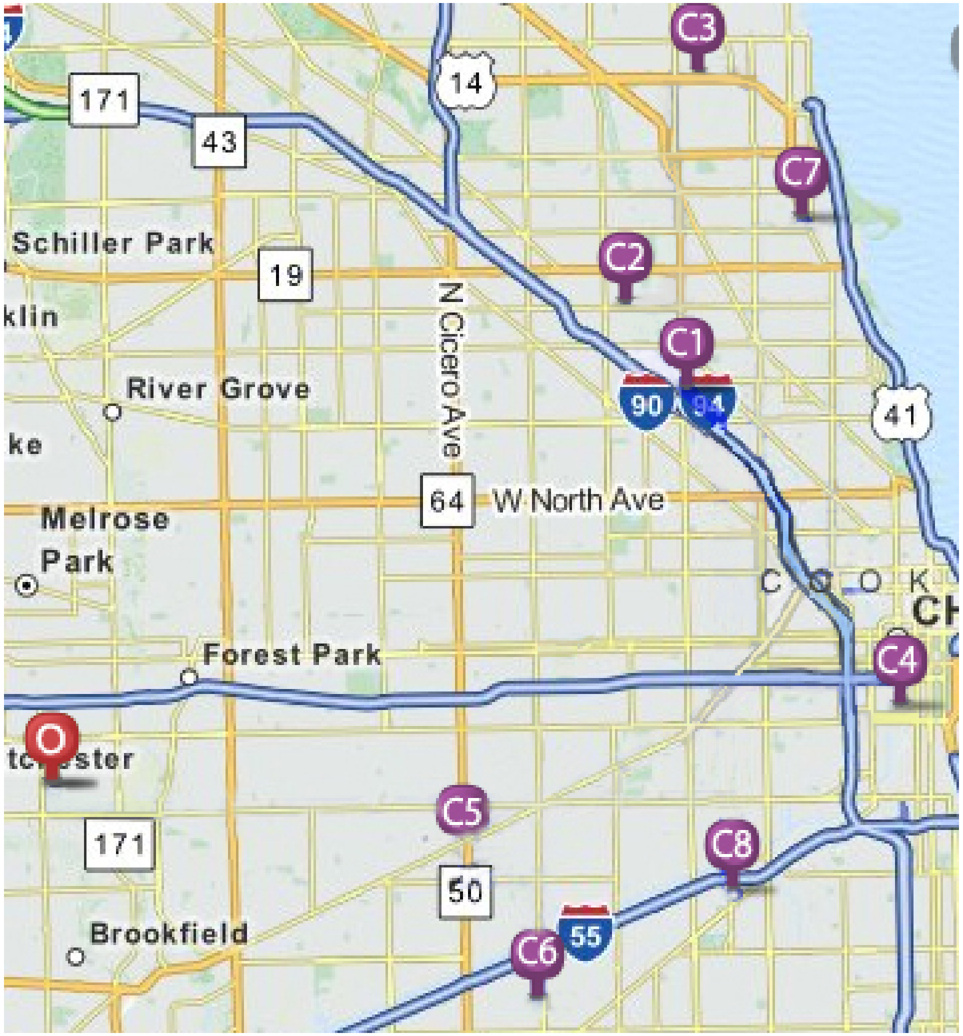


Fig: Cost function plots by travel speed: (a) total cost, (b)) $PM_{2.5}$
(travel speed from bottom to top between 10 and 70 mph at 10 mph increment respectively).

Small Numerical Example



The network covers as far north as Lincolnwood, as far south as West 47th St, as far east as Grant park, and as far west as Westchester.

The distance from south to north is 14.1 miles and 13.3 miles from east to west.

Network Setup (at T*)

Node	Address	Demand (1000lbs)	Service Type (*u*)	Dwell time (mins)
Depot (O)	800 Broadview Village Sq	0	+1	0
Customer1(C1)	2656 N Elston Ave	3	-1	15
Customer2(C2)	2939 W Addison St	1	+1	5
Customer3(C3)	2112 W Peterson Ave	5	-1	20
Customer4(C4)	1154 S Clark St	2	+1	10
Customer5(C5)	2901 S Cicero Ave	4	-1	15
Customer6(C6)	4433 S Pulaski Rd	3	-1	10
Customer7(C7)	4466 N Broadway St	4	+1	15
Customer8(C8)	1940 W 33rd St	4	-1	15

Model Parameter Values

Parameter	Description	Values	Source
p	Hourly driver wage ($)	16.43	Payscale (2009)
C_f	Diesel Price ($/gallon)	4	Bektas and Laporte (2011)
C_d	Unitless coefficient of rolling drag	0.7	Akçelik et al. (2003)
A	Frontal surface area of a vehicle (m^2)	5	Akçelik et al. (2003)
a	Acceleration (m/s^2)	0	Genta (1997)
θ_{ij}	Road angle (degree)	0^o	Genta (1997)
ρ	Air density (kg/m^3)	1.2041	Genta (1997)
C_r	Unitless rolling resistance	0.01	Genta (1997)
C_e	$PM_{2.5}$ emission cost rate ($/ton)	34,175	CAFE CBA (2005)
g	Gravitational constant (m/s^2)	9.81	
w	Vehicle curb weight (tons)	3.629 (or 8,000 lbs)	
Q	Vehicle capacity (tons)	14.515 (or 32,000 lbs)	

Results

Objective (Minimize)	Optimal Route	Total distance (miles)	Total travel time (hrs)	Energy cost ($)	$PM_{2.5}$ emission cost ($)	Total cost ($)
(A) Total cost	O-**C7**-C6-C5-C4-C3-C2-C1-**C8**-O	52.50	2.07	11.08	0.946	45.98
(B) Travel time cost	O-**C7**-C5-C4-C3-C2-C1-C6-**C8**-O	52.49	2.06	12.30	0.974	47.05
(C) Fuel cost	O-**C7**-C6-C5-C1-C4-C3-C2-**C8**-O	53.90	2.19	11.03	0.959	46.73
(D) $PM_{2.5}$ cost	O-**C7**-C6-C5-C4-C3-C2-C1-**C8**-O	52.50	2.07	11.08	0.946	45.98

Summary Findings from Numerical Example

- Strategy (B) achieves the minimal travel time with the price of higher fuel use (+11%) and more harmful emissions (+3%).
  - ➢ The travel time strategy does not necessarily yield the same as the total cost strategy.
  - ➢ Fuel cost and emission cost can not be ignored when green routing is also an important routing criterion.
- Strategy (C) has the lowest energy consumption but requires the longest travel time, which yields a slightly increase of total cost from (A).
- The total cost strategy (A) represents a trade-off between travel time and fuel consumption.
- PM2.5 cost is at least an order of magnitude smaller than any other cost components.
- The total cost strategy (A) and emission strategy (D) yield the same results.

Larger Case Study

- **Area**: Austin, Texas.
- **Geographical Coverage**: As far north as Salado, as far south as San Antonio, as far east as Bryan, and as far west as Fredericksburg. The distance from south to north is 113 miles and 172 miles from east to west.
- **Network Size**: 138 vehicles in the fleet and 1005 customers nodes.

Methods	Optimal Solution (Y/N)	Computation Time (mins)
Exact solution	Y	9.00
Emission-based Heuristic Algorithm	Y	1.64

Conclusion on Dynamic En-route Cargo Consolidation

- Fuel cost is not trivial in total cost.

- Vehicle load cannot be ignored when energy and emission costs are considered in the total cost function.

- The total cost strategy represents a compromise between travel time and energy consumption.

- Examples seem to suggest the total cost strategy and the emission strategy tend to be consistent while the fuel strategy can yield quite different results.

Closing Remarks

- On the one hand, green supply chain and logistics has not only a long term effect on tackling climate change but also a short term business reward such as fuel savings
- On the other hand, urban freight strategies are often a trade-off between monetary and environmental benefits
- Dynamic cargo consolidation lies in the ability to match the demand and supply better and make more efficient use of the otherwise unutilized or underutilized vehicle capacities in delivery services
  - ➢ Advanced information technology can greatly facilitate it
- UCC requires large capital and operating investment and the right ingredients to make it work

Thank you!


ALL ELECTRIC VEHICLE
plug in.
SMITH
150 miles
50mph
Class 5,6 & 7
www.SmithElectricVehicles.com


amazon PrimeAir
Google Express