Image from NYK Logistics

Locating Short-Term Empty Container Storage Facilities

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Stacks of chassis at East L.A. Intermodal yard, August,2006 R.L. Church

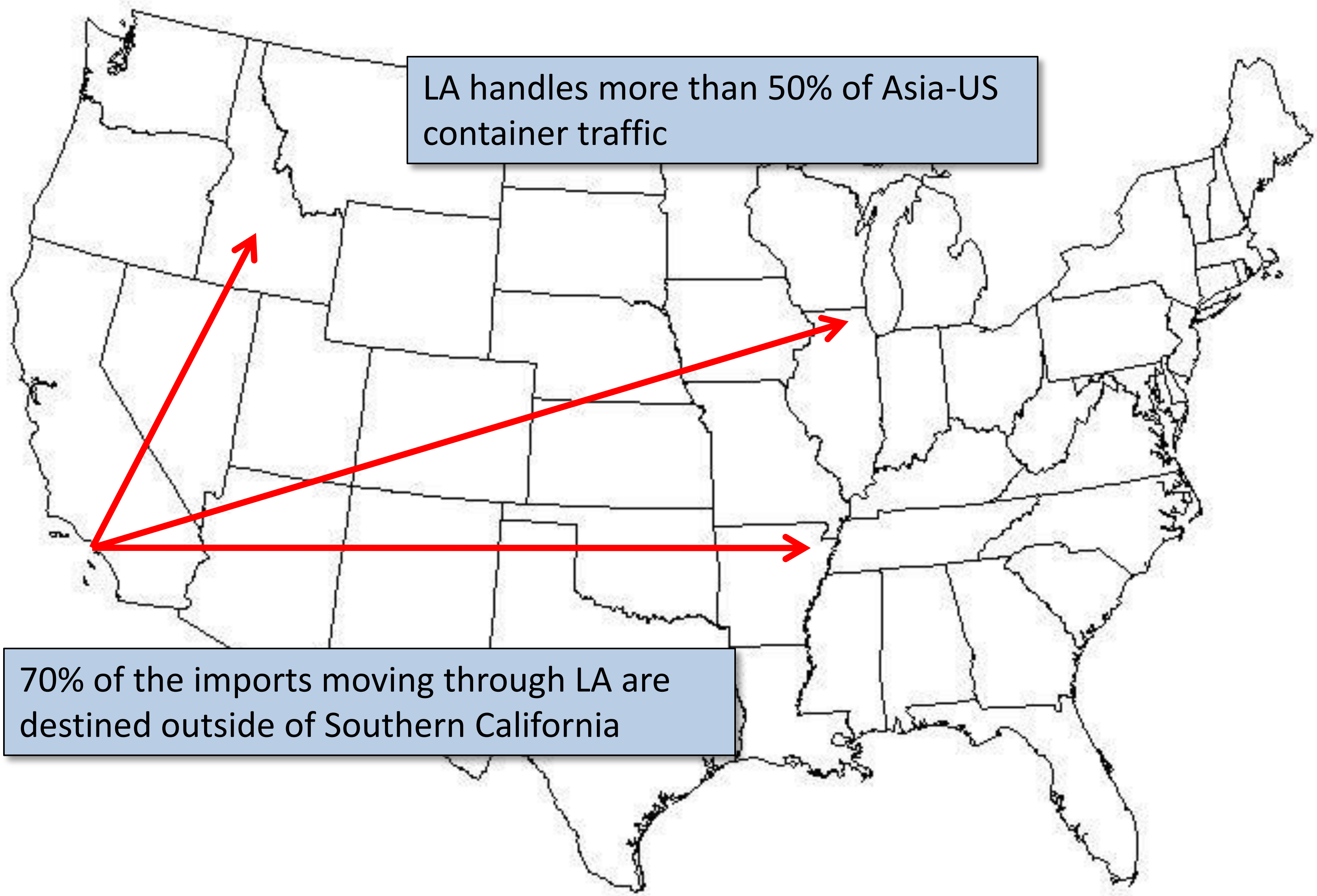
Stacked chassis, UPRR East LA Intermodal Facility

R.L. Church

A focus on Drayage

Talk Outline:

- Introduction to the Port Operations of LA/LB
- Understanding container trips & why focus on the movement of empties?
- Modeling truck routes
- Base case estimate of VMT associated moving empties
- Modeling the impact of storing containers away from the port
- Possible directions in future work



LA handles more than 50% of Asia-US container traffic

70% of the imports moving through LA are destined outside of Southern California

The forecast: LA/LB port complex

Year	Cargo Forecasts
2004	13.1*
2005	14.2*
2010	19.7
2020	36.0
2030	44.7

*actual volumes

It is estimated that one in seven jobs in Southern California is directly related to import/export operations

Ports of LA/LB handle approximately 40% of the import cargo into the US

Numbers in millions of TEUs (20 ft equivalent units)

On-dock rail & the Alameda Corridor

About 20% of the containers are handled directly by rail

Image from CALMITSIC

Some of the Alameda Corridor is below grade

Below grade track eliminates traffic crossing issues on local roads

Image from CALMITSIC

Drayage Trucks

Drayage trucks handle nearly 80% of the container volume………to DCs/CrossDocks/etc

Many Drayage trucks are/owner operated, contracted to handle specific moves. In 2009 there were approximately 14,000 drayage trucks

Image from GreenTrucker.com

I-710 heading north from the LA ports

Normal daily traffic congestion

March 11, 2003 during walk out of Port workers

Images from CALMITSIC

Major issues for port operations

- Environment
  - Pollution from ship operations
  - Pollution from rail operations
  - Pollution from drayage operations
- Road Congestion due to drayage operations
  - Truck
  - Intermodal: ship to truck to rail
- Terminal congestion
- Efficiency
- Infrastructure development

Current Operations

- 8 million import containers (16 million total)
- imports per day average: 28,000+
- 20 % leave port
  Co

Drayage is the big beast for the LA basin

- 80% leave port by truck
  - A certain percentage are transported to one of the rail yards by truck
- virtually all containers emptied locally are returned to the port by truck

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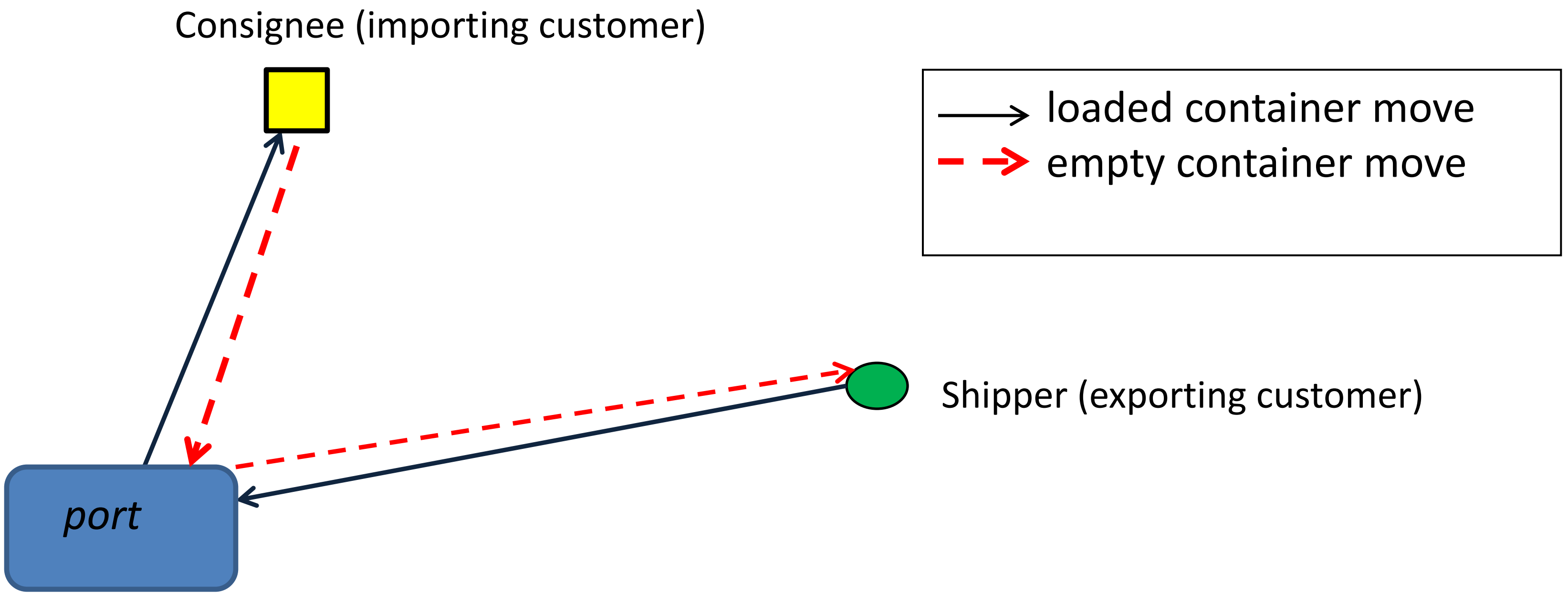
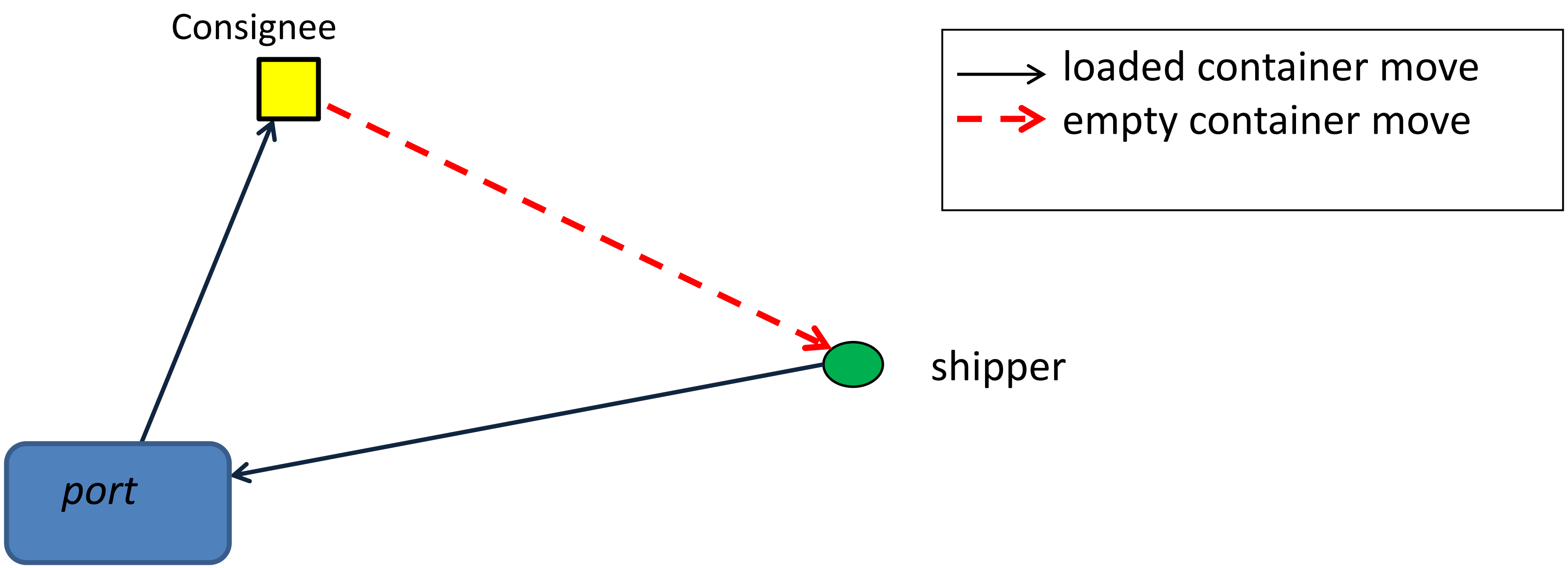
Depicting container moves



Most empties are taken to the port & stored. Many of those empties are then picked up and taken to a shipper for filling before export

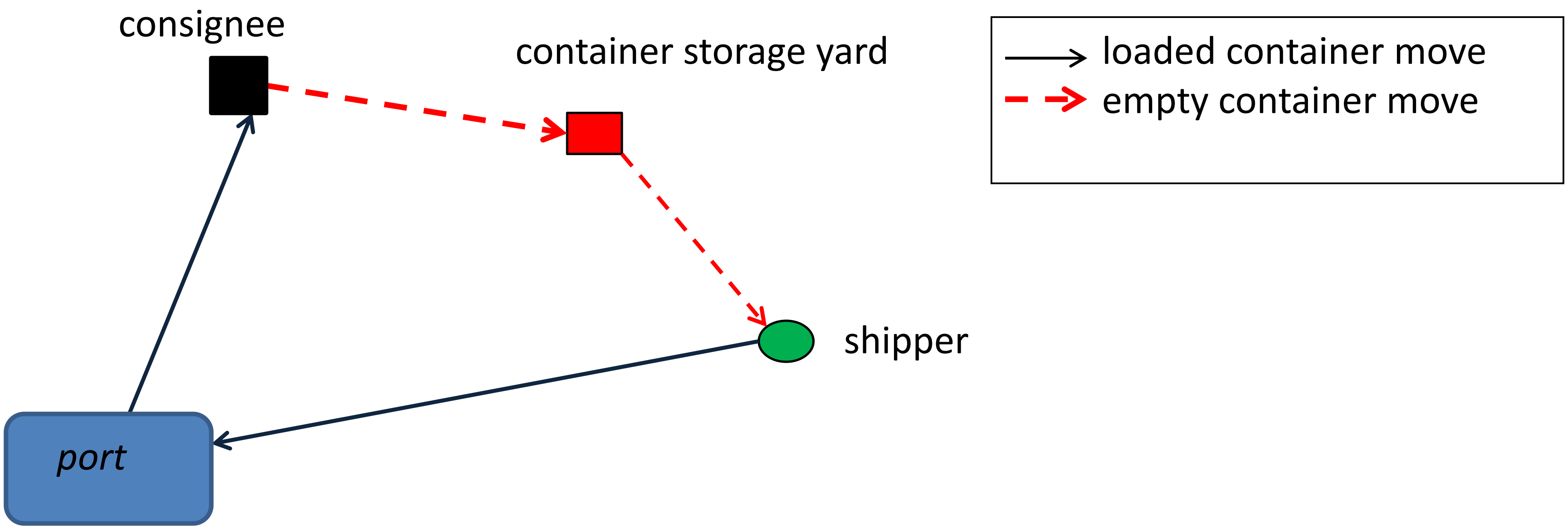
Depicting container moves



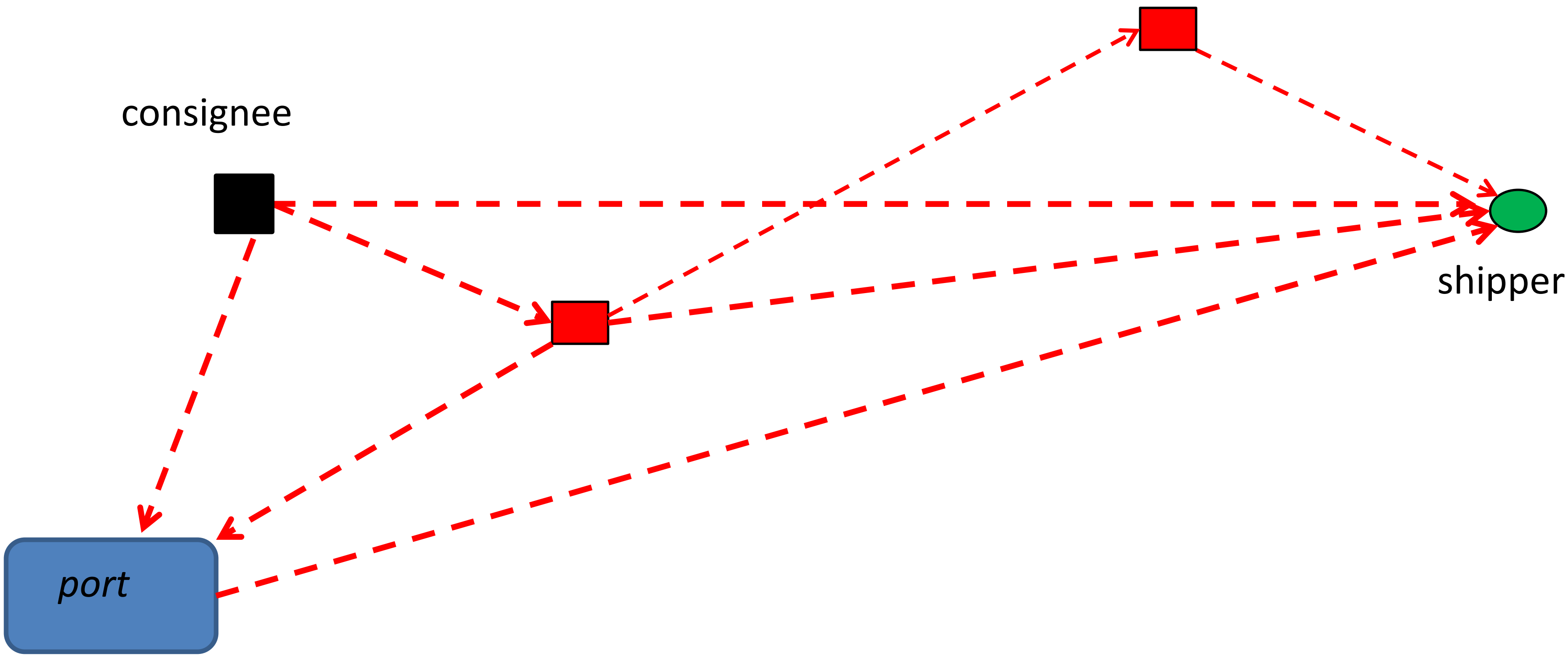
Empties can sometimes be taken directly to a shipper, thereby reducing a move to the port and a subsequent move from the port

Such moves are supported through the use of a virtual container yard

Depicting container moves



Empty container management



Note: Since moves of full containers are fixed; the issue is to focus on the movement of empties and keep empty VMT as small as possible

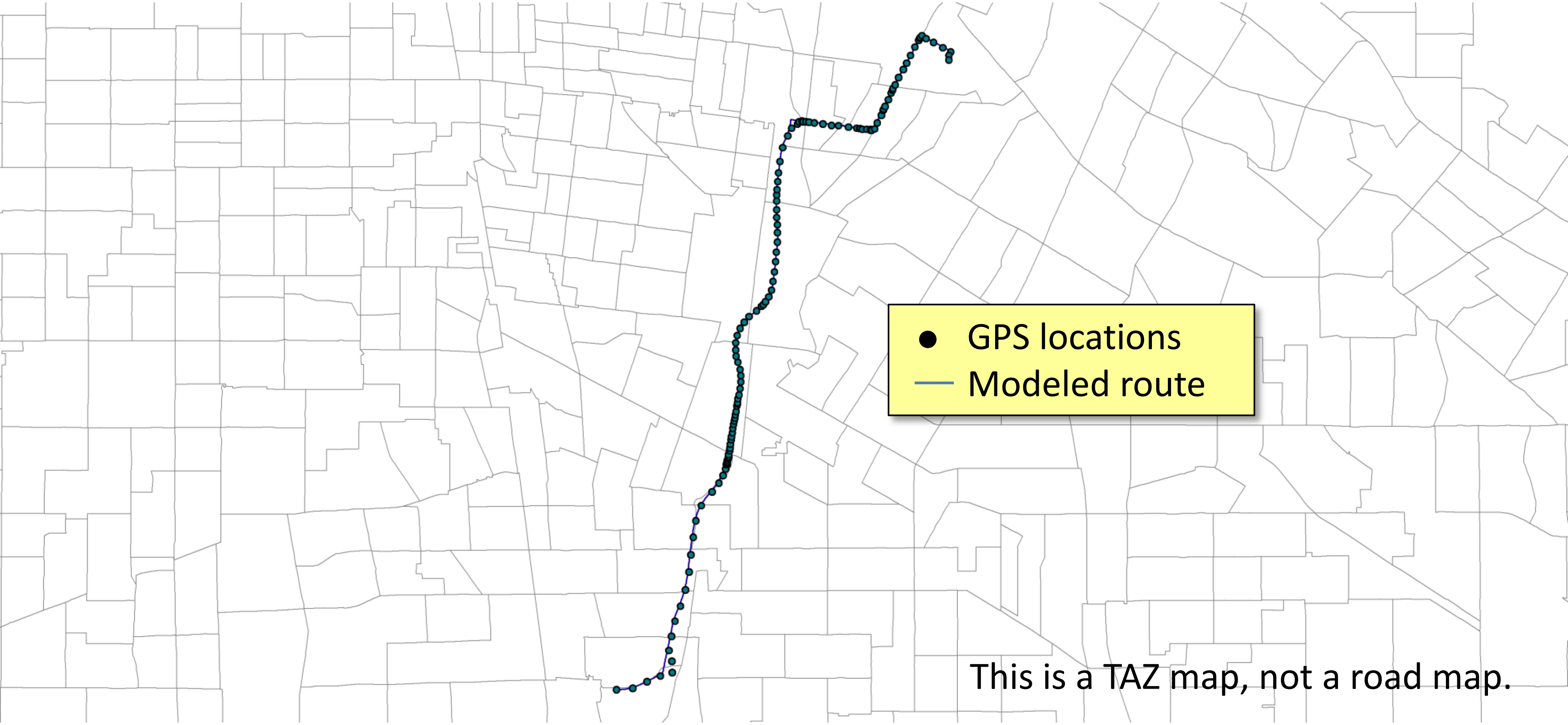
Why focus on empty containers?

- Full container moves are fixed, from port to consignees and from shippers to port
- Empty container moves are flexible
  - Street turns are possible with a virtual container yard, reducing VMT
  - Storage yards may reduce VMT
- Can reduce traffic into and out of port area by storing empties away from port
- Empties can be exchanged…full containers cannot
- Reducing VMT of drayage trucks may have a significant impact on improving air quality

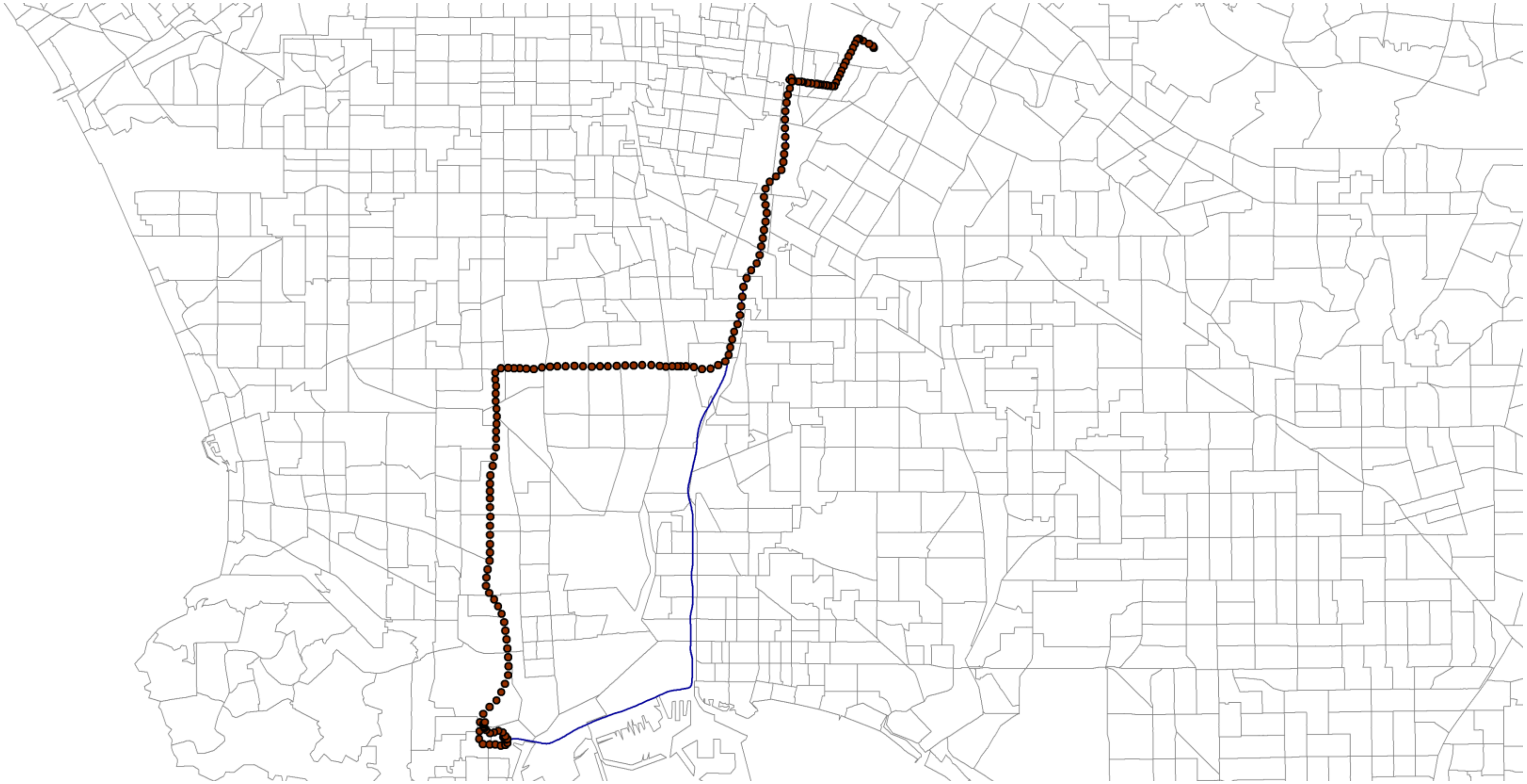
Modeling truck routes

- Data: TeleAtlas network & actual truck routes (GPS coordinates every 12 seconds)
- Model: shortest path problem
  - Uses travel times reported by TeleAtlas
- Compare computer generated routes and actual truck routes
  - report routes in terms of distances and times

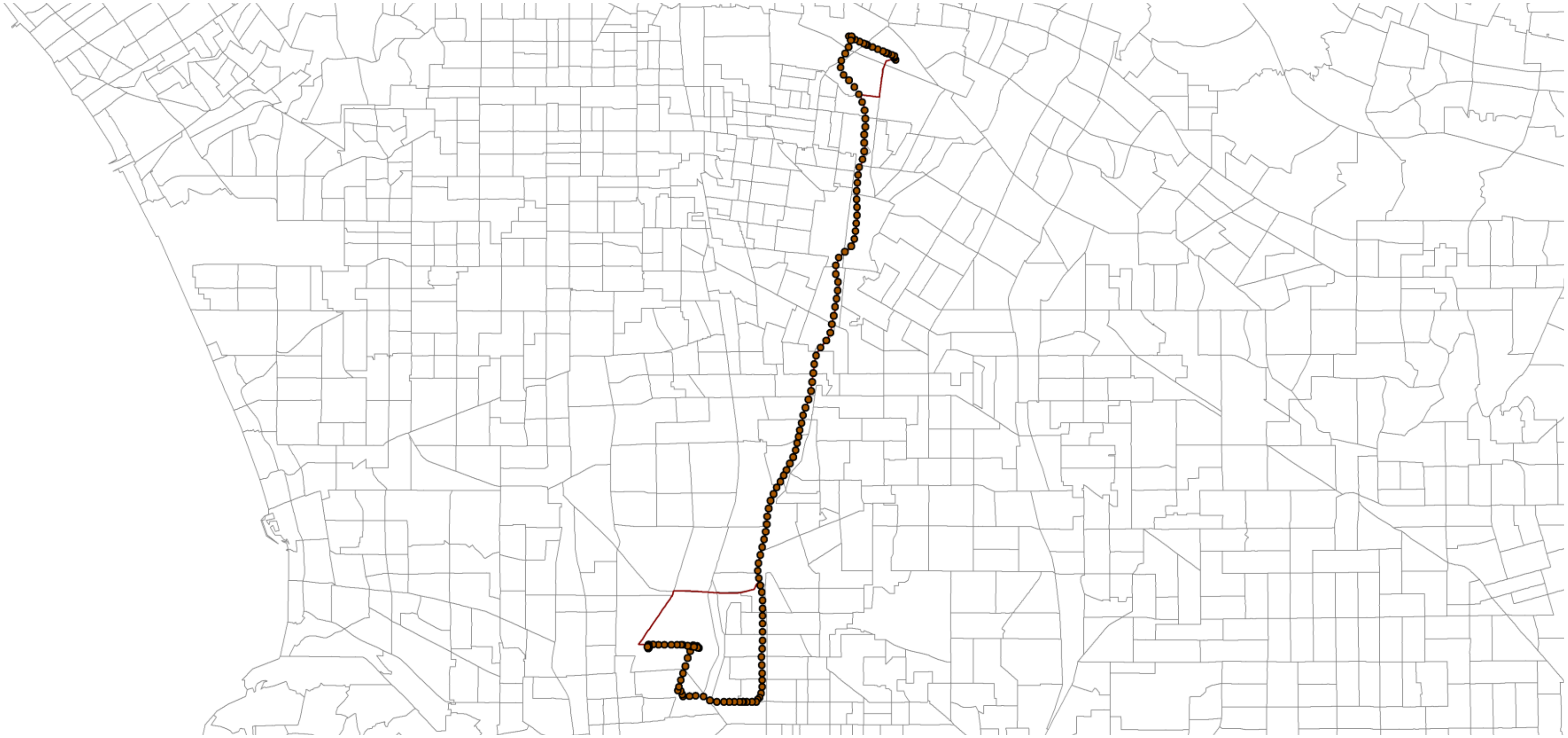
An example of GPS points coinciding with shortest time path



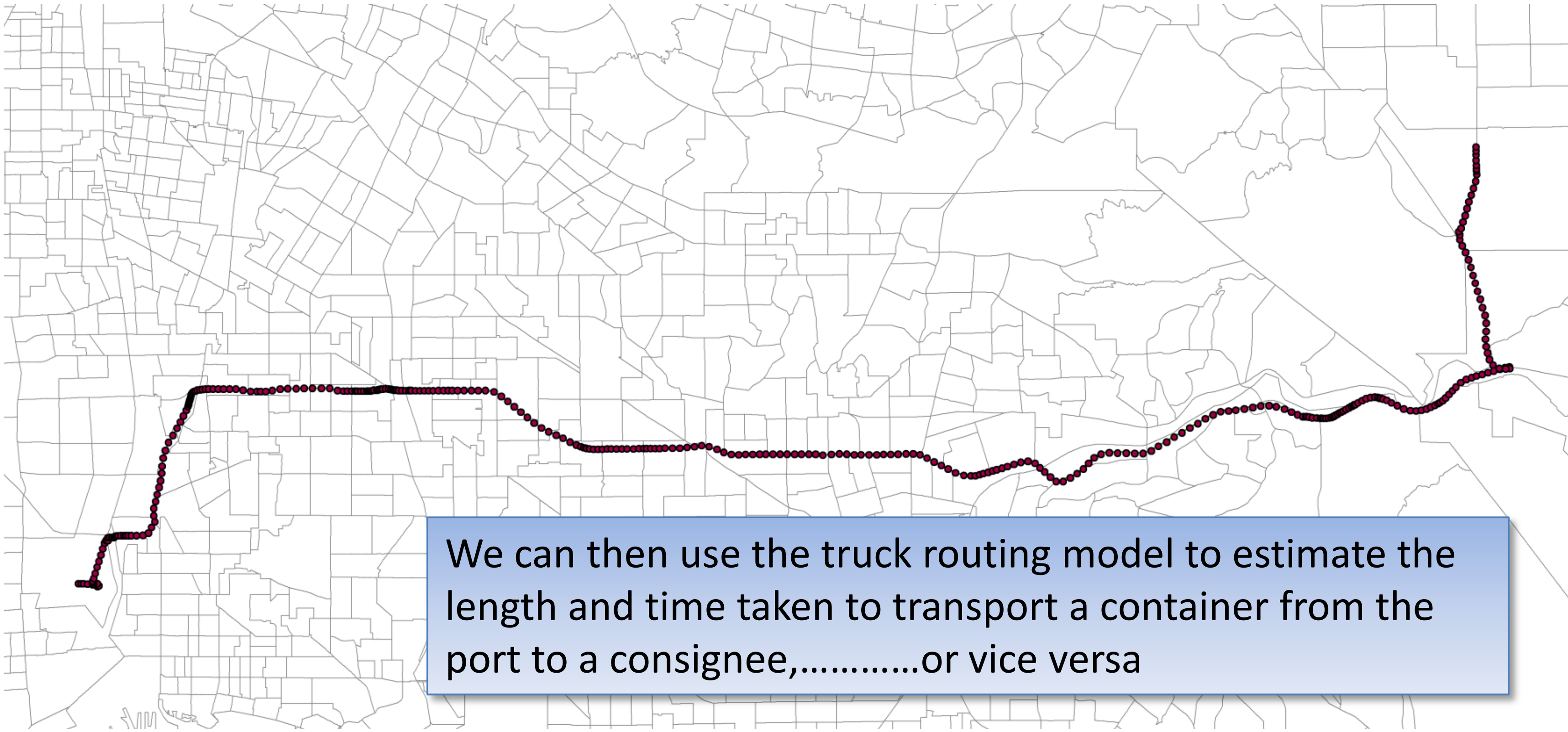
a second example



a third example



A fourth example



We can then use the truck routing model to estimate the length and time taken to transport a container from the port to a consignee,…………or vice versa

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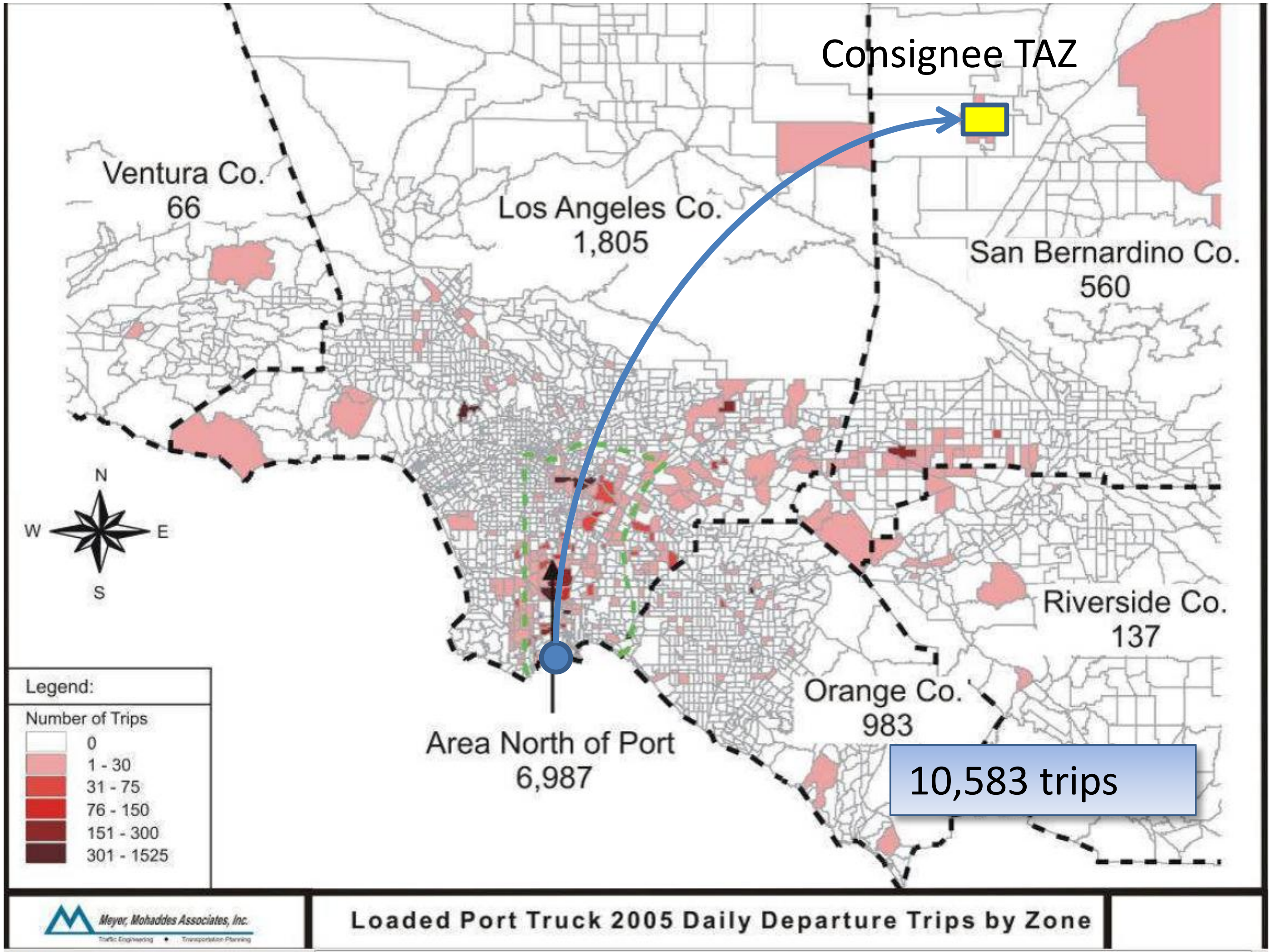
Modeling the movement of empties

- Construct a spatially distributed data set of:
  - consignee locations
  - shipper locations
- Estimate movement of containers: full & empty
  - Base case: port is the only storage yard & all empties are stored at the port
  - Truck routing model can be used to estimate mileage of each trip

Distribution of consignee locations

Trips from port to TAZs



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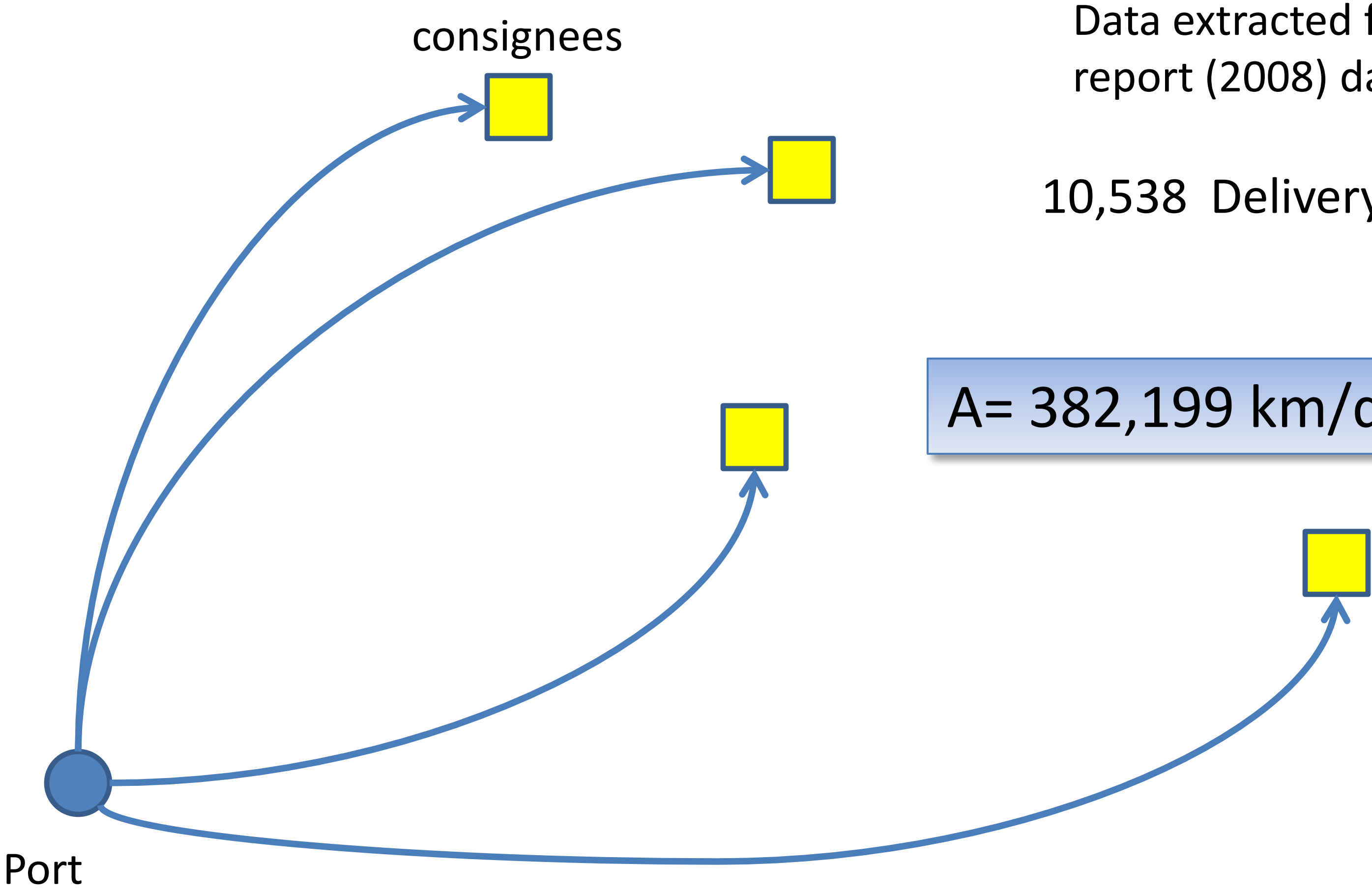
We can then calculate the distance traveled to all consignees in transporting all 10,538 full containers (A)



Data extracted from Tioga report (2008) daily volumes

10,538 Delivery trips per day

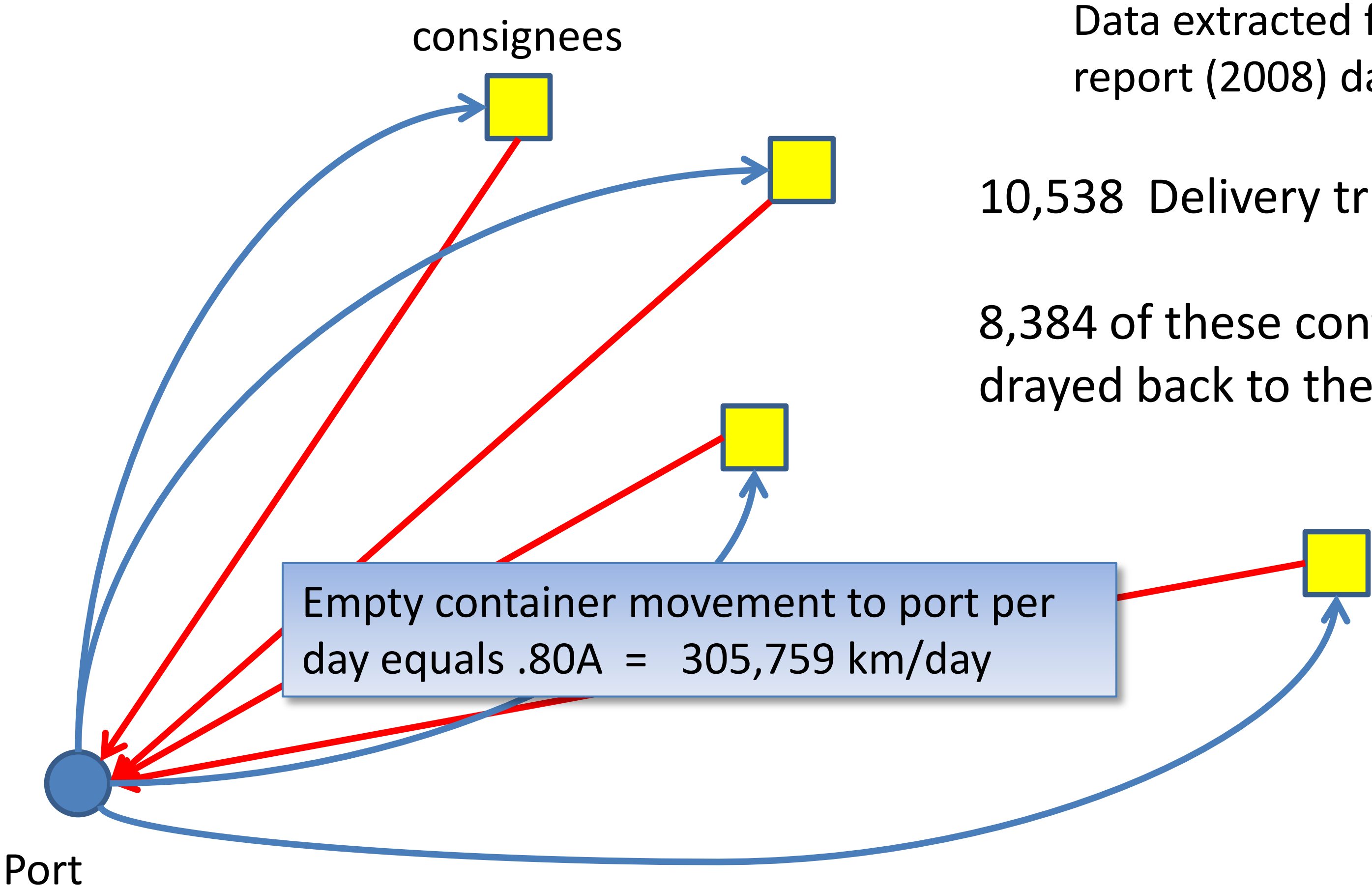
A= 382,199 km/day !

Estimating empty container VMT

Data extracted from Tioga report (2008) daily volumes

10,538 Delivery trips per day

8,384 of these containers are drayed back to the port as empties



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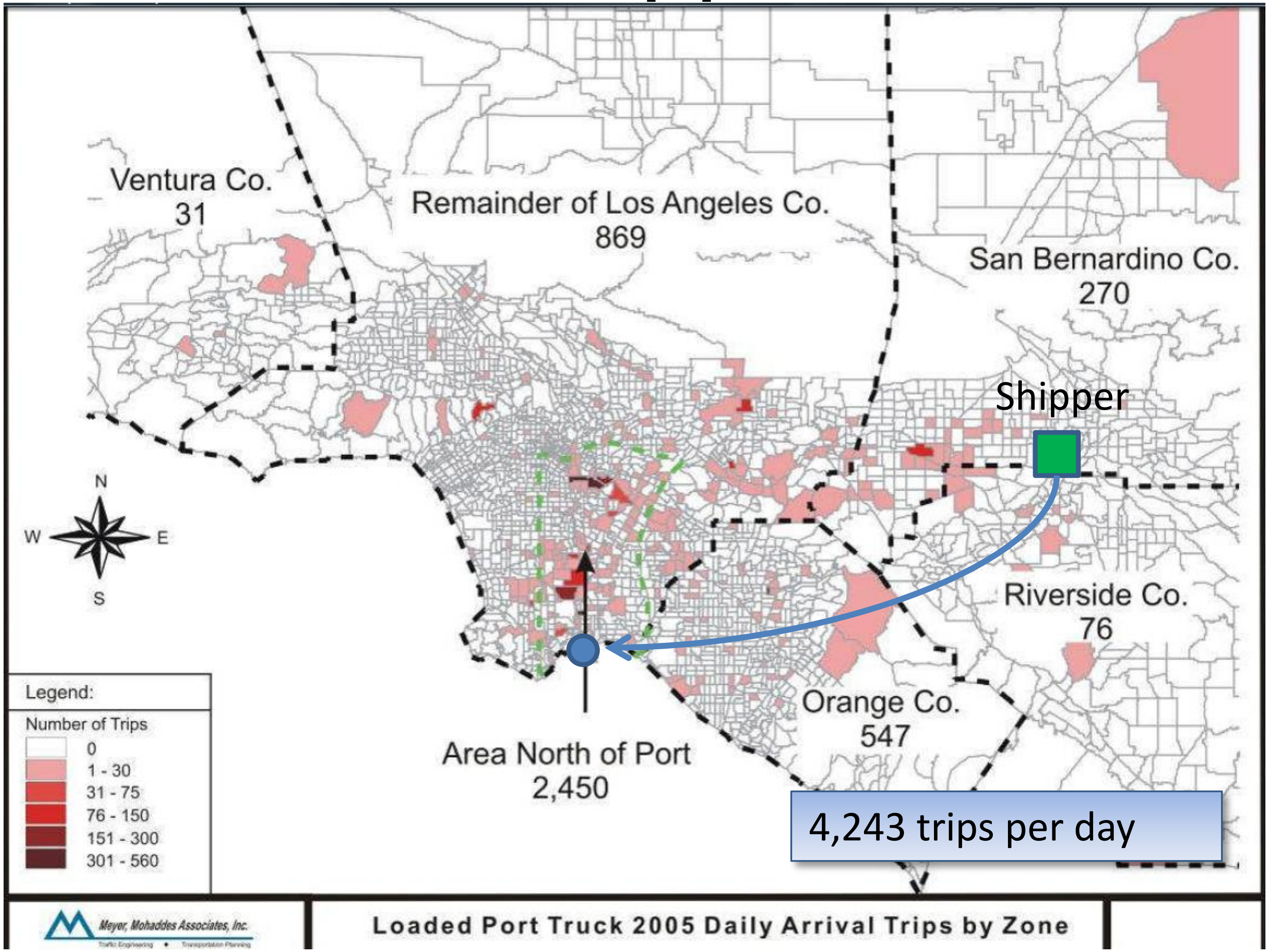
8,384/10,538 = .80 or 80% of containers are emptied and taken directly to port

Distribution of shipper locations

Trips from port to TAZs



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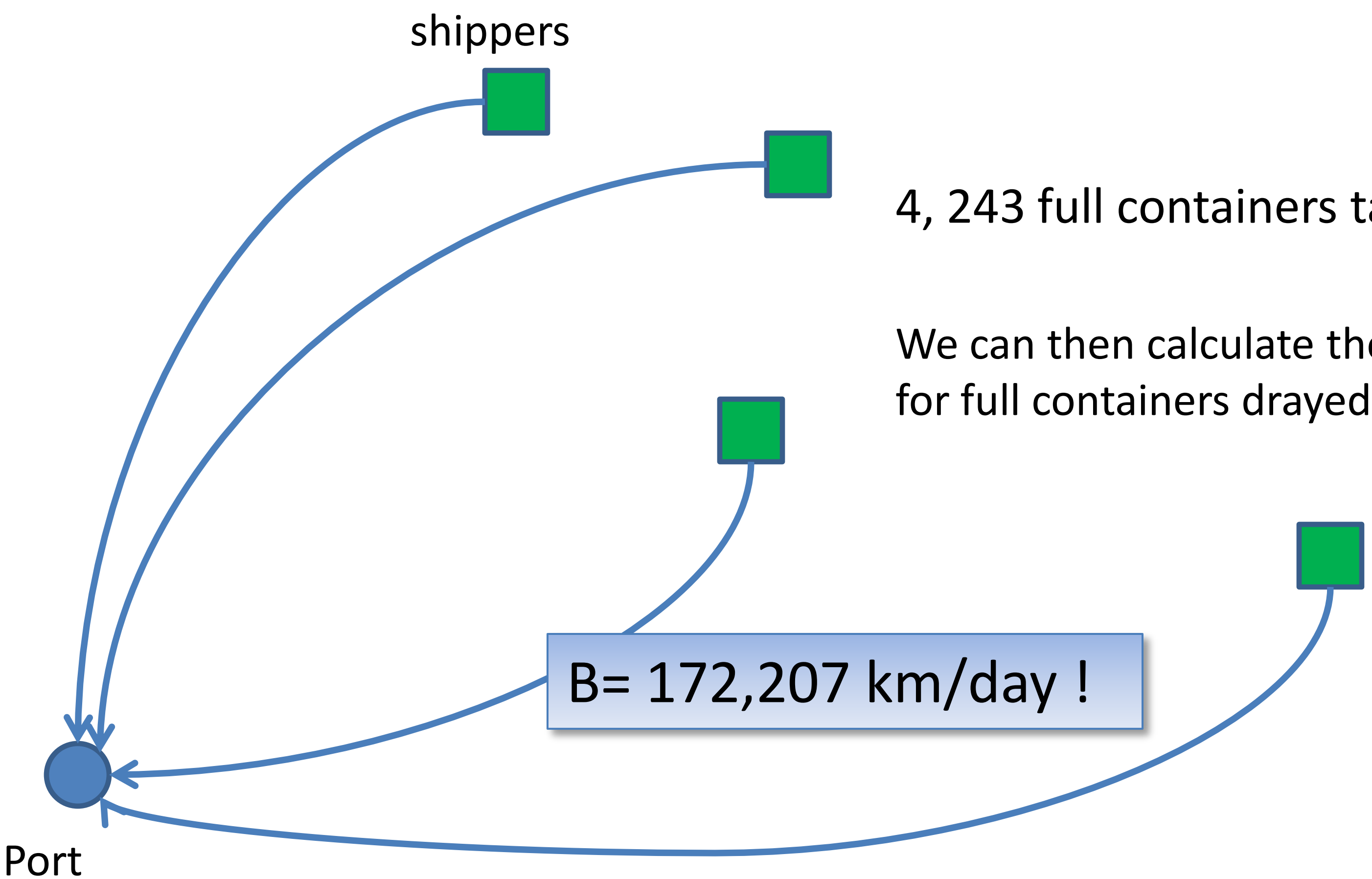
Data extracted from Tioga report (2008) daily volumes

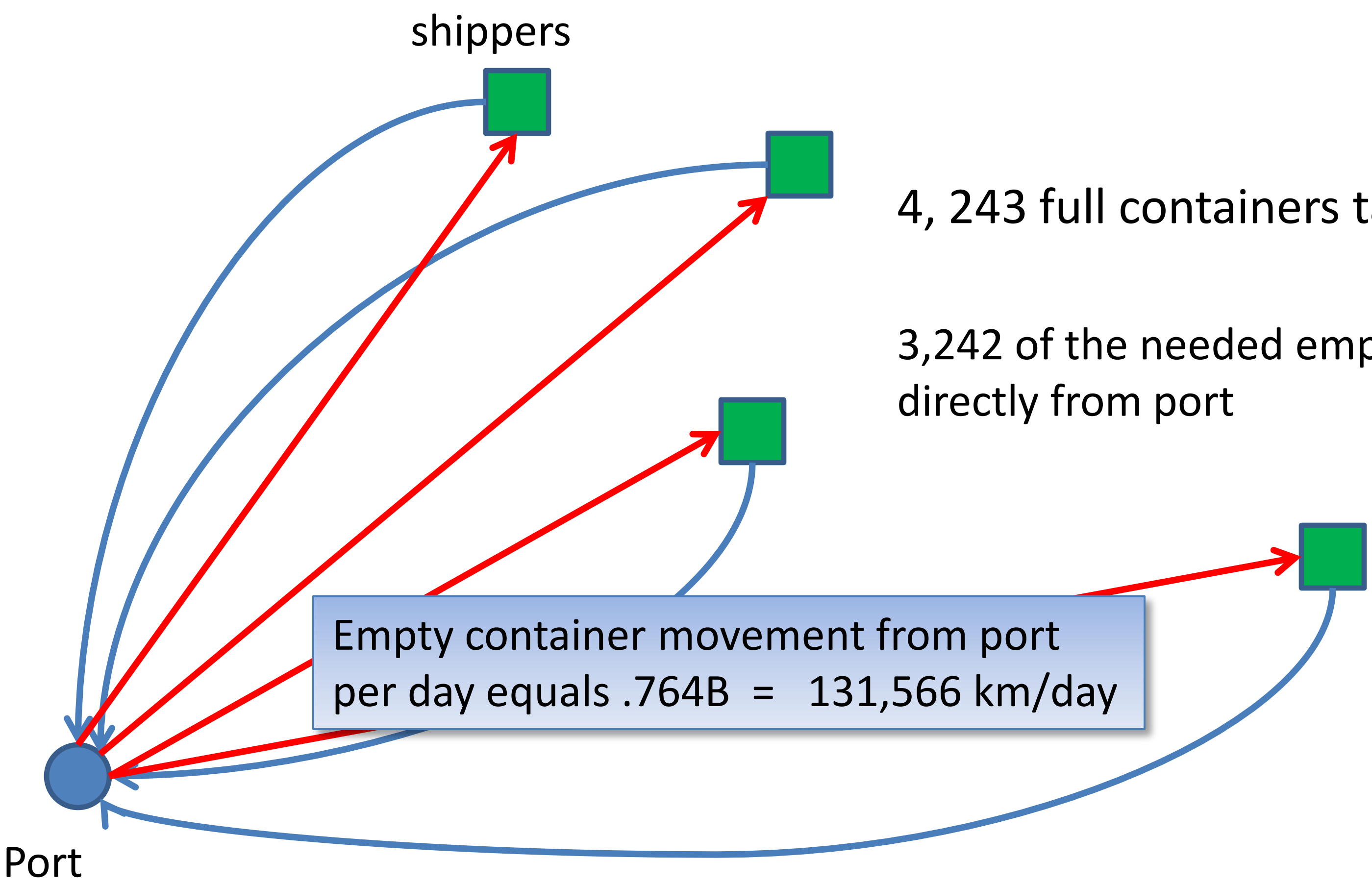


4, 243 full containers taken to port

We can then calculate the distance traveled for full containers drayed to port (B)

3

Data extracted from Tioga report (2008) daily volumes



4, 243 full containers taken to port

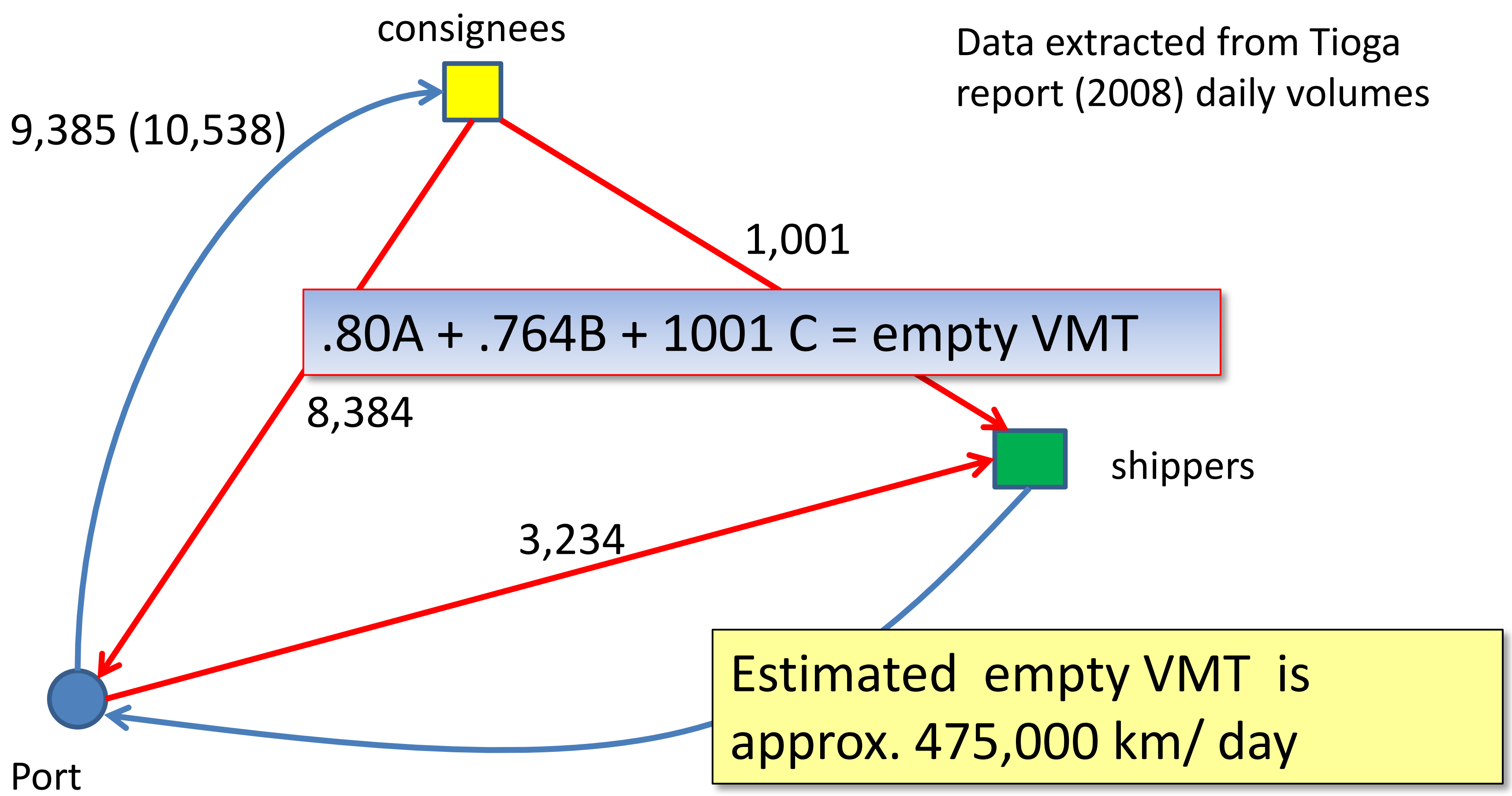
3,242 of the needed empties are supplied directly from port

3,242/4,243 = .764 or 76.4% of empty containers are supplied from port

3

Estimating total empty container VMT

Data extracted from Tioga report (2008) daily volumes



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OSEM models: Operating perspectives

- System optimal (OSEM1)
  - In a system optimal model, the system operates in such a manner that empty container miles are minimized
  - Truckers may be told to drop off empties at far away yards
  - Solving for system optimality allows us to determine the highest efficiency achievable
- User optimal (OSEM2 & OSEM3)
  - In a user optimal model, the system tries to achieve similar objectives but at the same time respects user choice.
  - As the drayage business is fragmented and dominated by small and medium-sized companies, user optimality is a more realistic assumption. In this context, we assume user prefers closer depots.
  - Consequently, it will necessary to rebalance inventories among storage yards

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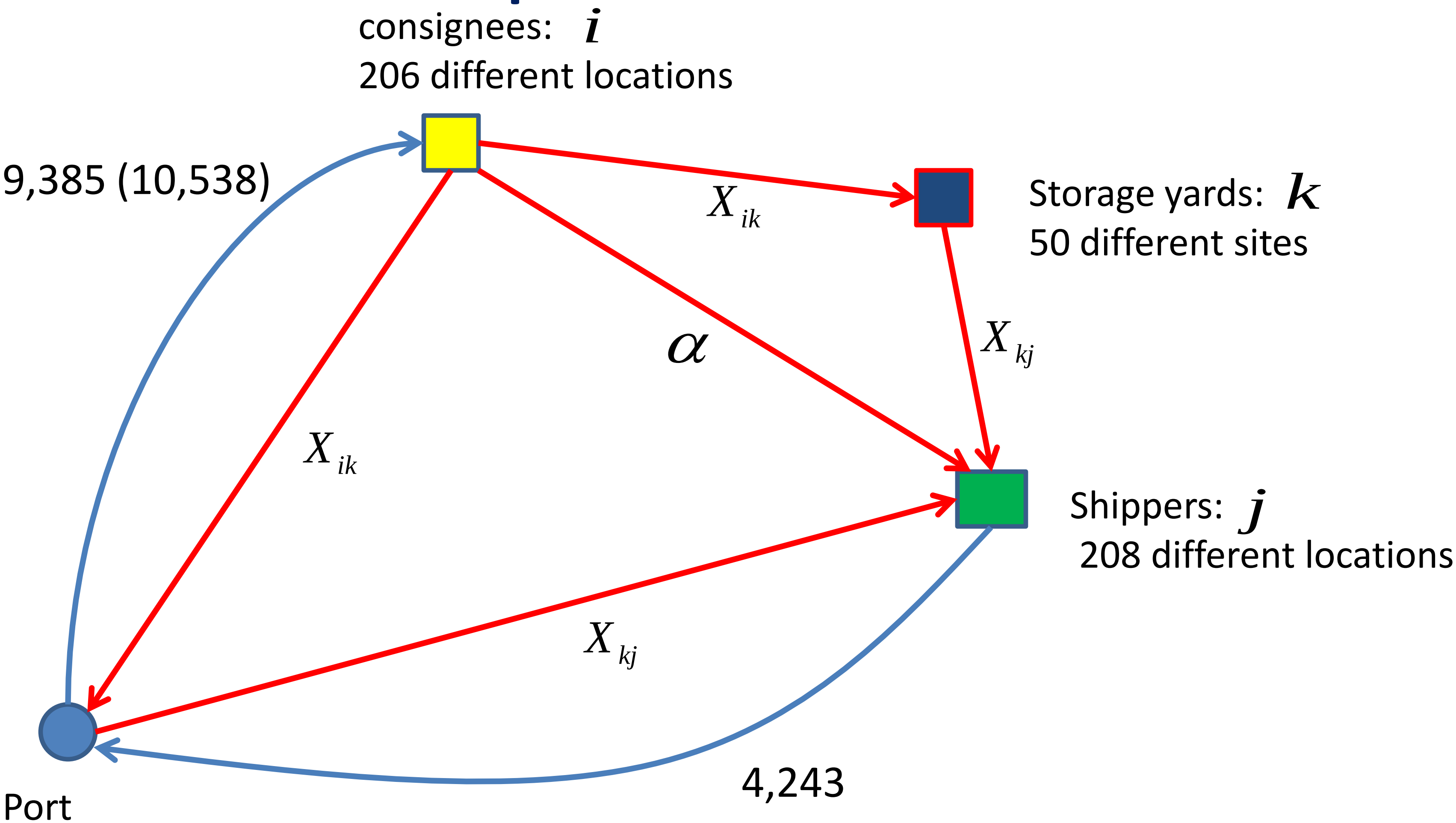
Basic problem format



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OSEM Models: Notation

i = index representing positions of consignees $i = 1,2,\dots,n$

j = index representing positions of shippers, $j = 1,2,\dots,m$

k = index representing potential locations for empty storage,

$k = 1,2,\dots,S$ where $k = 1$ represents the port

l = ind…

Technically speaking, the X variables in the first model need not be binary integer, but are continuous, representing the fraction of the trips assigned to a given depot

…, $l = 1,2,\dots,L$

e_{tk} = the volume of empty flow from depot t to depot k

$y_k = 1$, if the a depot is selected at site k, 0 otherwise

$x_{ik} = 1$, if consignee i uses depot k to drop off empties, 0 otherwise

$x_{kj} = 1$, if shipper j picks up empties from depot k, 0 otherwise

1

OSEM1: System Optimal

Minimize EMT: empty container miles traveled

$$Minimize\ Z = \sum_{t=1}^{K}\sum_{k}^{K} d_{tk}e_{tk} + \sum_{k=1}^{K}\sum_{i=1}^{n} d_{ik}(1-\alpha_i)S_i x_{ik} + \sum_{k=1}^{K}\sum_{j=1}^{m} d_{kj}(1-\beta_j)D_j x_{kj}$$

percentages of street turns

$$\sum_{k=1}^{K} x_{ik} = 1, \qquad \forall i \in I$$

$$\sum_{k=1}^{K} x_{kj} = 1, \qquad \forall j \in J$$

Empties from consignees must be sent out to depots

$$x_{ik} \le y_k, \qquad \forall i \in I, k \in K$$

$$x_{kj} \le y_k, \qquad \forall j \in J, k \in K$$

$$\sum_{t \ne k} e_{tk} + \sum_{i=1}^{n}(1-\alpha_i)S_i x_{ik} - \sum_{t \ne k} e_{kt} - \sum_{j=1}^{m}(1-\beta_j)D_j x_{kj} = \begin{cases} D_{port}, & \text{if } k=1 \\ 0, & \text{otherwise} \end{cases}, \quad \forall k \in K$$

$$\sum_{t \in K} e_{tk} + e_{kt} \le M \cdot y_k, \quad \forall k \in K$$

Meet demand for global repositioning of empties at port; and keep empty container inventories balanced at other depots.

$$\sum_{k=1}^{K} y_k = p$$

Locate *p* storage depots

5

OSEM2 model

OSEM 2: Optimizes driver efficiency, assuming drayage companies drop off at the closest depot to the consignee or pick up at the closest depot to the shipper

That is, assume the driver is very “greedy”

A “hot potato” approach to representing the drivers actions

Minimize EMT: empty container miles traveled

OSEM2

$$Minimize\ Z = \sum_{t=1}^{K}\sum_{k}^{K} d_{tk}e_{tk} + \sum_{k=1}^{K}\sum_{i=1}^{n} d_{ik}(1-\alpha_i)S_i x_{ik} + \sum_{k=1}^{K}\sum_{j=1}^{m} d_{kj}(1-\beta_j)D_j x_{kj}$$

$$\sum_{k=1}^{K} x_{ik} = 1, \qquad \forall i \in I$$

$$\sum_{k=1}^{K} x_{kj} = 1, \qquad \forall j \in J$$

$$x_{ik} \le y_k, \qquad \forall i \in I, k \in K$$

$$x_{kj} \le y_k, \qquad \forall j \in J, k \in K$$

$$\sum_{q \in C_{ik}} x_{iq} + x_{ik} \ge y_k, \quad \forall i \in I, k \in K$$

Require that consignee *i* uses its closest depot

$$\sum_{q \in C_{jk}} x_{qj} + x_{kj} \ge y_k, \quad \forall j \in J, k \in K$$

Require that shipper *j* is served by its closest depot

$$\sum_{t \ne k} e_{tk} + \sum_{i=1}^{n}(1-\alpha_i)S_i x_{ik} - \sum_{t \ne k} e_{kt} - \sum_{j=1}^{m}(1-\beta_j)D_j x_{kj} = \begin{cases} D_{port}, & \text{if } k=1 \\ 0, & \text{otherwise} \end{cases}, \quad \forall k \in K$$

$$\sum_{t \in K} e_{tk} + e_{kt} \le M \cdot y_k, \quad \forall k \in K$$

$$\sum_{k=1}^{K} y_k = p$$

3

OSEM3 model

Model 3: Also optimizes driver efficiency, but it assumes that drayage companies would select a mix of drop off locations (and pick up locations) for empties based upon relative closeness of the depots

- Drayage companies might have reasons for picking up an empty container (or dropping off an empty container) at a storage yard location other than the closest
- For example, a farther facility may be on their way to a subsequent destination

OSEM3

percentage of times the l^{th} closest depot is used

$$Minimize\ Z = \sum_{t=1}^{K}\sum_{k}^{K} d_{tk}e_{tk} + \sum_{l=1}^{L}\sum_{k=1}^{K}\sum_{i=1}^{n}\theta_{il}d_{ik}(1-\alpha_i)S_i x_{ik}^l + \sum_{l=1}^{L}\sum_{k=1}^{K}\sum_{j=1}^{m}\theta_{jl}d_{kj}(1-\beta_j)D_j x_{jk}^l$$

$$\sum_{k=1}^{K} x_{ik}^l = 1, \qquad \forall i \in I, l = 1..L$$

$$\sum_{k=1}^{K} x_{kj}^l = 1, \qquad \forall j \in J, l = 1..L$$

$$x_{ik}^l \le y_k, \qquad \forall i \in I, k \in K$$

$$x_{kj}^l \le y_k, \qquad \forall j \in J, k \in K$$

$$\sum_{q \in C_{ik}} x_{iq}^l + \sum_{s \le l} x_{ik}^s \ge y_k \qquad \forall i \in I, l = 1, 2, 3, \ldots, L$$

$$\sum_{q \in C_{jk}} x_{qj}^l + \sum_{s \le l} x_{kj}^s \ge y_k \qquad \forall j \in J, l = 1, 2, 3, \ldots, L$$

Forces x_{ik}^l to be 1 if k is the l^{th} closest depot to consignee i.
(Generalized Closest Assignment constraint due to Church and Cohon)

$$\sum_{t \ne k} e_{tk} + \sum_{l=1}^{L}\sum_{i=1}^{n}\theta_{il}(1-\alpha_i)S_i x_{ik}^l - \sum_{t \ne k} e_{kt} - \sum_{l=1}^{L}\sum_{j=1}^{m}\theta_{jl}(1-\beta_j)D_j x_{kj}^l = \begin{cases} D_{port}, & \text{if } k = 1 \\ 0, & \text{otherwise} \end{cases}$$

$$\sum_{t \in K} e_{tk} + e_{kt} \le M \cdot y_k, \quad \forall k \in K$$

$$\sum_{k=1}^{K} y_k = p$$

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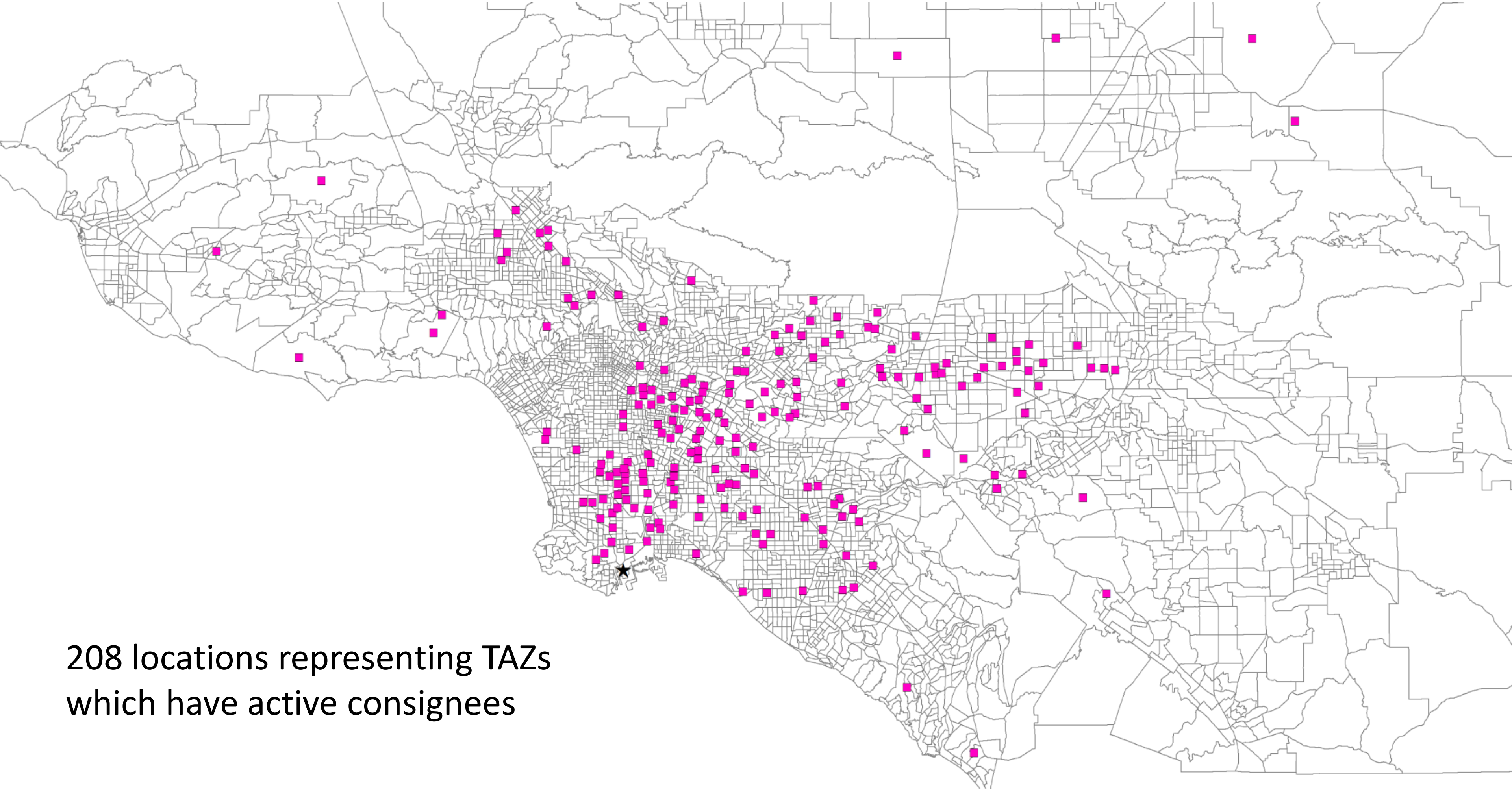
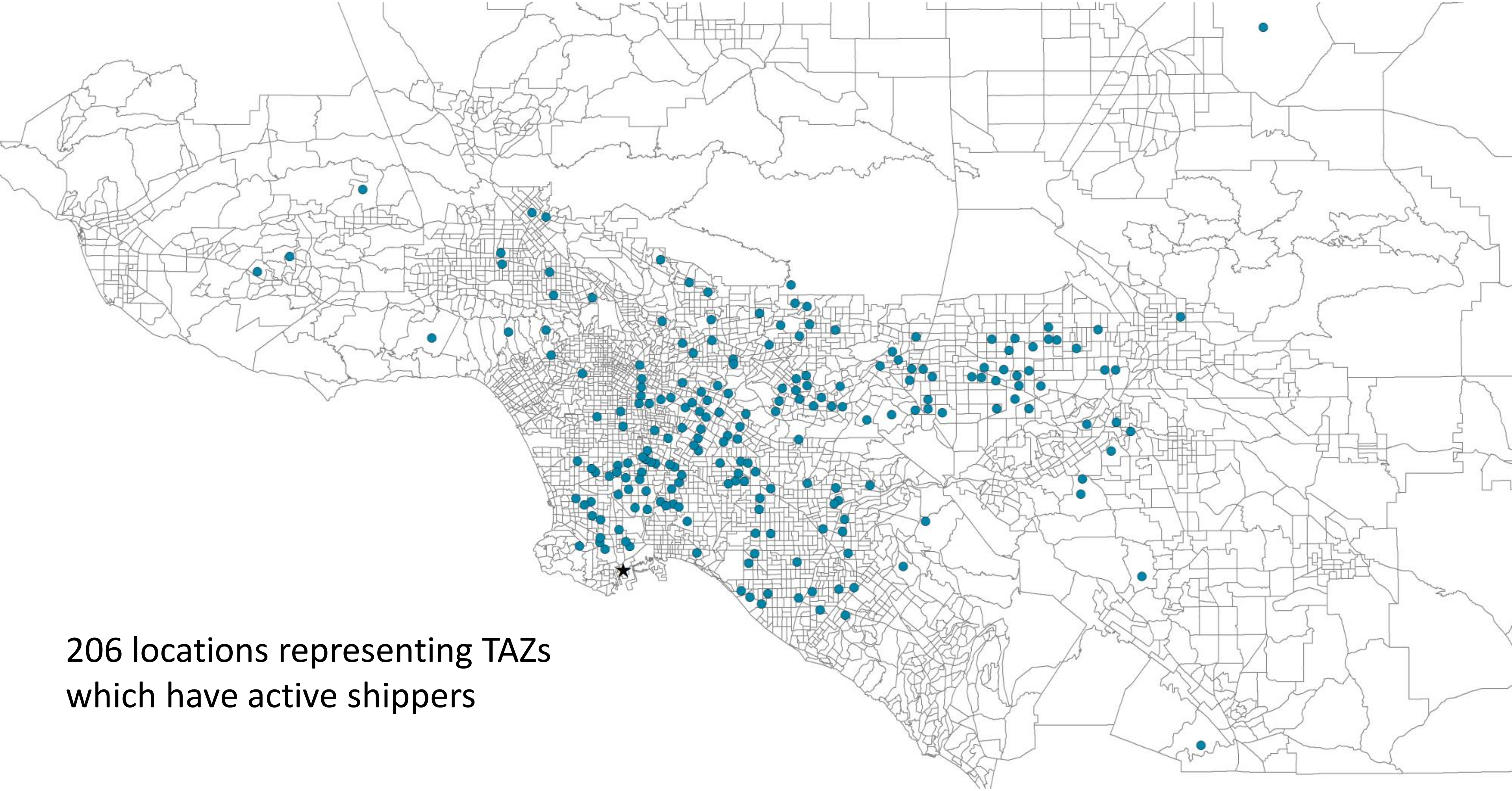
Consignee Locations



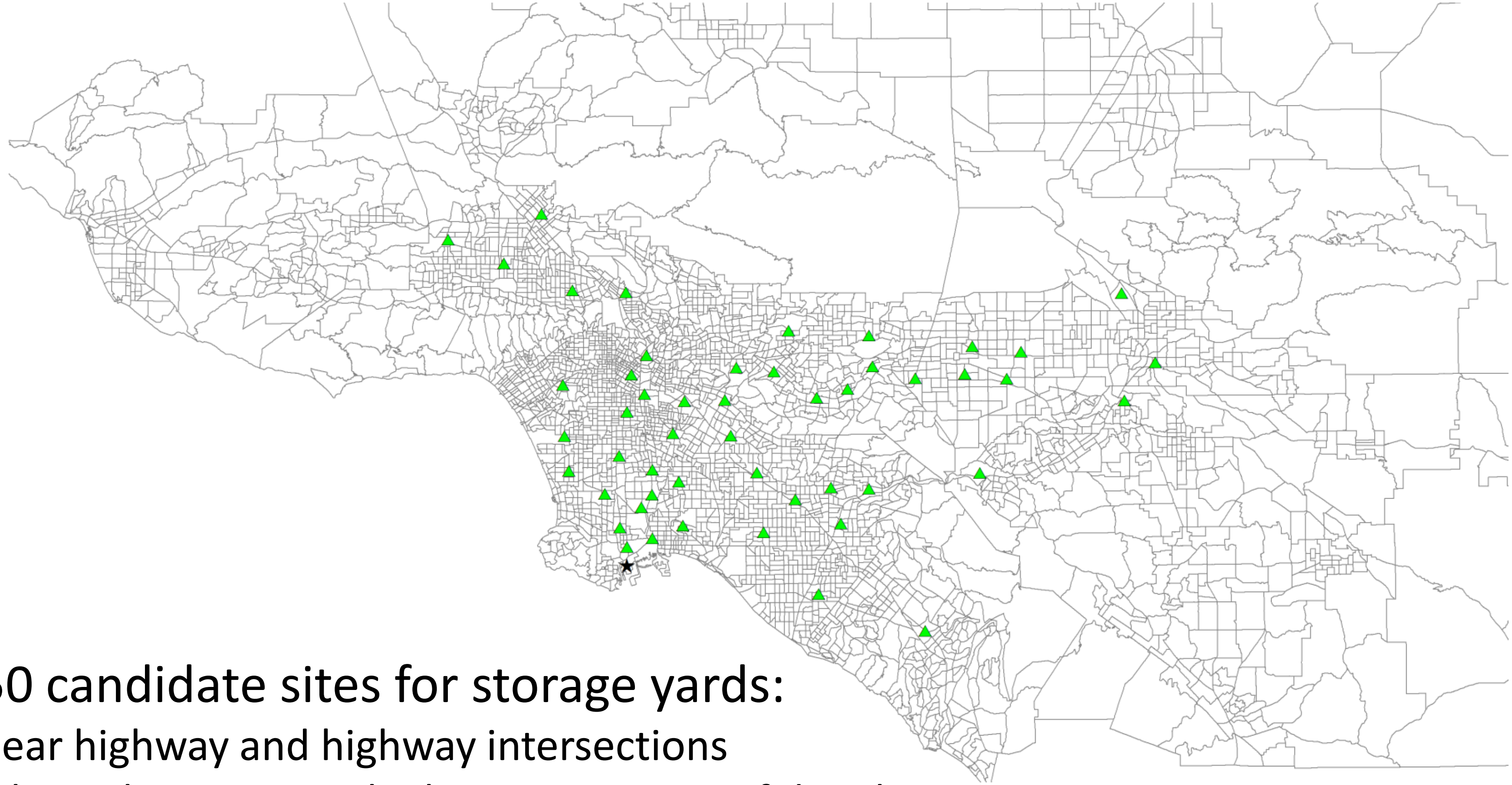
208 locations representing TAZs which have active consignees

Shipper locations



206 locations representing TAZs which have active shippers

Potential sites

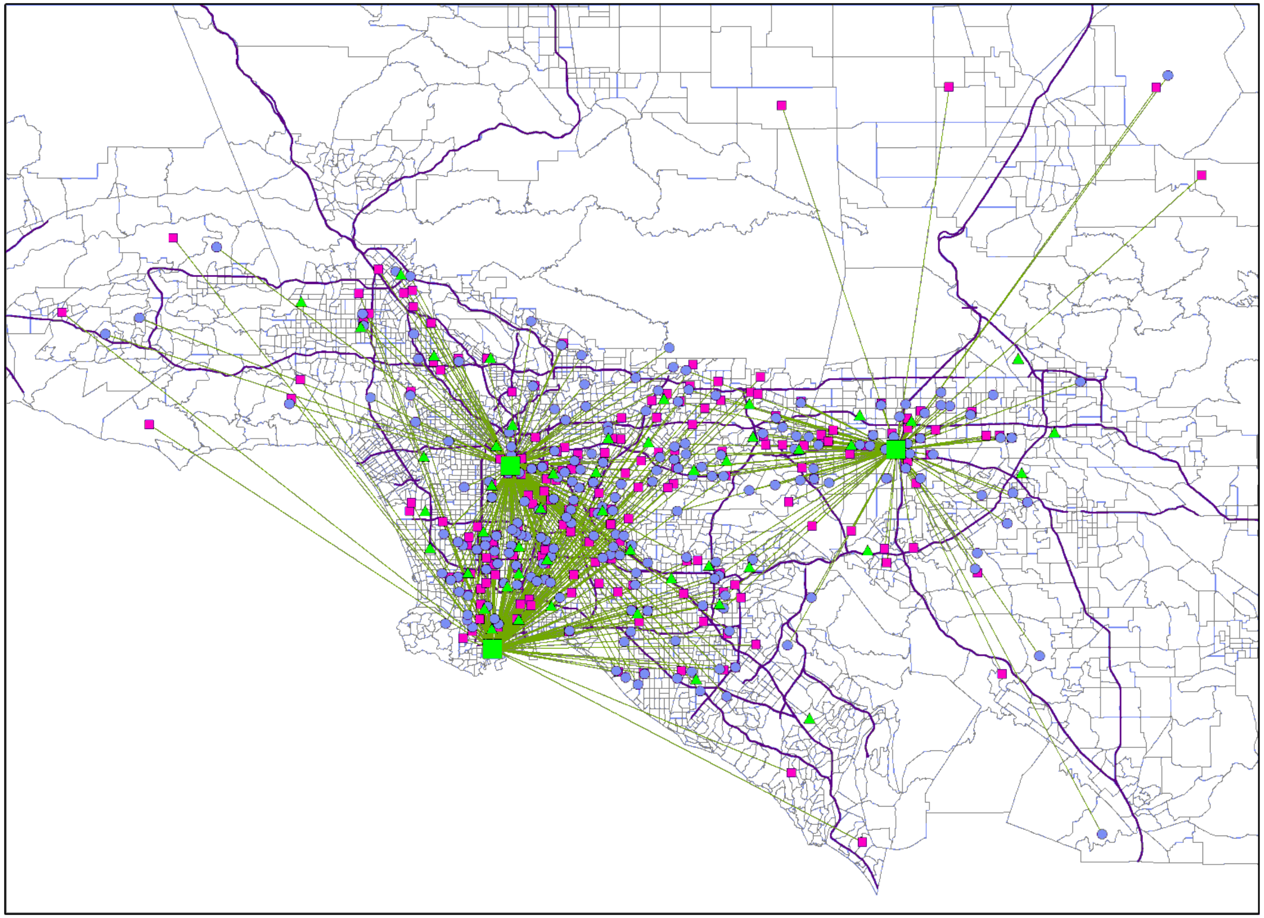


50 candidate sites for storage yards:

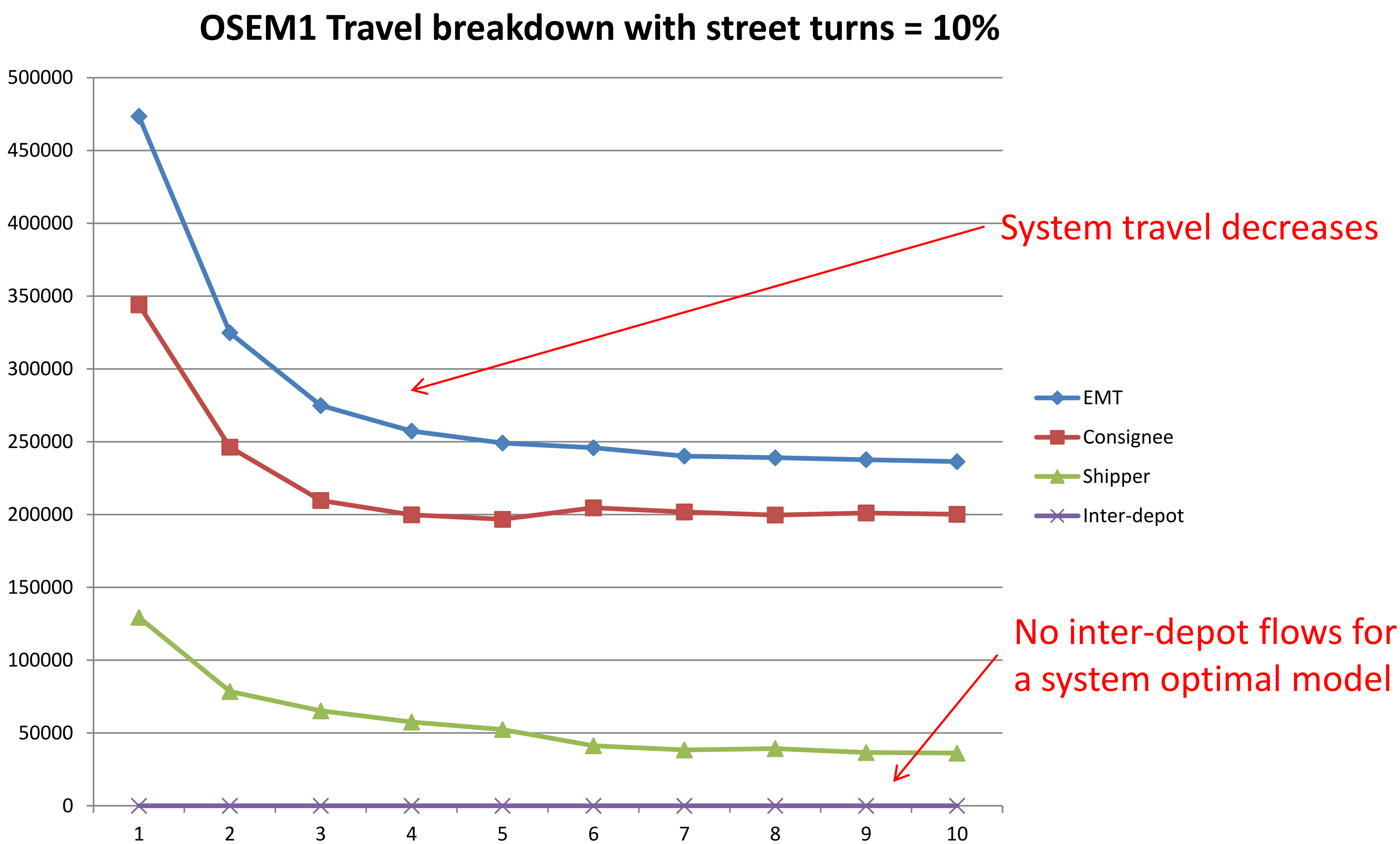
near highway and highway intersections

where there exists a high concentration of distribution centers.

OSEM1 result for 10% street turns and 3 storage yards (including port)



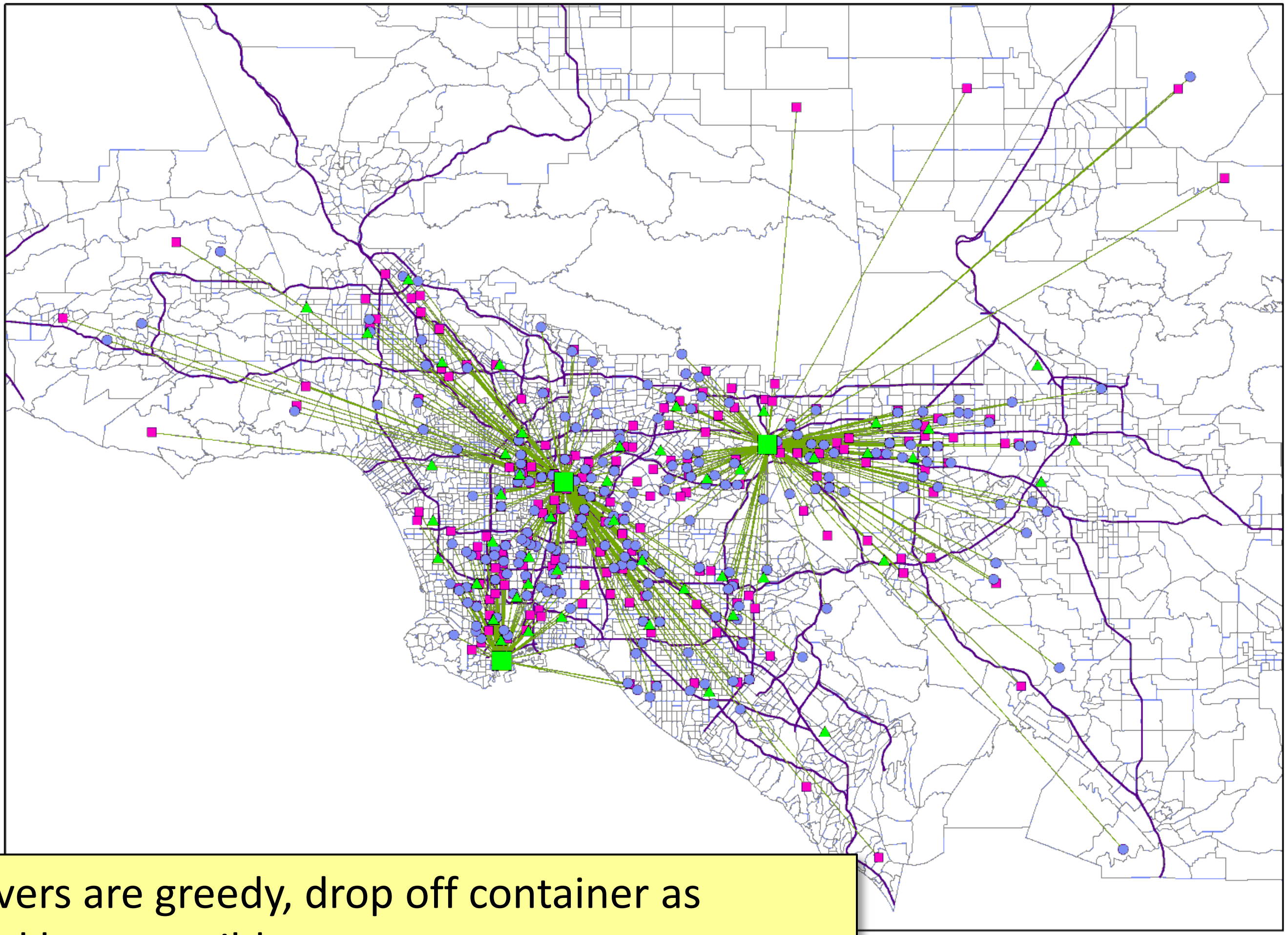
VMT in moving empty containers can be reduced by more than 30% using 1 depot away from the port!



Perspective: achieving only half of the savings yields…….

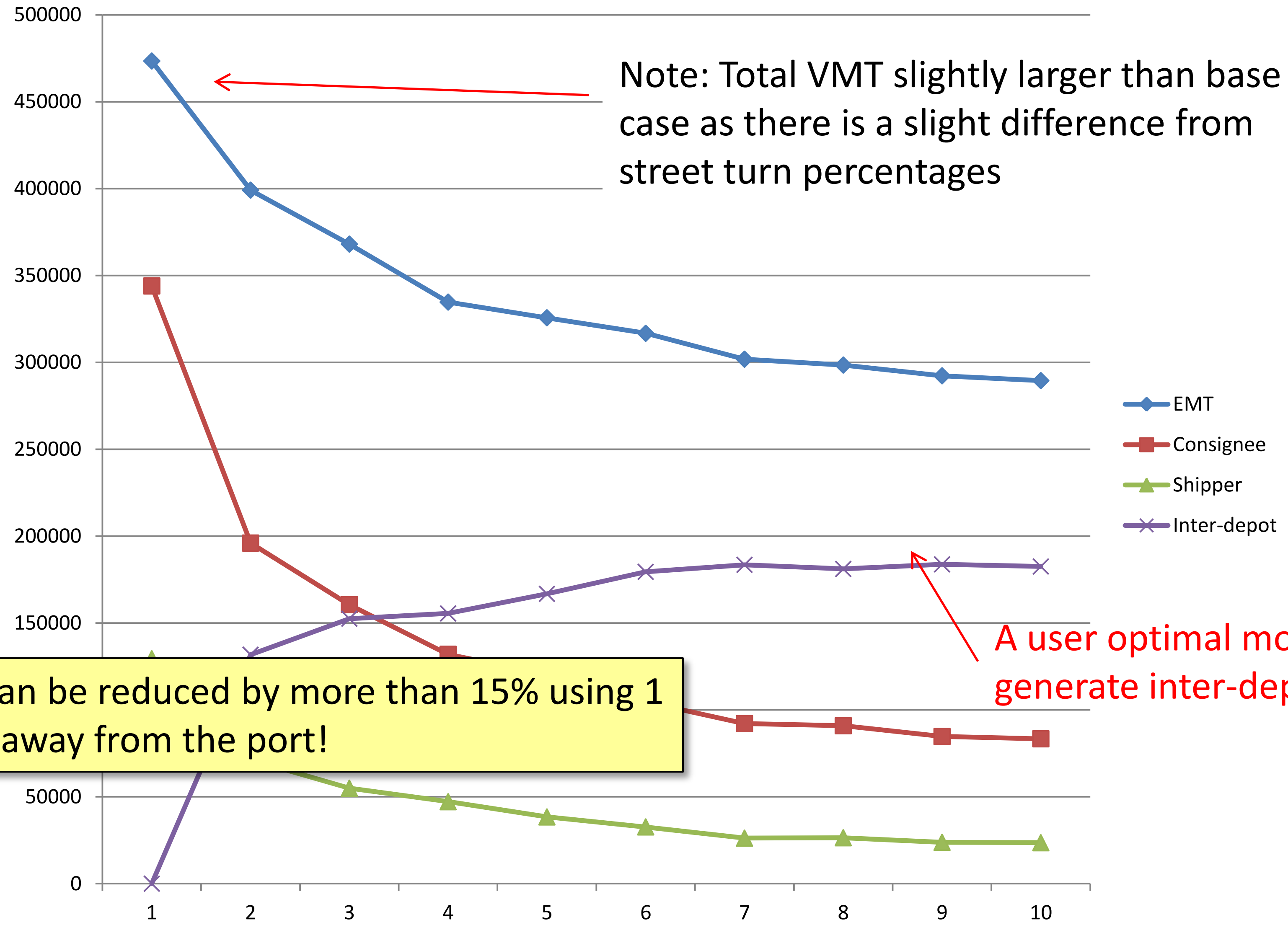
- 75,000 km / day reduction for 1 additional storage yard
- Equals 46,500 miles/day reduction in VMT
- saves 5,200 gallons of fuel (9 mpg)
- Saves $15,600 per day in fuel ($3 /gal.)
- Reduces CO_2 emissions by 115,000 lbs per day

OSEM2 result for 10% street turns and 3 storage facilities



Drivers are greedy, drop off container as quickly as possible

OSEM2 Travel breakdown with 10% street turns

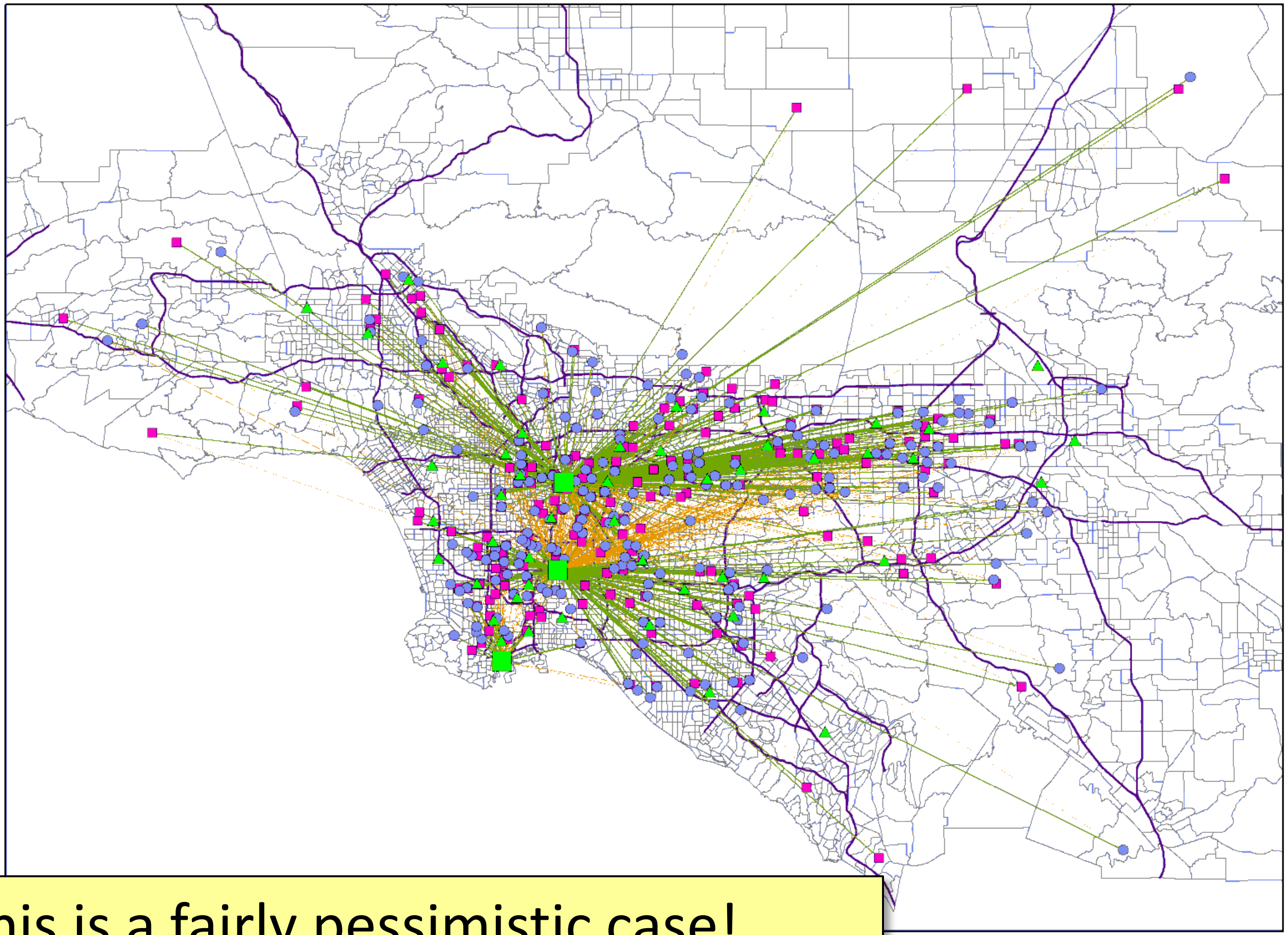


Note: Total VMT slightly larger than base case as there is a slight difference from street turn percentages

A user optimal model will generate inter-depot flow

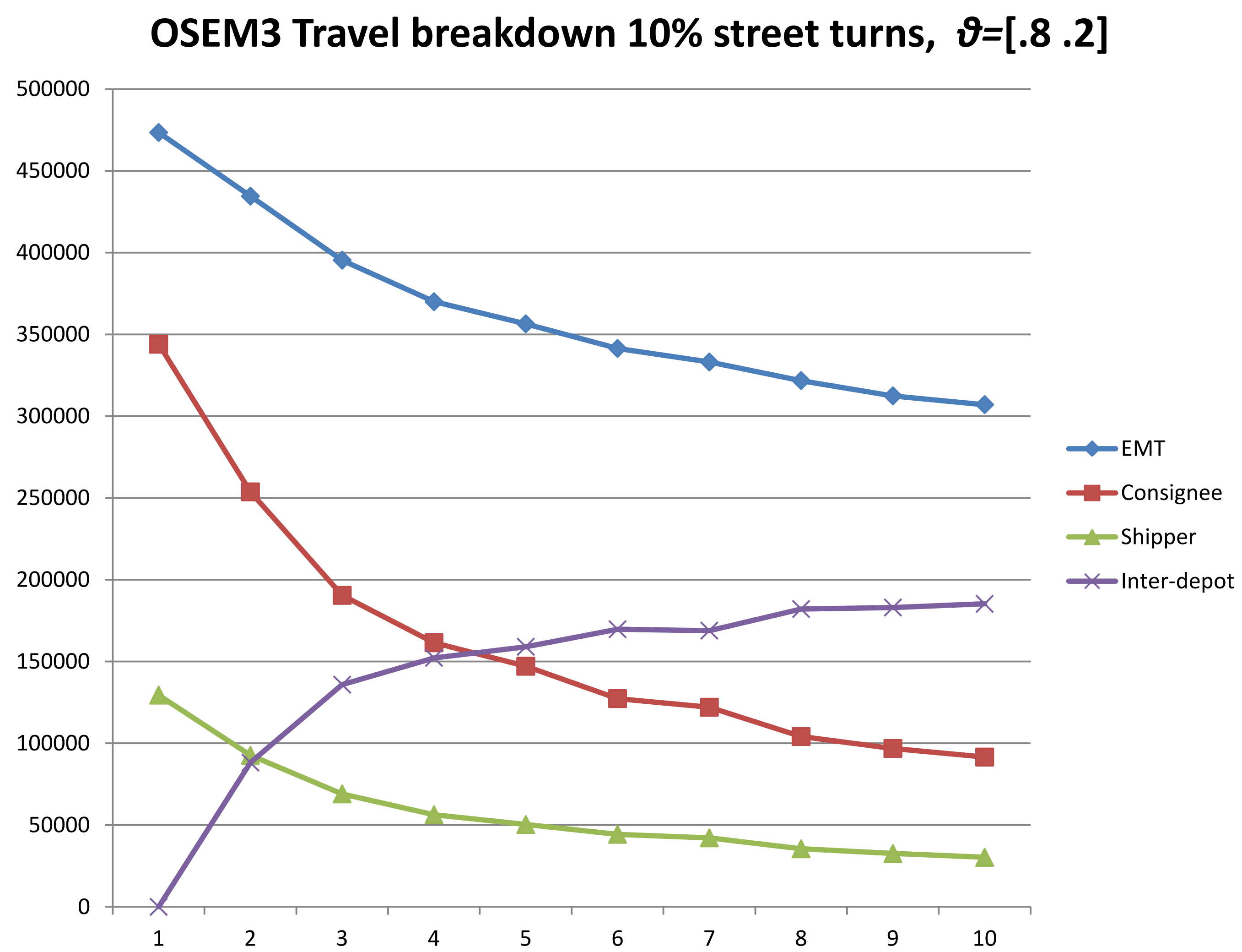
VMT can be reduced by more than 15% using 1 depot away from the port!

OSEM3 result for 10% street turns and 3 storage yards, with [0.8,0.2]

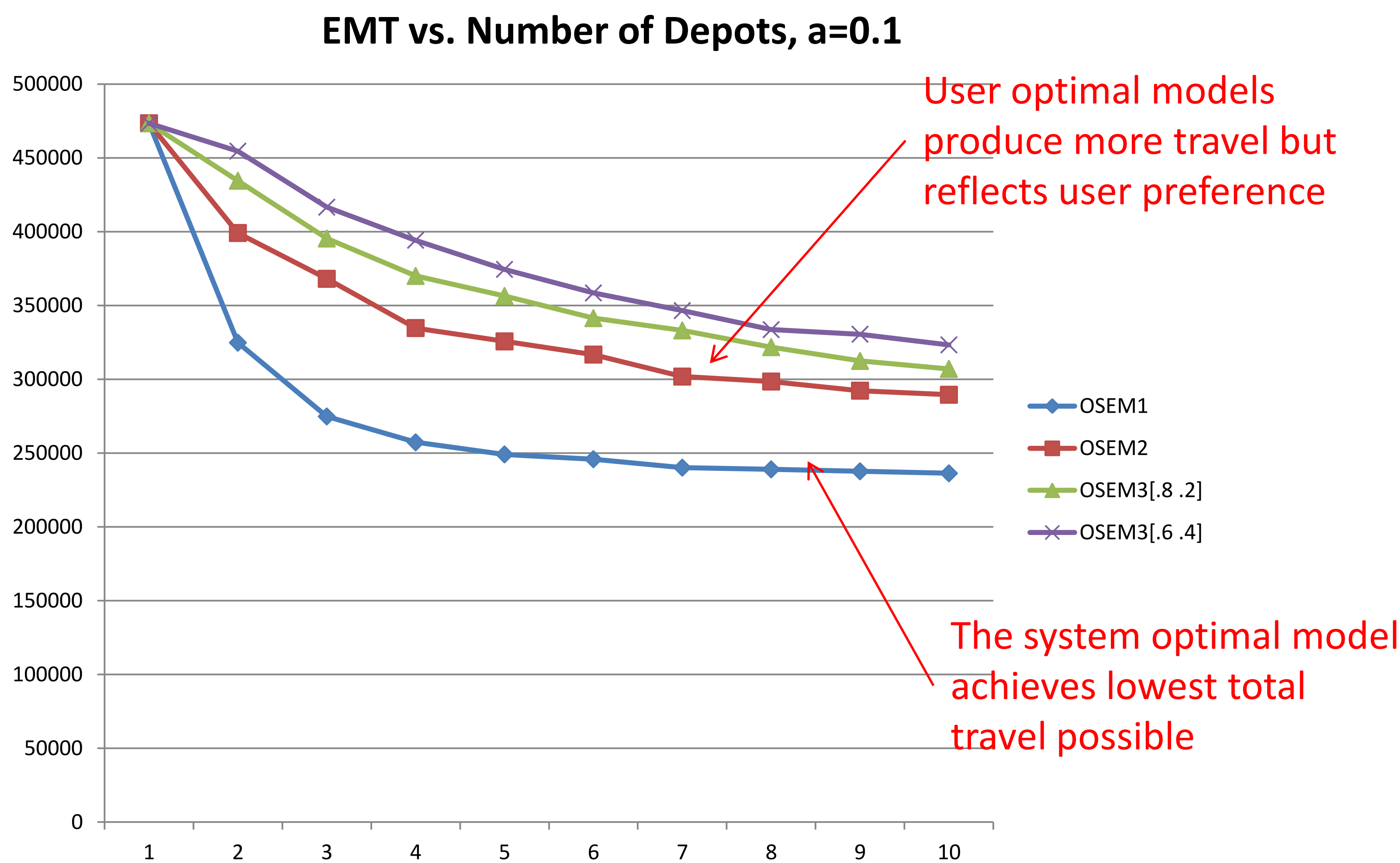


This is a fairly pessimistic case!

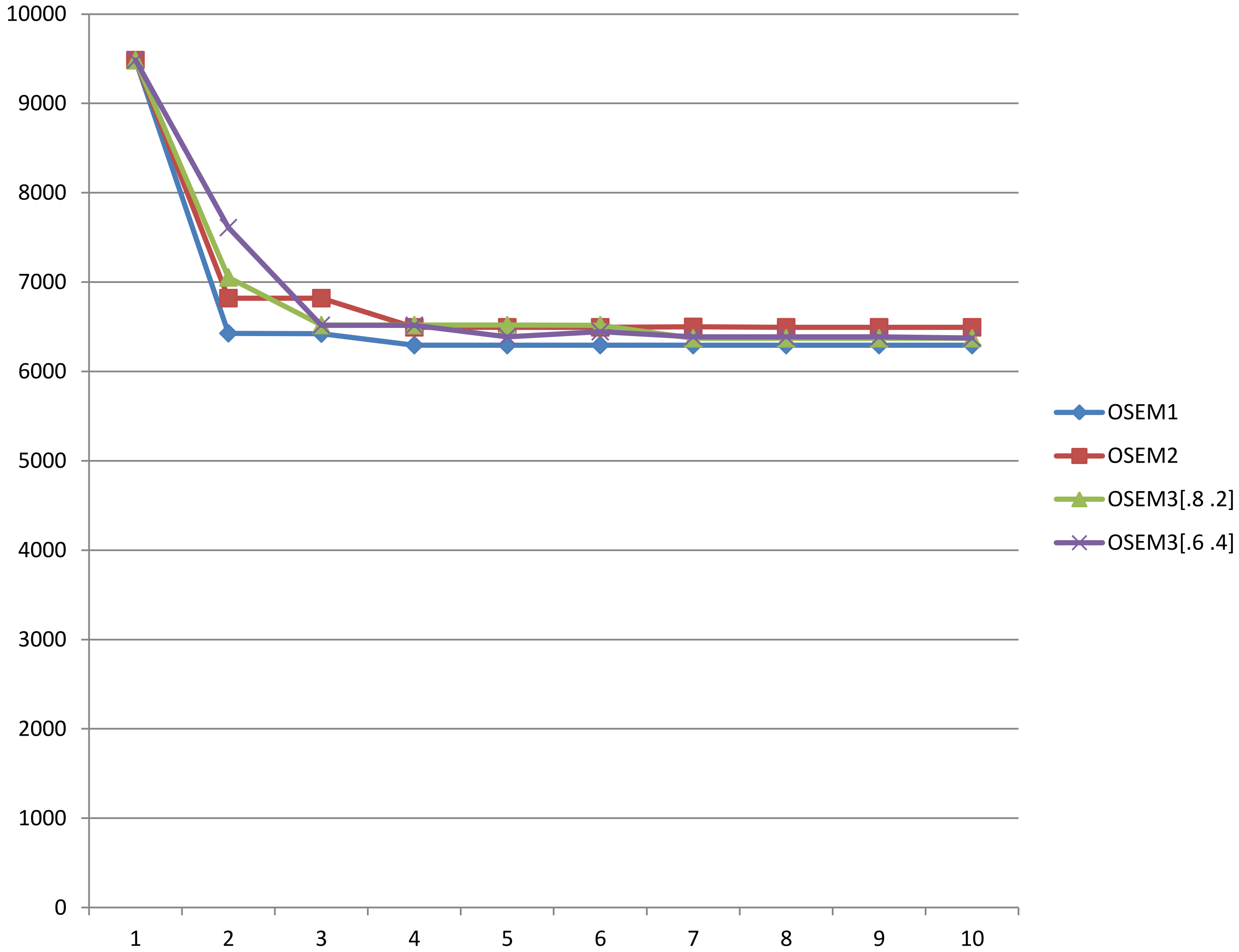
VMT can be reduced by more than 10% using 1 depot away from the port!



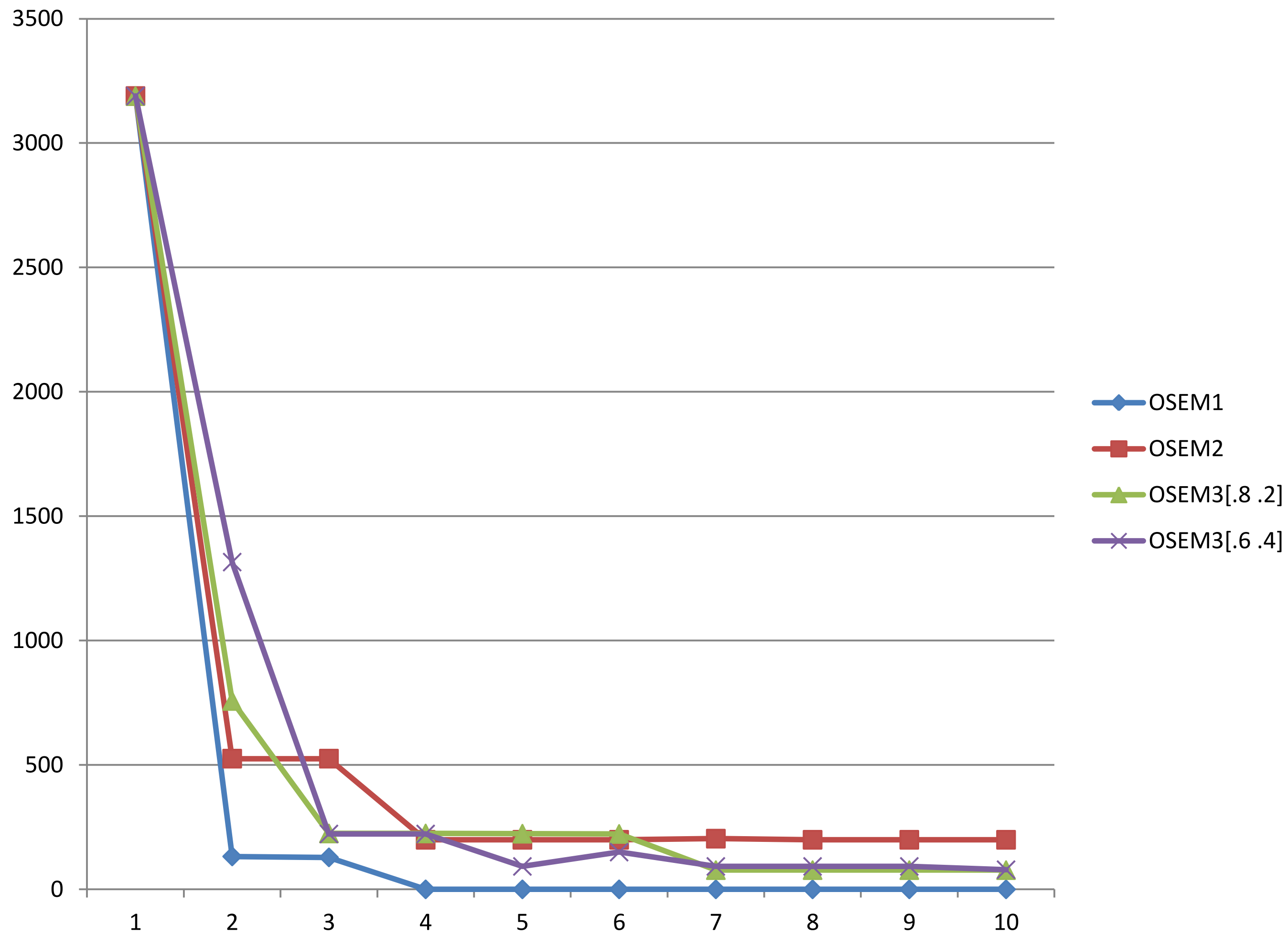
Model results: User opt. *vs.* System opt.



Model results: Empties entering the port



Model results: Empties leaving the port



Empties moving in/out of port: 1 storage yard

- Empties entering: 8,300 reduced to 6,500
- Empties leaving: 3,200 reduced to 500
- Total reduction of empties entering or leaving port 4,500 per day
- Note: many trips are preceded by a bobtail leg:
  - Entering as a bobtail to pick up an empty or full
  - Exiting as a bobtail after dropping off an empty or full
  - Thus, there is the possibility of better trip coordination to reduce traffic further

Summary

- We now have an accurate picture of the potential savings associated with developing away from port storage yards for empties
  - Significant reductions in VMT
  - Significant reductions in port entries
  - Significant reduction in vehicle operator times (may allow them to do more trips in a given day)
  - Fuel savings and emissions reductions

End/Aft

Image from gcaptain.com/marintime/blog

What makes sense as a next step

- Simulate empty transport trips and estimate impacts on air emissions with added storage yards
- Estimate traffic impacts on I-710, I-110, and 47
- Develop a truck simulation model for simulating movement of drayage truck activity to focus on bobtail movement (moves when the truck is not pulling an empty container)

References

This presentation is based principally upon the following two papers:

- Lei and Church (2011) " Constructs for Multilevel Closest Assignment in Location Modeling, *International Regional Science Review*
- Lei and Church (2011), Locating Short term empty container storage facilities to support port operations: a user optimal approach, *Transportation Research E*

The following references are relevant to the subject of empty container storage and movement

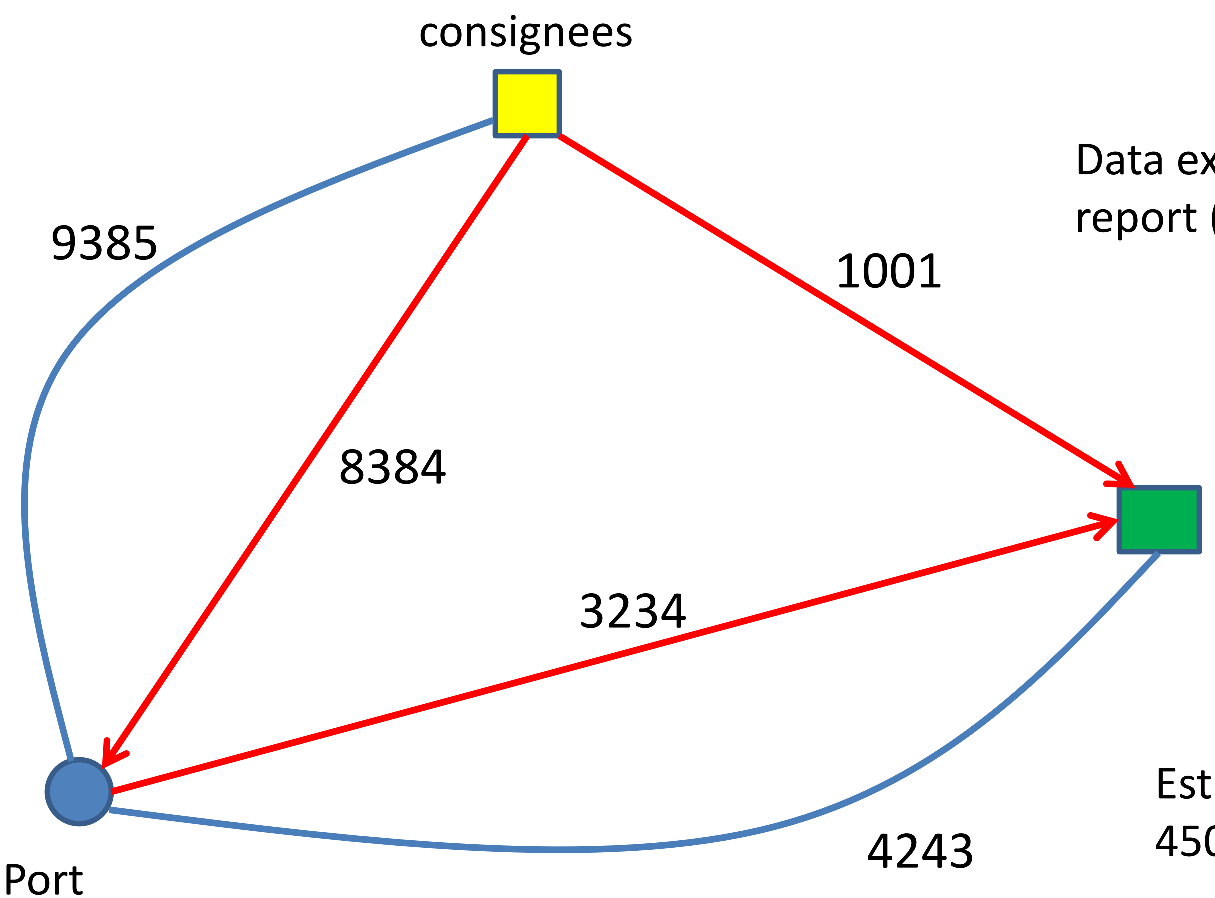
- Gendron, B. and T.G. Crainic (1995) "A branch and bound algorithm for depot location and container fleet management," Location Science 3: 39-53.
- Imai, Nashimura and Current (2007)
- Shen & Khoong (1995)
- Namboothiri & Erera (2004)
- Jula, Dessouky, Ioannou, & Chassiakos (2005)
- Lopez, E. (2003)
- Davies, P. (2006)
- Cheu, Chew, and Wee (2003)
- Boile, M. (2007) TRB
- Crainic, Gendreau, and Dejax (1993)
- Jula, Chassiakos, and Ioannou (2006)
- Choong, Cole, and Kutanoglu (2002)
- Chang, Jula, Chassiakos, Ioannou (2006)
- Bourbeau, Crainic, and Gendron
- Dejax and Crainic (1987)
- Crainic, Gendreau, Soriano, and Toulouse (1993)
- Gendron and Crainic (1995)
- Crainic, Dejax, and Delorme (1989)

Models incorporating assignment beyond the closest facility

- At times the closest facility may be busy and unable to serve
  - Weaver, J.R. an R.L. Church (1985) A median location model with nonclosest facility service," Transportation Science 19: 58-74.
  - Pirkul, H. and D. Schilling (1989) The capacitated maximal covering location problem with backup service," Annals of Operations Research 18: 141-154.
  - Narasimhan, S. , H. Pirkul and D.A. Schilling (1992) "Capacitated emergency facility siting with multiple levels of backup," Annals of Operations Research 40: 323-337.
- At times the closest facility may fail or be closed due to an emergency
  - Snyder, L.V. and M.S. Daskin (2005) "Reliability Models for Facility Location: the expected failure cost case," Transportation Science 39: 400-416.
- The properties of maintaining closest assignment constraints
  - Gerrard, R.A. and R.L. Church (1996) "Closest assignment constraints and location models: properties and structure," Location Science 4: 251-270.
- Planning for system failure :
  - Church, R.L., M.P. Scaparra, and R. Middleton (2004) " Identifying critical infrastructure: interdiction median and covering problems," Annals of the Association of American Geographers 94:

the following slides are for reference only

Estimating empty container VMT



Data extracted from Tioga report (2008) daily volumes

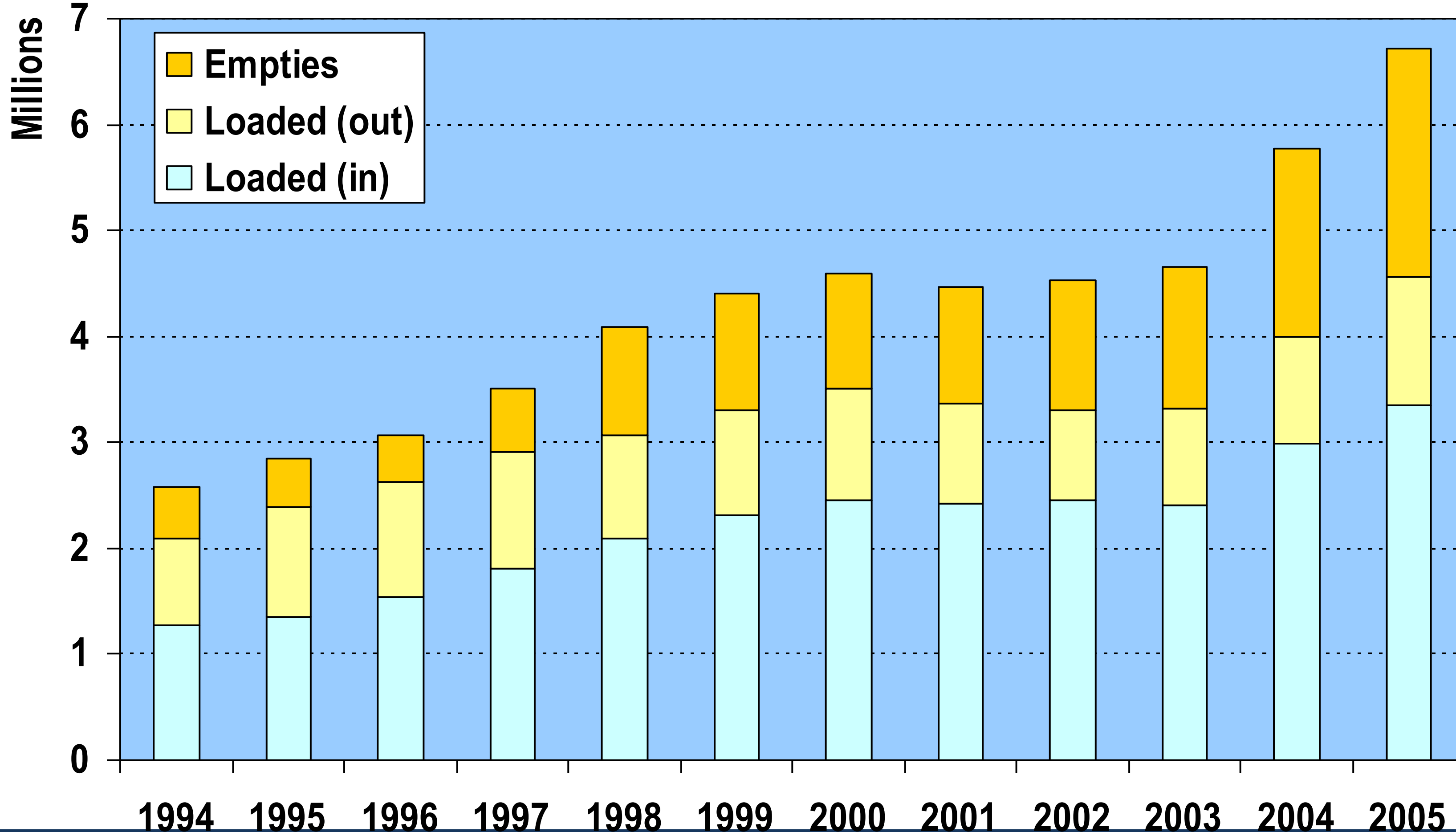
Estimated empty VMT
450,000 km/ day

Import *vs*. Export

- Trade imbalance: imports exceed exports
  - Imports: nearly 100% full
  - Exports: nationally 70% full

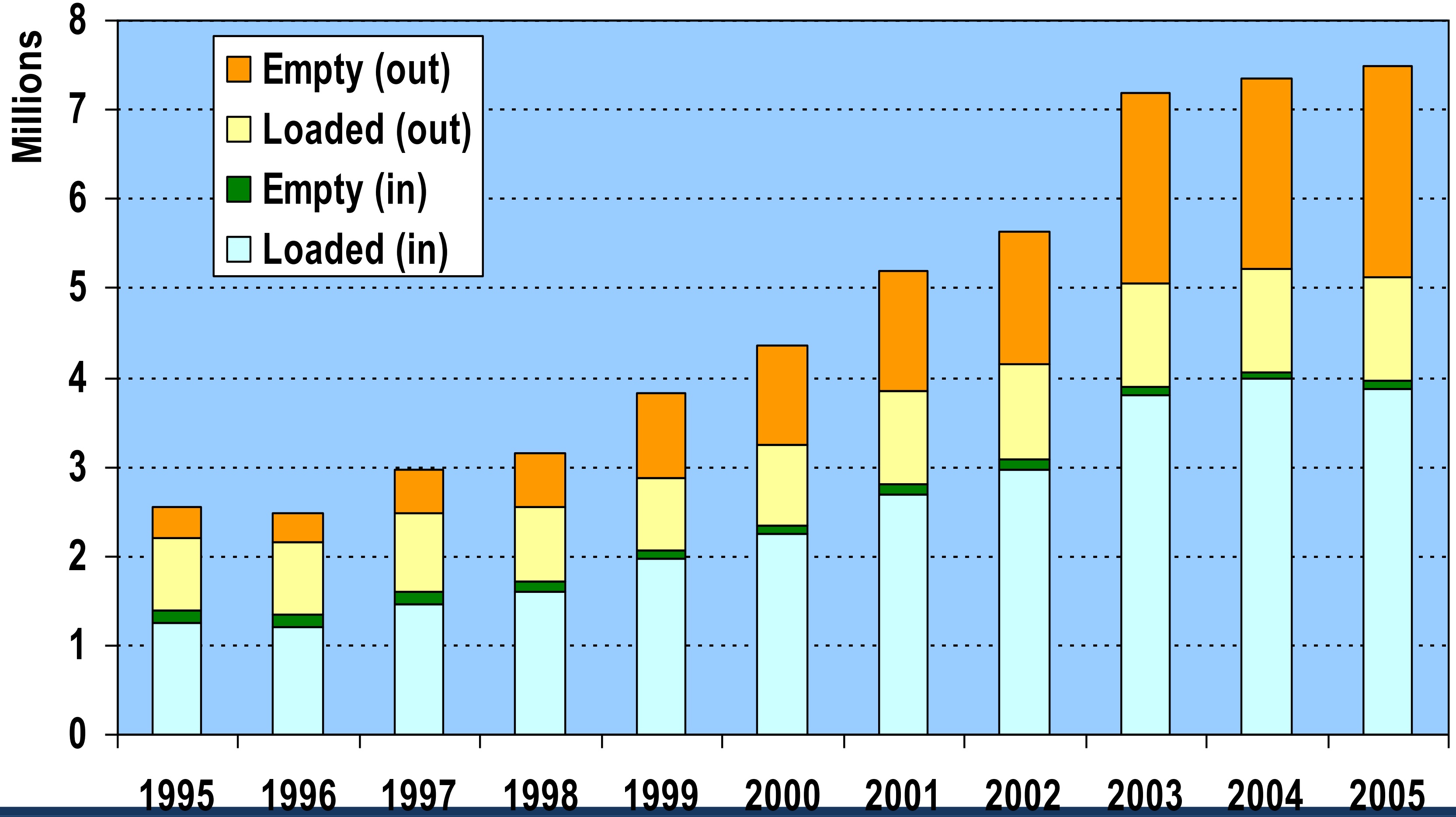
    LALB, 30-40% full
- Export containers to China: wastepaper, electronic waste, and scrap metals
- Terminals want empties returned as soon as possible
  - Makes sense to terminal operator since many are reloaded onto ships empty

Containers handled by Port of LB, in millions of TEUs



Data: Port of Long Beach

Containers handled by Port of LA, in millions of TEUs



Data: Port of Los Angeles Authority

Optimal Storage of Empties Model (OSEM)

- System-wide objectives:
  - Minimize the total empty container travel in terms of distances or travel times
  - Respect the need for empties at the port for global repositioning to *e.g.* Asia
  - Keep empty container traffic at the port complex to a minimum

Port of long beach image   FTR International INC