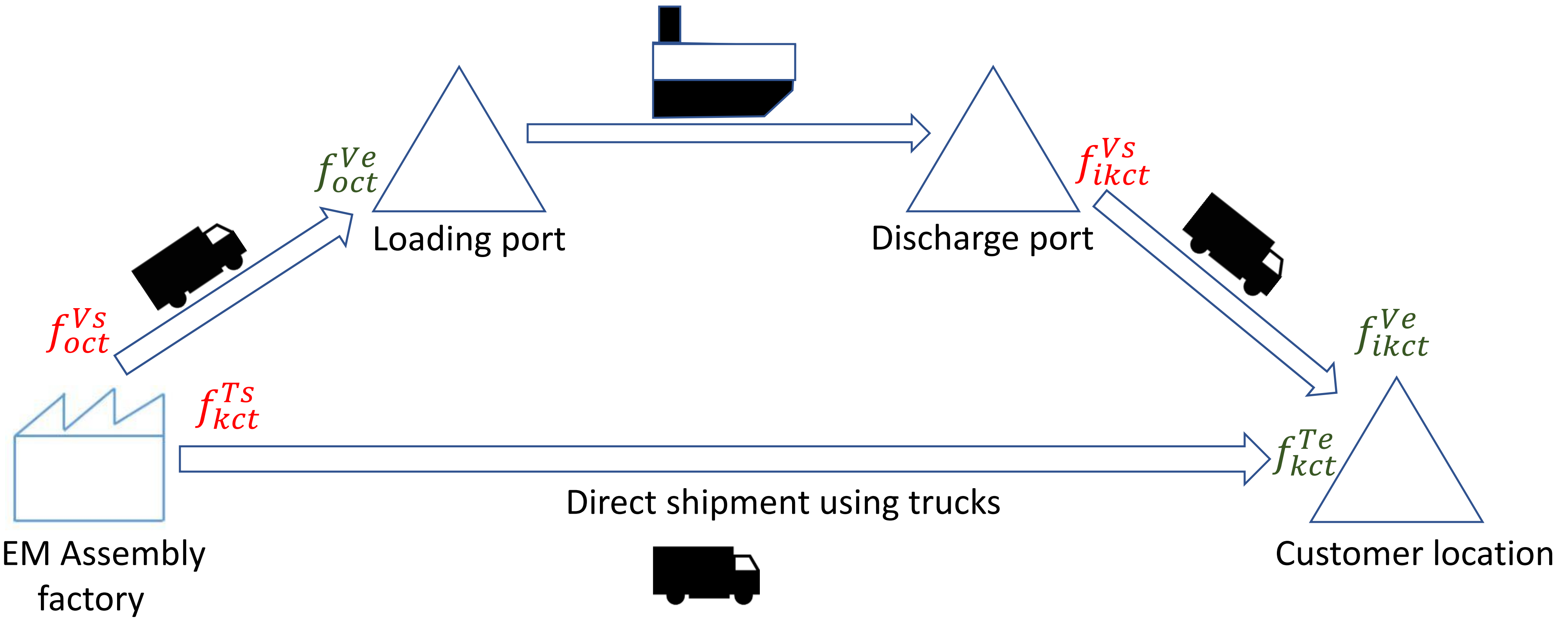
A maritime logistics system design model for automotive distribution

Saurabh Chandra

Automotive industry and market in India

- Industry produced around 25 million vehicles in 2017
- 5 percent per year growth in production volumes from 2016
- Manufacturing clustered in three main locations:
  - North near Delhi
  - West near Mumbai and
  - South in Chennai
- Market spread pan-India in terms of sales
- Domestic distribution is a challenge for all stakeholders
- 96% distribution through roadways
- Government keen to develop alternative modes- coastal and rail

Coastal logistics of vehicles:



Pertinent questions for a new system

- What ships are required for the maritime logistics?
- Which ports and the routes are best?
- What cost savings can be expected with alternative mode?
- **How the inventory cost of cargo would impact the logistics share?**

Mathematical Model

- Ro-ro liner service network design along a coastline
- Fleet deployment for ro-ro ships for voyages along given routes
- Mode choice among two options- road and coastal
- Inventory routing problem

Objective function

1. Direct truck delivery cost

$$\sum_{k\in\mathcal{K}}\sum_{c\in C_k}\sum_{t\in\mathcal{T}} C_k^T f_{kct}^{Ts}$$

2. Fixed cost of using a ship of type v in the planning horizon

$$\sum_{v\in\mathcal{V}} C_v^{FS} u_v$$

3. Cost of voyages served on various routes

$$\sum_{v\in\mathcal{V}}\sum_{r\in\mathcal{R}_{\mathcal{V}}}\sum_{t\in\mathcal{T}} C_{vr}^S x_{vrt}$$

Objective function terms

4. Cost of first mile trucking

$$\sum_{c\in\mathcal{C}}\sum_{t\in\mathcal{T}} C_0^T f_{oct}^{Vs}$$

5. Cost of last mile trucking

$$\sum_{i\in\mathcal{I}}\sum_{k\in\mathcal{K}}\sum_{c\in\mathcal{C}_{k}}\sum_{t\in\mathcal{T}} C_{ikt}^T f_{ikct}^{Vs}$$

6. Variable cost of cargo loading/discharging at port *i*

$$\sum_{v\in\mathcal{V}}\sum_{r\in\mathcal{R}_{\mathcal{V}}}\sum_{i\in\mathcal{I}_{\mathcal{r}}:i\neq 0}\sum_{t\in\mathcal{T}} C_i^{VH} q_{ivrt}^U$$

Objective function terms- inventory costs

7. Inventory cost at the storage locations

$$\sum_{i \in \mathcal{I}} \sum_{c \in C} \sum_{t \in \mathcal{T}} H_{ic} s_{ict}$$

8. Pipeline inventory cost

$$h^P \left[\left(\sum_{i \in \mathcal{I}} \sum_{k \in \mathcal{K}} \sum_{c \in C_k} \sum_{t \in \mathcal{T}} f_{ikct}^{Te} U_c + \sum_{i \in \mathcal{I}} \sum_{k \in \mathcal{K}} \sum_{c \in C_k} \sum_{t \in \mathcal{T}} f_{ikct}^{Ve} U_c \right) - \left(\sum_{k \in \mathcal{K}} \sum_{c \in C_k} \sum_{t \in \mathcal{T}} f_{kct}^{Ts} U_c + \sum_{c \in C} \sum_{t \in \mathcal{T}} f_{ct}^{Vs} U_c \right) \right]$$

Constraints:

Numbers loaded at a loading port = Numbers discharged at subsequent discharge ports

$$q_{vrt}^{L} = \sum_{i \in \mathcal{P}_r} q_{ivr(t+\Delta t_{voi}^{V})}^{U}$$

Loading is possible only when a voyage on a route begins on that day.

$$q_{vrt}^{L} \leq x_{ovrt} \overline{Q_v}$$

Number of ships required of a type:

Number of ships of type v serving route r at a point of time t

$$y_{vrt} = \sum_{r \in R_v} \sum_{t \in [t - T_{vr}, t]} x_{vrt}$$

$$u_v \geq y_{vrt}$$

Inventory balance constraints

At the origin port:

$$s_{ct}^{o} = s_{c,t-1}^{o} + f_{ct}^{Ve} - \sum_{v \in V} \sum_{r \in R_v} q_{vrct}^{L}$$

$$f_{ct}^{Vs} = f_{c,t+\Delta t_o^T}^{Ve}$$

At the discharge port:

$$s_{ct}^{i} = s_{c,t-1}^{i} + \sum_{v \in V} \sum_{r \in R_v} q_{vrct}^{U} - \sum_{k \in K} f_{ikct}^{Vs}$$

$$f_{ikct}^{Vs} = f_{ikc,t+\Delta t_{ik}^T}^{Ve}$$

Direct trucking flow

$$f_{ckt}^{Ts} = f_{ck,t+\Delta t_{ik}^{T}}^{Te}$$

Demand constraint

$$\sum_{i \in I} f_{ikct}^{Ve} + f_{ckt}^{Te} \geq D_{ckt}$$

Conditions on variables

$$x, y \in \{0,1\}$$

$$f, q^{L}, q^{U}, s \geq 0$$

Data estimation

- A southern Indian port city (Chennai), home to many auto manufacturers take as base port
- District-wise sales data estimated from secondary sources
- Freight rates estimated from primary sources
- For possible destination ports, all major ports (12) considered
- 10 ship types with varying cost/capacity/speed characteristics considered

Computational results

- MILP modeling of a simpler version of model (without inventory constraints)
- IBM CPLEX 12.6.2 optimization library on Python 2.7.10 programming language.
- Dell Precision T5610 with Intel Xeon CPU E5-2620 v2 @ 2.10 GHz 6 cores CPU and 32.0 GB RAM.

Route options:

- Chennai as main origin/return port
- Routes assumed to follow the geographical sequence
- All combinations considered under the given assumptions
- For each district in India, nearest port will change based on the route
- Total options generated: 2047

Four scenarios were run for comparison:

1. With only trucking options
2. With a single ship under operation and serving only 2 ports in the Western coast
3. With both coastal and direct trucking and port charges at GRT, and
4. With both coastal and direct trucking and port charges at DWT.

MILP computational results for different scenarios

Scenario	#Ship types	#Ports	#Routes	Opt. objective (mil. USD)	Comp. time* (sec)
1	0	0	0	109.49	1.4
2	1	3	3	101.54	1.6
3	10	12	2047	82.52	19,780
4	10	12	2047	76.28	107,421

* Computational time includes model build-up and solution time to optimality.

Scenario analysis

For 431272 cars sold in 12 months across 261 dealer locations

A. Only direct trucking option ($ 109.5 million or $ 254/car)

24.6% cost reduction

B. Port cost charged as GRT ($ 82.5 million or $ 191/car)

30.3% cost reduction

C. Port cost charged as DWT ($ 76.3 million or $ 177/car)

Scenario B: Ports charging w.r.t. GRT

IIM INDORE

Ship suggested:

S.N	ShipType	Capacity RT	Year built	Max deck height	GRT	DWT	Length (m)	Width (m)	Draft-min	Draft-avg	Draft-max	Speed -avg
6	F	6000	2000	4.9	29317	20144	200	32	6.5	8.2	9.5	12.1

S.N	Speed -max	Var Cost@ sea ($/day)	Var Cost@ port ($/day)	Fixed cost ($/year)	Var. cost @sea($/ day)	Var.fuel cost @port($/ day)	Capital	Fixed capital Cost/chart. cost ($/yr)	Maintenance and repair cost/yr	Crew cost	V/L insurance	Admin costs
6	21.3	17,362	1,511	1,046,424	17,362	1,511	14,185,576	556,075	106,392	50,246	283,712	50,000

Number of ships of this type of be hired for an year: **5**

Ship Utilization: **91.32%**

CO_2 emission reductions

- CO_2 emissions for Trucks: 3.14 kg/fuel-kg (EEA guidelines 2017)
- CO_2 emissions for ships: 3.17 kg/fuel-kg (Corbett et al., 2009)

Overall reduction in CO_2 emissions = **14.5% approx**.

Scenario C: Ports charging w.r.t. DWT

Ship suggested:

S.N	ShipType	Capacity RT	Year built	Max deck height	GRT	DWT	Length (m)	Width (m)	Draft-min	Draft-avg	Draft-max	Speed - avg
4	D	4800	2008	5.3	46800	12315	183	32	4	8.2	9.4	13.2

S.N	Speed - max	Var Cost@ sea ($/day)	Var Cost@ port ($/day)	Fixed cost ($/year)	Var. cost @sea($/ day)	Var.fuel cost @port($/ day)	Capital	Fixed capital Cost/chart. cost ($/yr)	Maintenance and repair cost/yr	Crew cost	V/L insurance	Admin costs
4	21.9	11,190	931	760,442	11,190	931	10,101,507	395,979	75,761	36,672	202,030	50,000

Number of ships of this type of be hired for an year: **5**

Ship Utilization: **98.24%**

Solution approaches planned

- Problem extension with inventory constraints seems to be complex
- We wish to run multiple scenarios for policy analysis
- Bender’s partitioning
- Branch and Price
- MILP based rolling horizon heuristic

Thanks

Questions?