Measuring logistics performance in intermodal freight transport corridors: An integrated decision analysis framework

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Competitive advantage of intermodal logistics compared to over-the-road logistics is not only based on cost, but also on added services allowing postponement practices. However, the increase of product variety, and multiple interfaces needed to deliver products have raised their vulnerability to variability and at the same time, added costs related to the use of logistics platforms. In manufacturing industries, variability not only affects the desired service level of the product availability, but also the total landed cost.

In front of challenges rising by just-in-time systems used by competitive manufacturing clusters located in the NAFTA (North American Free Trade Agreement) corridors, a systemic analytic tool for improving the use of intermodal freight transport in small and medium enterprises (SME) was designed. Consequently, the paper, from an emerging markets approach, proposes an integrated decision analysis framework calibrating the impact of specific improvements on logistics performance (time, cost, and reliability of lead times) to compare different intermodal freight corridors when a SME is selecting the best path to transport their products.
AGENDA

1. Background
2. Objectives
3. Methodology
4. Analysis and findings
5. Conclusions and future research
BACKGROUND

A “reverse globalization” is today a reality as firms back off from low-cost countries to North American region for sourcing and manufacturing requirements.

As Ghemawat (2005) argues there are today two crucial truths:

1. Geographic and other regional distinctions are increasing in significance;

2. Regionally focused strategies, used in conjunction with local and global initiatives, can significantly boost a company's performance.
BACKGROUND

An archipelago economy or in network

Manuel Castells

Jean-Paul Rodrigue

Pierre Veltz

Yossef Sheffi

Michel Savy
SUPPLY CHAIN CLUSTERING

Cluster $n-1$  
Cluster $n$  
Cluster $n+1$

Region $n-1$  
Region $n$  
Region $n+1$

Supply Chain
SUPPLY CHAIN CLUSTERING

- Aerospace Supply Chains
- Financial Services Supply Chains
- Informatics Supply Chains
- Automotive Supply Chains
- Technology Services for Supply Chains

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Supply Chain Clustering HUBs

Logistics Platform

Supply Chain Hub
FREIGHT FLOWS

Source: ALG, 2013
LOGISTICS HUBS

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Source: ALG, 2013
LOGISTICS HINTERLANDS

LEYENDA
- Macroámbitos funcionales
- Ciudades principales
- Nodos logísticos secundarios
- Nodos logísticos principales
- Relaciones logísticas consolidadas

Source: ALG, 2013
OBJECTIVES

- **To Identify** the processes involved when Mexican export-oriented small or medium enterprises (SME) are selecting the best intermodal path to transport their products;

- **To propose** a quantitative model to compare different intermodal freight corridors;

- **To analyze** the impact of specific improvements on logistics performance (time, cost, and reliability of lead times);

- **To provide** insights for improving logistics performance in SME based on an emerging markets approach.
AUTOMOTIVE ASSEMBLY PLANTS
Export of light vehicles (2.14 million units) ¹

World’s largest vehicle producer (2.69 million units) ¹

World wide producer of light vehicles (2.55 million units)

19 of the top leading automakers are located in 15 states of Mexico.

The automotive industry in Mexico represents:

- 6% of the Foreign Direct Investment ⁶
- 4% of the National GDP ⁷
- 20% of the manufacturing GDP ⁷
- 23% of total exportations ⁸

Exporter of commercial vehicles* (95,175 units) ²

World wide producer of commercial vehicles (136,678 units) ²

Occupied workers⁴: 68,895

States with automotive production

¹ Source AMIA ² Source: OICA ³ Source: Ministry of Economics ⁴ Source: INEGI ⁵ Source: Business Monitor International

*Estimated
KEY PROBLEM

- 27 APPRI's
- 12 FTA's
- 6 ACE's
KEY PROBLEM
KEY PROBLEM

Based on: Cheng, 2012
RELATIONSHIP BETWEEN TRANSPORT COST AND DISTANCE

Unimodal

Intermodal

Assumption
**METHODOLOGY**

1. **Problem Identification**
   - Operations context = Systems point of view

2. **KPI's Identification**
   - Key data = \( f \) (Lead time, reliability, cost)

3. **Mapping Process**
   - Field Work + Literature = Abductive approach

4. **Scenarios based on a mathematical model (quantitative approach)**
   - Modeling = Quantitative approach

5. **Analysis & Conclusions**
   - Analysis = Quanti & Quali approach

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ANALYSIS AND FINDINGS

Based on Janic (2007), Cheng (2012), and Hanssen et. al. (2012), the **Total Cost** was defined as follows:

\[
TC(Q, l, t) = C_{DC} + C_{MC} + C_{UC} + C_{FC} + C_{OC}(Q, l, t) + C_{RC}
\]

Where:

- \( TC \) = total cost;
- \( Q \) = tonnage of transported cargo;
- \( l \) = distance;
- \( t \) = time;
- \( C_{DC} \) = design cost of the IFTC;
- \( C_{MC} \) = management cost of the IFTC;
- \( C_{UC} \) = use cost of the IFTC;
- \( C_{FC} \) = fixed cost of the IFTC;
- \( C_{OC} \) = operational cost of IFTC;
- \( C_{RC} \) = random risk cost of IFTC.
ANALYSIS AND FINDINGS

Operational costs were computed as follows:

$$C_{oc}(Q, l, t) = \left[ \frac{\psi^s}{q^s_{\alpha}} \right] Q + \frac{\sum_{i=1}^{n} \psi^i}{q^i_{\alpha}} l^i + \frac{\psi^d}{q^d_{\alpha}} d + r^s C^s_{y} + r^d C^d_{y} + \sum_{i=1}^{n} l^i C^i_{y} + TT_{Total} *$$

Cost of infrastructure’s use divided by the volume of transported cargo.
ANALYSIS AND FINDINGS

Operational costs were computed as follows:

\[ C_{oc}(Q, l, t) = \left[ \frac{\psi^s}{q_0^{\alpha_s}} + \sum_{i=1}^{n} \frac{\psi^i}{q_0^i \alpha^i} + \frac{\psi^d}{q_0^d \alpha^d} + r^s C_y^s + r^d C_y^d + \sum_{i=1}^{n} l^i C_y^i \right] Q + \sum_{i=1}^{n+1} L_z^i + SS + TT_{Total} \]

Hinterland for each region multiplied by the transportation cost for each vehicle used.
ANALYSIS AND FINDINGS

Operational costs were computed as follows:

\[ C_{oc}(Q, l, t) = \left[ \frac{\psi^s}{q_0^s \alpha^s} + \sum_{i=1}^{n} \frac{\psi^i}{q_0^i \alpha^i} + \frac{\psi^d}{q_0^d \alpha^d} + r^s C_y^s + r^d C_y^d + \sum_{i=1}^{n} l^i C_y^i \right] \tau Q + \sum_{i=1}^{n+1} L_z^i + SS + TT_{Total} \ast \]

Average transit time multiplied by the cost value of the time.

VARIABILITY.
ANALYSIS AND FINDINGS

Operational costs were computed as follows:

\[ C_{oc}(Q, l, t) = \left[ \frac{\psi^s}{q_0 \alpha^s} + \sum_{i=1}^{n} \frac{\psi^i}{q_0 \alpha^i} + \frac{\psi^d}{q_0 \alpha^d} + r^s C_y^s + r^d C_y^d + \sum_{i=1}^{n} l^i C_y^i + TT_{Total} \right] \]

\[ \tau \left[ Q + \sum_{i=1}^{n+1} L_z^i + SS \right] \]

Tonnage of transported cargo.

VARIABILITY.
ANALYSIS AND FINDINGS

Operational costs were computed as follows:

\[
C_{oc}(Q, l, t) = \left[ \frac{\psi^s}{q_0^{\delta_s}} + \sum_{i=1}^{n} \frac{\psi^i}{q_0^{\delta_i}} + \frac{\psi^d}{q_0^{\delta_d}} + r^s C_y^s + r^d C_y^d + \sum_{i=1}^{n} l^i C_y^i + TT_{Total} \right] Q + \sum_{i=1}^{n+1} L_z^i + SS
\]

Average loading and unloading cost in logistics platforms.

VARIABILITY.
ANALYSIS AND FINDINGS

Operational costs were computed as follows:

\[ C_{oc}(Q, l, t) = \left[ \frac{\psi_s}{q_0 \alpha_s} + \sum_{i=1}^{n} \frac{\psi_i}{q_0 \alpha_i} + \frac{\psi_d}{q_0 \alpha_d} + r^s C_y^s + r^d C_y^d + \sum_{i=1}^{n} l_i C_y^i + TT_{Total} \right] \frac{1}{\tau} Q + \sum_{i=1}^{n+1} L_i + SS \]

Safety stock

VARIABILITY.
ANALYSIS AND FINDINGS

The logistics platform costs are related to the process followed by the freight that this infrastructure uses:

- Handling cost
- Storage cost
- In-house transport cost
- Unloading process

- Damage cost
- Handling cost
- Loading process
The **logistics platform costs** are a critical element when defining a transport path, since it influences the costs slope and consequently, the total cost of a defined path.
ANALYSIS AND FINDINGS

Logistics platform costs were computed as follows:

\[ L^i_z = C_{H_f} + C_{stg} + C_{tr} + C_c + C_d \]

Where:

- \( C_{H_f} \) = handling cost;
- \( C_{stg} \) = storage cost;
- \( C_{tr} \) = in-house transport cost;
- \( C_c \) = consolidation cost;
- \( C_d \) = damage cost.
ANALYSIS AND FINDINGS

Based on Richarson (2004), handling costs were understood as “the total number of touch points”. Thus, touch points represent the effort needed to unload from a vehicle, sort, store, and load freight to another vehicle. They were computed as follows:

\[
C_{Hf} = \left[ \varphi \left( q_0 \alpha \right) \frac{Q}{q_0 \alpha} \right]
\]

Where:

\( \varphi = \) monetary equivalent of time needed to move a ton;
\( q_0 = \) load capacity of each vehicle in each section of the IFTC (ton);
\( \alpha = \) use of the available load capacity for each vehicle in each section of the IFTC (%);
\( Q = \) tonnage of transported cargo.
**ANALYSIS AND FINDINGS**

Handling cost were computed as follows:

\[ C_{Hf} = \varphi(q_0 \cdot \alpha) \cdot \frac{Q}{(q_0 \cdot \alpha)} \]

Cost of handle every ton in a vehicle multiplied by the number of vehicles needed to transport all the cargo
**ANALYSIS AND FINDINGS**

**Storage cost.** The freight can be stored in the logistics platform during ten days without cost. After this period of time, an extra cost per day is charged and is calculated as follows:

\[
C_{stg} = \begin{cases} 
(\varepsilon - 10) \times \theta \times Q & \text{if } \varepsilon > 10 \\
0 & \text{if } \varepsilon \leq 10 
\end{cases}
\]

Where:

- \( \varepsilon \) = storage time in the logistics platform (day);
- \( \theta \) = cost per day of storage after 10 days (dollar/day/ton).
ANALYSIS AND FINDINGS

In-house transport costs are related to the movement of transported units inside the different logistics platform’s areas. The cost is computed as follows:

\[ C_{tr} = Q \times a \]

Where:

\( a = \text{cost per ton moved inside logistics platform (dollar/ton)} \).
**ANALYSIS AND FINDINGS**

**Consolidation costs** represent the **effort to integrate** the transported units (pallets, box, etc.) into another vehicle. The consolidation cost is computed as follows:

\[ C_c = (y \cdot \tau) \cdot \frac{Q}{q_0 \cdot \alpha} \]

Where:

\[ y = \text{share of unloading and loading cycle incurred in unit’s selection (hour);} \]
\[ \tau = \text{cost value of the time (dollar/hour).} \]
**ANALYSIS AND FINDINGS**

Damage costs are related to the percentage of loss derived of damage caused to the freight all along the different processes as unloading, storage, in-house transport, and loading inside the logistics platform. The damage costs are calculated as follows:

\[
C_d = \phi_l \times Q \times p
\]

Where:

\[
\phi_l = \text{damage rate at loading (\%)};
\]

\[
p = \text{value of freight (dollars/ton)}.
\]
**ANALYSIS AND FINDINGS**

**Variability.** It is generally accepted that reducing the variability of the lead time can offer significant benefits to process efficiency.

According to Germain et al. (2008) *supply chain variability can be defined as the level of variation in the flow of goods* into and out of the industrial cluster.
ANALYSIS AND FINDINGS

Transit time (TT) from a variability approach can be solved as follows:

\[
TT^s = \left[ \left( \frac{CV_a^2 + CV_c^2}{2} \right) \times \left( \frac{a^s}{k^s} \right) \times \left( k^s \times y^s + s^s \right) + 1 \right] \times \left( \frac{r^s}{v^s} \right)
\]

Where:

- \(CV_a^2\) = CV of inter arrival times;
- \(CV_c^2\) = CV related to time to process every batch in every hub in section \(i\) of the IFTC.
- \(a^s\) = arrival rate;
- \(k\) = serial batch size (average load capacity of vehicles used);
- \(y\) = share of unloading and loading cycle incurred in unit’s selection (hour);
- \(s\) = time to perform a transshipment.
ANALYSIS AND FINDINGS

Transit time \((TT)\) from a variability approach can be solved as follows:

\[
TT^s = \left[ \frac{(CV_d^2 + CV_c^2)}{2} \right] \times \left( \frac{a_i^s}{k^s} \right) \times (k^s \times y^s + s^s) + 1 \] \times \left( \frac{T^s}{v^s} \right)
\]

- Variability factor in every section
- Utilization factor
- Time

\[
TT_{Total} = TT^s + TT^d + \sum_{i=1}^{n} TT^i + 24 \sum_{i=1}^{n+1} \varepsilon^i
\]
Safety stock is calculated as follows, taking into account the times of standard deviation of average daily demand during transit time ($\sigma_{D_{TT}}$):

$$ SS = F_s^{-1}(CSL) \times \sigma_{D_{TT}} $$

Where:

- $F_s^{-1}$ = normal inverse Gaussian distribution;
- $CSL$ = customer service level;
- $\sigma_{TT}$ = standard deviation of transit time.
The $\sigma_{DDTT}$ can be calculated based on Fetter and Dalleck (1961) as follows:

$$\sigma_{DDTT} = \sqrt{TT_{Total} \cdot \sigma_D^2 + D^2 \cdot \sigma_{TT_{Total}}^2}$$

Where:

- $TT_{Total}$ = total transit time;
- $D$ = average demand;
- $\sigma_D^2$ = variance of demand;
- $\sigma_{TT_{Total}}^2$ = variance of total transit time.
NUMERICAL EXAMPLE

ROUTE A

Road  → Rail  → Water  → Road
100 Km  → 730 Km  → 800 Km  → 120 Km

ROUTE B

Road  → Water  → Rail  → Road
90 Km  → 1000 Km  → 650 Km  → 120 Km

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# NUMERICAL EXAMPLE

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## GENERAL DATA

<table>
<thead>
<tr>
<th>Q</th>
<th>Quantity of transported cargo (Ton)</th>
<th>r</th>
<th>Cost value of the time (Dollars per hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td></td>
<td>2.00</td>
<td></td>
</tr>
</tbody>
</table>

## BASIC COSTS

| C_a  | Design cost of the IFTC          |
| C_m  | Management cost of the IFTC      |
| C_u  | Use cost of the IFTC             |
| C_f  | Fixed cost of the IFTC           |
| C_r  | Random risk cost of IFTC        |
| **TOTAL** |                                  |

## OPERATIVE COSTS

<table>
<thead>
<tr>
<th>Transportation cost</th>
<th>Use cost,</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
</tr>
</tbody>
</table>

## LOGISTICS PLATFORM COSTS

| C_h | Handling cost                           |
| C_s | Storage cost                             |
| C_t | In-house transport cost                  |
| C_c | Consolidation cost                       |
| C_d | Damage cost                              |
| **TOTAL** |                                       |

## SAFETY STOCK COSTS

| SS | Safety stock Cost of safety stock          |

## TRANSIT TIME VARIABILITY

<table>
<thead>
<tr>
<th>T_{Time}</th>
<th>Total transit time. Cost of Total transit time.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C_{ICU} (RU)</th>
<th>C_{ICU} (MU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>91.750.12</td>
<td>91.903.61</td>
</tr>
<tr>
<td>95.774.12</td>
<td>95.121.61</td>
</tr>
</tbody>
</table>
NUMERICAL EXAMPLE

Best Case

Route 1

Route 2

Almost equal cost

US$ 95,274

US$ 95,121
NUMERICAL EXAMPLE

ROUTE A

- Road
- Rail
- Water
- Road

100 Km
730 Km
800 Km
120 Km

ROUTE B

- Road
- Water
- Rail
- Road

90 Km
1000 Km
650 Km
120 Km
NUMERICAL EXAMPLE

Worst Case

Route 1

- Basic Costs: US$ 46,771.92
- Operative Costs: US$ 3,524.00
- Logistics Costs: US$ 22,813.58
- Transit Time Variability: US$ 5,516.79

Route 2

- Basic Costs: US$ 3,128.00
- Operative Costs: US$ 16,577.57
- Logistics Costs: US$ 44,359.38
- Transit Time Variability: US$ 51,823.80

Time spent in the port’s backyard is critical

US$ 95,274

US$ 153,121
CONCLUSIONS

Contribution

• An easy and friendly-user method to get an optimal transport path when using intermodal transport;

• A flexible and custom-made tool;

• A solution which takes into account variability of time along the intermodal corridors which is a key element when designing inventory policies;
CONCLUSIONS

Key issues

• Supply chain visibility in export-oriented SME (cost, processes, practices, etc);
• Trade facilitation and risk assessment;
• Supply chain clustering identification.
CONCLUSIONS

Future research

• **Supply chain visibility.** Designing a social networking service among export-oriented companies which, for example, share interests, activities or backgrounds to improve trust and potentially establish a “NAFTA Security Certification” in collaboration with programs as C-TPAT, NEEC, and PIP;

• **Trade facilitation and risk assessment.** Developing a risk self assessment tool for SME which could take into account risk costs;

• **Supply chain clustering approach.** Providing insights about the advantages as a result of consolidation of supply chains along the National System of Logistics Platforms in Mexico.