Integrating Regional Strategic Freight Transportation Planning and Supply Chain Management Along the Path to Sustainability

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Research Presentation
2nd Annual Transportation Student Research Symposium

MAITE
Boston, MA
February, 10th 2006
Acknowledgments

Academic Advisor: Prof. Joseph Sussman,
Fellow ESD Students and especially: Chris Glazner

Support for this research has been provided by
• the Martin Fellowship for Sustainability,
• the Motorola Company seed funding for the Malaysian University of Science and Technology (MUST)/MIT Collaboration, and
• the Alexandros Onassis Foundation
Agenda

- Overview, Hypothesis, Motivation, and Methodology
- Supply Chain Management (SCM) Overview
- Regional Strategic Transportation Planning (RSTP) for Freight Overview
- Proposed RSTP/SCM Process
- Conclusions, Further Research
Research Overview

- Transportation Planning (Public Sector)
  - SCM (Private Sector)
  - Other Agencies (Public Sector)
    - Zoning (land use)
    - Trade (tariffs and taxes)
    - Subsidies
    - ...
  - Transport Regulations
  - Infrastructure
  - Infrastructure Operations
    - ...
  - Suppliers
  - SCM methods
  - Modal Choice
    - ...

Environment

Economy

Creation of an Integrative Process

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“… failure to account for such network economies can lead to a substantial understatement of the prospective impacts of transportation investment on productivity and economic growth” (TRB 1991)
Hypothesis:

SCM-based, freight transportation planning that considers integrated policies across agencies can benefit both the economic and environmental performance of a region.

Principles:

Sustainability is defined by 3E performance (Economy, Environment, Equity). (Cutcher-Gershenfeld et al. 2004) In the following we focus on two dimensions: Environment and Economy.

A sustainable freight transport system should be considered within the context of its uses. (Hall and Sussman 2004)
Motivation

Freight transportation is a necessary component of modern society (Coyle, Bardi et al. 2000) but the externalities generated may be higher than the nominal price for its use (simply for highway traffic: FHWA 2000):

- Current transportation trends (increasing demand and average distances) lead to:
  - Dependence on increasingly congested infrastructure facilities
  - An increase in the contribution of the sector to GHG emissions (+ pollutants).
- Freight transportation is currently dependent on depleting fossil fuels reserves (In the US: ~50 billion gallons/year of internal freight or 1% of global petroleum consumption! (BTS 2004)).

Freight transportation planning is under-emphasized and when conducted follows an isolated and capacity-focused approach.
Methodology

• Process Development:
  – Use the **Complex Large-scale Integrated Open Socio-technical (CLIOS)** Process (Dodder et al. 2004) as *meta-process* to integrate RSTP and SCM.
  – Utilize Engineering Systems tools for insight:
    • Design Structure Matrix (DSM 2000),
    • Systems Dynamics (Sterman 2000)
SCM and RSTP Overview
SCM Overview

SCM aids private sector (producers and retailers) to increase the efficiency of their operations by “integrat[ing] suppliers, manufacturers, warehouses and stores, so that merchandize is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize systemwide costs while satisfying service level requirements.” (Simchi-Levi, Kaminsky et al. 2003)
SCM Overview

Points where public sector decision-makers can affect Supply Chains

Source: Modified from ESCAP (2001)
RSTP Overview

Definition of transportation planning by the US. DOT (FHWA & FTA 2005):
“A … comprehensive … process to encourage and promote the development of a multimodal transportation system to ensure safe and efficient movement of people and goods while balancing environmental and community needs.”

(Sussman, Sgouridis and Ward 2005) include operations and institutions along with infrastructure building and maintenance.
Proposed RSTP/SCM Process
Methodology Overview: using CLIOS for creating RSTP/SCM

• CLIOS:
  3-Stage, 12-step, iterative process for complex system analysis

• Core feature:
  Nested complexity

1. Definition
2. Physical Domain
3. Institutional Sphere
4. Implementation
5. Seek Insight about System Behavior

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Initial Representation through CLIOS diagrams:
DSM Clustering

Type
- Land Use
- Transportation
- Economy
- Manufacturing
- Environment
- Institutional Sphere
- Policy Driver

Color Coding
- Land Use (L)
- Transportation (T)
- Economy (EC)
- Manufacturing (M)
- Environment (EN)
- Institutional Sphere (I)
- Policy Driver (ID)
### DSM Ranking

#### Component Ranking by Number of Outgoing Links

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Insights from DSM

**Clustering**: allows us to understand which components have greater interdependency. In case of change in one component the components within the cluster will be directly affected.

**Ranking**: The components higher in the list are the ones that may provide the greater leverage for affecting change.

*In our case*
- *highly interdependent system,*
- *Sub-systems mapped onto DSM clusters but (for example) Infrastructure operators and Carriers were clustered within the SCM cluster,*
- *Ranking indicates that infrastructure, externality regulations and demand are critical drivers.*
Insights from Systems Dynamics

- **Dynamic understanding**: SD modeling offers understanding of the system over time and over relative importance of variables.

- **Focusing on function**: The SD model clarifies the interactions that in the DSM are shown as clusters and brings forward the more important ones.

- **Quantification of Influence**: Allows for quantification of relative influence of variables for testing various policies.
**Proof-of-Concept RSTP/SCM SD model (GUI)**

**Inputs**

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<td><strong>Lambda</strong></td>
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**Outputs**

**Model Parameters**

- **Capacity Cost**: 30,000
- **Gas Price (per US gal)**: 1.5, $0.75
- **Landfill Price (per lb)**: 1.5, $0.03
- **Emissions Price (per kg of CO2)**: 1.5, $1
- **Fuel Efficiency (km/gal)**: 1.5
- **Truck Emissions (kg/mi)**: 1.5

**Objectives**

- **Environmental Externals**: 
  - Profit: $5.00
  - Objective: $5.00

**Constraints for Optimization**

- **NetCap**: $50
- **NetCap**: 20K
- **Landfill**: 2.5B
- **Emissions**: max 100M
- **Profit**: $15

Source: Glazner and Sgouridis (2005) – Term Project for ESD. 77
(Some) preliminary insights from SD model

Multi-objective optimization on this model showed:

- All proposals prefer larger trucks (safety was not considered)
- Gas tax was retained medium because otherwise infrastructure deteriorates too fast and sinks the economy.
- Relative impact of production taxes was found to be low.
Conclusions
Further Research
Conclusions

The proposed RSTP/SCM process differs from traditional planning by:

• Focusing on regions across political boundaries,
• Considering the impact of changes (as strategic alternatives) in:
  – Physical architecture,
  – Institutional architecture
  – Operational changes,
  – Non-transport regulations,
• With respect to their effect on both the economics of supply chains and the overall environment.
• Offering a modeling tool for engaging stakeholders.
• Optimizing on the system level.

This way it is closer to meeting the DOT definition for comprehensive transportation planning.
Further research

• The SD model can be improved towards more realistic representation and validated.

• Application of the process on a real-world region along with recommendations.

• Investigate the barriers to adoption of the RSTP/SCM process: potentially more costly upfront, need for inter-agency and public/private cooperation etc.
Concluding comment

“If a serious attempt is to be made to achieve sustainable freight transport, then a group of states has to take the lead and demonstrate the art of the ‘impossible.’”

Banister et al. (2000)
Selected References


Thank you for your attention and input!

Questions?
Model Overview
Insights from application of SA at this stage:
1. Consideration of decomposition levels that were not necessary for the high level CLIOS representation.
2. Consideration of system as blank slate – visualize non-obvious solutions.

More valuable in real-world systems -- non-obvious physical or institutional solutions may be identified.
RSTP Overview

Despite the stated objectives, shortcomings have been identified: (Conklin and Sussman 2000)

- [Lack of] Intermodalism, economic integration, private sector involvement, freight, operations, sustainability and others.

Researchers have addressed the connection of transport and the economy [e.g. (Porter 2001), (TRB 1991 & 2002), (Lakshmanan 2002)] or the environment [e.g. (De Cicco 1998), (Hester 2004)]. Their work models interactions in general but not in dynamic terms.

Comprehensive planning processes that take into account non-transport policies and SCM are rare. Related literature focuses on capacity provision (e.g. Ogden 1992), and intermodal facilities (TRB 1998).
Importance
Transportation greatly influences environment, economy, and society through complex interactions. Planners need aids in understanding the impacts of their decisions.

Overarching Goal
Create an integrated transportation planning tool for providing insight to policy-makers.

Project Objective
Create a proof-of-concept simulation model and use it to optimize transportation planning in an imaginary region using realistic inputs.
Disciplines/Fields Involved

- Economics
- Transportation Engineering
- Supply Chain Management
- Environmental Assessment
- Political Science
- Regional Planning

Disclaimer: in this application only rudimentary algorithms from the respective disciplines were used
Model Vital Stats/ Key Assumptions

- 1 Region (no explicit imports/exports--Closed system)
- 3 Supply Chains
- $\sim \infty$ raw materials
- 1M base population (consumers)
- 1 Mode / 1 type of truck
- Cost+ market (demand driven vs. supply/competitively driven)
Model Platform

Anylogic® by XJTek v5.2:

• A versatile platform that integrates Systems Dynamics, Agent-based modeling, and discrete event simulation capabilities.

• Java-based object oriented GUI.

• Integrated optimization engine (OptQuest):
  – Tabu search with Neural network learning capability
Model Methods and Structure

• System Dynamics engine
• Modular design:
  – 3 Supply Chain / Production modules
  – Network flows and capacity module
  – Environmental impact module
  – Economic module