Simulation Model for Intermodal Freight Transportation in Louisiana

Peter Kelle and Christopher Claypool
Information Systems and Decision Sciences
Louisiana State University

Mingzhou Jin
Industrial and Systems Engineering
University of Tennessee at Knoxville

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- Louisiana Department of Transportation and Development (LaDOTD)
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Project Goals

Project 1: Intermodal performance measurement system for freight management – Apply to Louisiana

Project 2: Comprehensive simulation model for an intermodal freight network - Case study for the Louisiana intermodal network

Application tools for:
What-if analysis to evaluate and compare different network improvement initiatives
Evaluating the tradeoff between environmental goals and other performance measures
Problems of existing measures for freight transportation

- Many are only applicable for a single mode
- Not scientific: factors ≠ performance measures
- Not user-oriented
- Not all quantitative
- High cost to calculate, track, and use
Proposed Performance Measures

Users

- Industries
- Investors
- Society Users

Proposed Performance Measures

- Mobility and Reliability
- Safety
- Environmental Stewardship
- Cost Efficiency
- Economic Growth

US Dept. of Transportation (DOT) Goals

- Reduced Congestion
- Global Connectivity
- Security, Preparedness, and Response
- Safety
- Environmental Stewardship
- Organizational Excellence

Industries

Investors

Society Users
Mobility and Reliability

**Mobility (M): Ton-Hours Traveled per Ton Miles Required (TMR)**

TMR is based on geographic distances providing a *normalized measure*.

So we can appropriately

- compare different years,
- evaluate/compare different plans and scenarios.
Step 1) Get the intermodal network of Louisiana

TransCAD with the three major surface transportation modes

Step 2) Origin-Destination (OD) data generation (estimation) and mode selection for Louisiana using Freight Analysis Framework Version 3 (FAF³) data based on a national freight survey containing

- OD volume and transportation modes (including mode changes)

Within Louisiana: only 4 FAF zones

- Disaggregation: OD flow is assigned to the parishes proportionally to their population and economic activities

Louisiana borders: FAF zones from remaining 44 continental states along with export and import data

- Aggregate out-of-state traffic at access points at the State’s borders
Step 3) Calculate Total Miles Required (TMR)

- Obtain geographic **distances** for each OD pair (Center of a parish or an access point of out-of-state traffic at the state border).
- Add the product of **OD volume** (in tons) times geographic distance (in miles) of all pairs.

<table>
<thead>
<tr>
<th></th>
<th>Total TMR (Ton-Miles Required)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highways</td>
<td>$3.56 \times 10^{10}$</td>
</tr>
<tr>
<td>Railways</td>
<td>$1.03 \times 10^{10}$</td>
</tr>
<tr>
<td>Waterways</td>
<td>$2.80 \times 10^{10}$</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$6.39 \times 10^{10}$</td>
</tr>
</tbody>
</table>
Calculating Ton-Hours Traveled

Step 4) Routing and Travel Time Estimate

- Assign OD data on the transportation network based on the shortest-time path (the all or none rule) by mode in TransCAD.
  - Highway: free flow speeds – effect of congestion
  - Railway: speed at links and the dwell time at yards.
  - Waterway: no dams/locks.
- Estimate traffic volume and travel time on each segment.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Ton-Hours Traveled (Ton-Hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highways</td>
<td>$9.60 \times 10^8$</td>
</tr>
<tr>
<td>Railways</td>
<td>$3.33 \times 10^8$</td>
</tr>
<tr>
<td>Waterways</td>
<td>$20.00 \times 10^8$</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$32.93 \times 10^8$</td>
</tr>
</tbody>
</table>
Assigned Traffic
Step 5) Mobility Calculation

The mobility of the freight network in Louisiana in 2011 can be calculated as:

\[ M = \frac{\text{Ton} - \text{Hours Traveled}}{\text{TMR}} \]

\[ = \frac{3.29 \times 10^9}{6.39 \times 10^{10}} = 0.0515 \text{ hours per geographic mile.} \]

- Freight can travel about 19.42 geographic miles per hour on average in the State of Louisiana in 2011.
### Energy Consumption Rate (EC) is the average unsustainable energy consumption (BTU) per TMR (Ton Miles Required).

The BTU consumption is calculated using the Transportation Energy Data Book (Edition 32) data

#### Energy Consumption of Freight Transportation in Louisiana in 2011

<table>
<thead>
<tr>
<th></th>
<th>BTU per Ton-Mile Traveled</th>
<th>Total Ton-Mile Traveled</th>
<th>Total Energy Consumed (Trillion BTU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highways</td>
<td>889</td>
<td>4.61×10^{10}</td>
<td>40.98</td>
</tr>
<tr>
<td>Railways</td>
<td>298</td>
<td>1.33×10^{10}</td>
<td>3.96</td>
</tr>
<tr>
<td>Waterways</td>
<td>217</td>
<td>4.00×10^{10}</td>
<td>8.68</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>9.94×10^{10}</strong></td>
<td><strong>53.63</strong></td>
</tr>
</tbody>
</table>

\[
EC = \frac{\text{Total Energy Consumed}}{\text{TMR}}
\]

\[
= \frac{53.63 \text{ Trillion BTU}}{6.39 \times 10^{10} \text{ Ton Miles Required}}
\]

\[
= 839 \text{ BTU per Ton Mile Required}
\]
Pollutant Released Rate $P$,  

**Air Pollution Data** (*AirData*) website maintained by the USEPA has the total emission data of each parish for each transportation mode. For highways, we only consider trucks consuming either diesels or gasoline.  

**Freight Transportation Emission in 2011 in Louisiana**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Carbon Emissions (Tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highways</td>
<td>$882 \times 10^4$</td>
</tr>
<tr>
<td>Railways</td>
<td>$1.46 \times 10^4$</td>
</tr>
<tr>
<td>Waterways</td>
<td>$16.6 \times 10^4$</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$900.1 \times 10^4$</td>
</tr>
</tbody>
</table>

$P = \frac{\text{Total Carbon Emission of Transportation}}{\text{TMR}}$

$= \frac{900.1^4 \text{ Tons}}{6.39 \times 10^{10} \text{ Ton Miles Required}} = 1.41 \times 10^{-4}$ tons per ton mile required.
### Performance Measures

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobility (M) (hours per geographic mile)</td>
<td>0.0515</td>
</tr>
<tr>
<td>Reliability (R, R_u) (no unit)</td>
<td>Calculated based on the simulation project</td>
</tr>
<tr>
<td>Fatality Rate (S_F) (fatalities per 10 billion TMR)</td>
<td>7.46</td>
</tr>
<tr>
<td>Injury Rate (S_I) (injuries per 10 billion TMR)</td>
<td>247.92</td>
</tr>
<tr>
<td>Energy Consumption Rate (EC) (BTU per TMR)</td>
<td>839</td>
</tr>
<tr>
<td>Transportation Pollutants (P) (tons per TMR)</td>
<td>(1.41 \times 10^{-4})</td>
</tr>
</tbody>
</table>
Project Objectives:

- Develop a comprehensive simulation model for an intermodal freight network (ARENA software)
- Consider the dynamics at the connections between transportation modes
Two sample OD pairs:

**OD1:** Calcasieu Parish $\rightarrow$ Sulphur, LA $\rightarrow$ No.1 Highway Outlet
- 3 nodes and 2 links

**OD2:** Rapides Parish $\rightarrow$ Alexandria, LA $\rightarrow$ Oakdale, LA $\rightarrow$ Iowa, LA $\rightarrow$ Sulphur, LA $\rightarrow$ No.1 Highway Outlet
- 6 nodes and 5 links

**Share the paths:** Sulphur, LA $\rightarrow$ No.1 Highway Outlet

**Example:** OD2 volume = 750 KT. It means 30 * 25 tons truckloads are transported from Rapides Parish to No.1 Highway Outlet daily on average.

With 5 truckloads for a batch, we have 6 animated highway entities (batches) traveling daily.

*On average (with variability and uncertainty) every 4 hours,* an animated truck (a batch of 5 semi-trailer trucks) is traveling.
Highway Simulation

Highway Network

Origin from Calcasieu Parish (Origin Index = 1)
- Assign 11: Calcasieu Parish to sulphur LA or to deQuincy or to the end
- Assign 7: sulphur LA to No.1 Hwy Outlet or to Iowa LA or to Calcasieu Parish

Origin from Rapides Parish (Origin Index = 2)
- Assign 115: Rapides Parish to Alexandria LA or to Natchitoches LA or to the end
- Assign 92: Alexandria LA to Oakdale LA or to Rapides LA or to Jonesville LA or to Bunkie LA
- Assign 12: Oakdale LA to Iowa LA
- Assign 2: Iowa LA to Sulphur LA or to Welsh LA
- Assign 25: Rapides Parish to No.5 Hwy Outlet

Assign from Rapides Parish to No.12 Hwy Outlet
Highway Simulation

The highway sub-model directs cargos to their desired destinations immediately.
The variables and entity in highway network:

\( o_i \): origin index, established in the “Assign” block;
\( d_i \): destination index, established in the “Assign” block;

Batches of Truckloads: 1 batch = 5 animated truck = a 125-ton shipment by truck.
Entity, established in the “Create” block.
Simulate speed based on congestion

**Speed-Volume Curve:**

\[ V = \frac{V_0}{1 + a \left( \frac{v}{c} \right)^b} \]

- \( V \): Congested speed,
- \( V_0 \): Free-flow speed,
- \( \frac{v}{c} \): volume-capacity ratio,
- \( a = 0.05 \) and \( b = 10 \):
  - two coefficients for model calibration.

Each simulation entity=5 trucks, each having 25 tons.
The **hourly total volume** for pair \((i, j)\) on day \(k\) by
\[
TT(i, j, k) = tk_{ij} + pk_{hrk} \cdot AADT_{ij} \cdot (1 - \alpha_{ij}) \cdot l_{ij} / (\beta_{ij} \cdot FFS_{ij} \cdot 24)
\]
- \(tk_{ij}\): number of trucks on pair \((i,j)\);
- \(pk_{hrk}\): peak hour factor that varies over time. Here, \(k = 0\) **weekday** from WD\% row; while \(k = 1\) **weekend** from the WE\% row;
- \(\alpha_{ij}\): percentage of truck over total traffic volume; \(l_{ij}\): the length of lane segment lanes on pair \((i,j)\)
- \(\beta_{ij}\): constant number indicates the estimated average percentage of free flow speed vehicles could travel on pair \((i,j)\).
- \(FFS_{ij}\): free-flow speed on pair \((i,j)\);

### Permanent Station 026 Louisiana DOTD
In Jefferson Parish
Located on I-0010
Btwn. Loyola and Williams, Kenner, Jefferson Parish
Monthly Volumes: Jun, 2014
Direction: All Directions

<table>
<thead>
<tr>
<th>Time</th>
<th>12:00 am</th>
<th>1:00 am</th>
<th>2:00 am</th>
<th>3:00 am</th>
<th>4:00 am</th>
<th>5:00 am</th>
<th>6:00 am</th>
<th>7:00 am</th>
<th>8:00 am</th>
<th>9:00 am</th>
<th>10:00 am</th>
<th>11:00 am</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average</strong></td>
<td>1328.2</td>
<td>883.2</td>
<td>746.1</td>
<td>895.2</td>
<td>1566.4</td>
<td>3688.9</td>
<td>5366.9</td>
<td>5943</td>
<td>5891.4</td>
<td>5857.2</td>
<td>6127.7</td>
<td>6277.6</td>
</tr>
<tr>
<td><strong>Weekday</strong></td>
<td>1078</td>
<td>719.4</td>
<td>640</td>
<td>872.4</td>
<td>1755.9</td>
<td>4548.8</td>
<td>6641.2</td>
<td>7153.3</td>
<td>6723.7</td>
<td>6121.9</td>
<td>6091.6</td>
<td>6073.7</td>
</tr>
<tr>
<td><strong>WD %</strong></td>
<td>23%</td>
<td>15%</td>
<td>14%</td>
<td>19%</td>
<td>37%</td>
<td>97%</td>
<td>141%</td>
<td>152%</td>
<td>143%</td>
<td>130%</td>
<td>130%</td>
<td>129%</td>
</tr>
<tr>
<td><strong>Weekend</strong></td>
<td>1911.8</td>
<td>1265.6</td>
<td>993.8</td>
<td>948.6</td>
<td>1124.2</td>
<td>2393.4</td>
<td>3118.9</td>
<td>3949.3</td>
<td>5239.7</td>
<td>6212</td>
<td>6753.4</td>
<td></td>
</tr>
<tr>
<td><strong>WE %</strong></td>
<td>41%</td>
<td>27%</td>
<td>21%</td>
<td>20%</td>
<td>24%</td>
<td>36%</td>
<td>51%</td>
<td>66%</td>
<td>84%</td>
<td>112%</td>
<td>132%</td>
<td>144%</td>
</tr>
<tr>
<td><strong>12:00 pm</strong></td>
<td>6436.9</td>
<td>6663.9</td>
<td>6973</td>
<td>7537.9</td>
<td>7860.1</td>
<td>8030</td>
<td>6780.7</td>
<td>5239.3</td>
<td>4235</td>
<td>3658.8</td>
<td>2767.1</td>
<td>1954.3</td>
</tr>
<tr>
<td><strong>Weekday</strong></td>
<td>6270.3</td>
<td>6492.9</td>
<td>6891.2</td>
<td>7705.1</td>
<td>8170.9</td>
<td>8470.9</td>
<td>6864.9</td>
<td>5107.1</td>
<td>4062.2</td>
<td>3465.4</td>
<td>2555.6</td>
<td>1755.1</td>
</tr>
<tr>
<td><strong>WD %</strong></td>
<td>134%</td>
<td>138%</td>
<td>147%</td>
<td>164%</td>
<td>174%</td>
<td>180%</td>
<td>146%</td>
<td>109%</td>
<td>86%</td>
<td>74%</td>
<td>54%</td>
<td>37%</td>
</tr>
<tr>
<td><strong>Weekend</strong></td>
<td>6825.6</td>
<td>7062.9</td>
<td>7164</td>
<td>7147.8</td>
<td>7135</td>
<td>7001.2</td>
<td>6584.3</td>
<td>5547.7</td>
<td>4638.3</td>
<td>4110.1</td>
<td>3260.7</td>
<td>2419.2</td>
</tr>
<tr>
<td><strong>WE %</strong></td>
<td>145%</td>
<td>150%</td>
<td>153%</td>
<td>152%</td>
<td>152%</td>
<td>149%</td>
<td>140%</td>
<td>118%</td>
<td>99%</td>
<td>88%</td>
<td>69%</td>
<td>52%</td>
</tr>
</tbody>
</table>

**Hourly average:** 4696.2

**WD Rush hrs:** Weekday RH avrg.
6 am to 7 pm 143%

**WE Rush hrs:** Weekend RH avrg.
10 am to 7 pm 146%
Most time is spent in classification yards rather than traveling on links.

- Each train has a maximum 100 railcars with capacity of 50 tons each.
- **Receiving**, R, **Classification** C, and **Departure**, D, area:

![Layout of a Typical Classification Yard](image)

Dwell time at each yard is reported weekly at [http://www.railroadpm.org/](http://www.railroadpm.org/).
Rail yard sub-model collects railcars from its originations or from an existing train in **receiving area**

All railcars are released from the existing train and go to **classification area** for sorting

In **departure area**, railcars are put up together again to form a train with the same direction
• Low-cost, low-carbon
• No locks on the lower Mississippi Rivers.
• The barge speed is assumed at 10 mph after considering the rest time of tugboats based on a former waterway project.
• An animated entity stands for a large tow with 30 barges (3,000 tons per shipment)
Waterway Network

Origin from Cracraft, AR

Ports: Cracraft, Vicksburg, Natchez, Above Old River, Baton Rouge, and New Orleans.

Variables and entity in waterway network:
- waterway destination index, in Assign block
- barge speed, constant. Equals to 10 mph.
- destination index, variable, established in Assign block
- tows with 30 barges: 1 tows with 30 barges = 1 animated boat = a 30000-ton shipment by water. Entity, established in Create block.
ORNL intermodal network applied to Louisiana

- 64 parishes
- 17 highway outlet
- 13 railroad outlet
- 6 ports

Around 9,000 Origination-Destination (OD) pairs
Reliability ($R$)

A measure of transportation system variability

coefficient of overall variation of travel time per travel mile required.

- Smaller $R$ is desirable because it means smaller variability in travel time, decreased recurrent congestion, and higher predictability of travel time.

- Two types of delays are frequently addressed in transportation engineering study:
  - **Recurrent** delay is regular and predictable
  - **Nonrecurring** delay is unpredictable, such as the ones caused by accidents

<table>
<thead>
<tr>
<th></th>
<th>Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability (recurring delay)</td>
<td>1.3229</td>
</tr>
<tr>
<td>Reliability (nonrecurring delay)</td>
<td>19.8342</td>
</tr>
</tbody>
</table>
Use the current Louisiana transportation network and
• with the same transportation OD (origin – destination volume) data
• check the tradeoff effects of different transportation mode rates
  - mobility vs. environmental effects, mobility vs. reliability.
• Change the OD data as a projected effect of
  • New industrial development scenarios
    • chemical industry development,
    • expansion of the Panama Canal,
    • increase in Cuba trade, etc.
  • check the effects on the performance measures

Make different changes in the transportation network to adjust to the above scenarios, compare the alternative plans
What-if-Analysis

Powerful tool predicting
- Effect of transportation system changes
- On the performance measures
- Detailed analysis of specific areas or measures

Different scenarios can be defined by
- Transportation demand changes in certain areas
- Changes in road, rail, waterway capacity
- Changes in congestion, accident, rush hours
Summary:

1. Developed a comprehensive simulation model for the intermodal freight network of Louisiana that considers freight dynamics (variability and uncertainty).

2. Validated the simulation model based on traffic counters at certain locations from LaDOTD, energy data, safety dataset, etc.

   - Scenario 1: Panama Canal expansion
   - Scenario 2: Traffic congestion
   - Scenario 3: Improvement in highway safety
Scenario 1: Panama Canal expansion

Increase the **travel volume** related to New Orleans (harbor) by 50%

- Show the impact of increased transportation demand on the
- Multimodal transportation **system performance**
  - Mobility, reliability, energy consumption,
  - Locally and
  - For the whole State
Scenario 1: Panama Canal expansion

Ton-miles before (Tonmiles_base) and after (Tonmiles_id) the demand increase

Ton-hours before (Tonhours_base) and after (Tonhours_id) the demand increase

Ton-miles were increased by 11.6%, ton-hours by 11.5%

The system level (State) mobility became worse increased from 0.1240 hour/required mile to 0.1306 hour/required mile (from 8.06 mi/hr to 7.65 mi/hr average speed decrease).
Scenario 1: Panama Canal expansion

Reliability before and after demand increase

<table>
<thead>
<tr>
<th>Reliability</th>
<th>Base</th>
<th>150% of the Base Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability (recurring delay)</td>
<td>1.3229</td>
<td>1.2193</td>
</tr>
<tr>
<td>Reliability (nonrecurring delay)</td>
<td>19.8342</td>
<td>21.6844</td>
</tr>
</tbody>
</table>

Recurring delay decreased by 8.84% due to larger **volume** (please note the average travel time is longer but the coefficient of variance becomes smaller)

Nonrecurring delay increased by 9.32% due to higher congestion and **accident** frequency

Energy consumption (BTU) before (Energy_consumption_base) and after (Energy_consumption_id) the demand increase
Scenario 2: Effect of traffic congestion

Consider disruptions on
• highway and
• waterway

Fatal accidents and injuries
and show their impacts on performance

Generated accidents on the selected highway segments.
• The accident triggered in average every 2.6 hours.
• When accident occurs, the travel would be fixed at
  • 30 mph for an only injury accident or
  • 10 mph if it was fatal crash.
• After clearance, the vehicle speed could be recovered to normal level.
Scenario 2: Effect of traffic congestion

Volume-to-capacity ratio on segments from New Orleans to Slidell (blue), from Jefferson to New Orleans (red), and from New Orleans to Jefferson (green) over time

Average speed on I-10 near New Orleans before and after demand increased

<table>
<thead>
<tr>
<th></th>
<th>New Orleans to Slidell</th>
<th>Jefferson to New Orleans</th>
<th>New Orleans to Jefferson</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base O-D</td>
<td>53.11</td>
<td>37.62</td>
<td>54.59</td>
</tr>
<tr>
<td>150% O-D</td>
<td>50.79</td>
<td>32.73</td>
<td>53.95</td>
</tr>
</tbody>
</table>
Scenario 3: Effect of safety improvement

Effects of a highway **accidence rate** decrease at different traffic demand

- Assume 50% decrease in the New Orleans area
- Change the transportation demand (100% and 150%) and
- Simulate the impact on the performance of the total Louisiana transportation system.
Scenario 3: Effect of safety improvement

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Accident Rate</th>
<th>Demand Level</th>
<th>( V/C ) from New Orleans to Slidell</th>
<th>( V/C ) from Jefferson to New Orleans</th>
<th>( V/C ) on from New Orleans to Jefferson</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>100% of Base</td>
<td>100% of Base</td>
<td>0.82</td>
<td>1.03</td>
<td>0.68</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>50% of Base</td>
<td>100% of Base</td>
<td>0.75</td>
<td>0.95</td>
<td>0.64</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>100% of Base</td>
<td>150% of Base</td>
<td>0.88</td>
<td>1.14</td>
<td>0.71</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>50% of Base</td>
<td>150% of Base</td>
<td>0.77</td>
<td>0.99</td>
<td>0.67</td>
</tr>
</tbody>
</table>

Comparison of volume to capacity ratio at different accident rates and transportation demands.
Conclusion

• A **multimodal traffic simulation** has been developed for Louisiana.
• It has been **valuated** with available data
• It provides **what-if-analysis tool** for the evaluation of different scenarios

• Three different scenarios have been evaluated showing the **capabilities of the simulation tool**

• To **apply the simulation tool** the requirements are
  • ARENA commercial **software**
  • **Training** of a user