Multimodal Freight Operations in a Connected Vehicle Environment

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October 18, 2017
Background

✓ Fixing America’s Surface Transportation Act (FAST Act) includes provisions for establishing a National Multimodal Freight Policy to address the conditions and performance of the multimodal freight system.

✓ Goals include identifying strategies and best practices to improve intermodal connectivity and performance of the national freight system.

✓ In-parallel with several on-going research programs that the United States Department of Transportation (USDOT) supports to improve safety, mobility and environment through connected vehicle technology (CVT).
Research Goals...

✓ Understanding factors for mobility and resilience of multimodal freight operations.
✓ Determining efficient routes for mobility and resilience with connected vehicles’ network reliability.
✓ Estimating economic costs for connected vehicle technology (CVT)-induced route guidance.
Research Approach

• 12 months; March 2017 – February 2018

• Task 1. Literature review
  • measures of mobility and resilience in the context of multimodal freight transportation (commercial trucks, freight rail, ships and air cargo)

• Task 2. Modeling mobility and resilience indicators
  • mobility and resilience indicators for links and nodes of a multimodal freight network system

• Task 3. Developing connected vehicles’ network reliability model for route guidance
  • probabilistic model for reliability of the communication network and will relate it to travel time changes for mobility

• Task 4. Develop CVT-induced routes for multimodal freight operations
  • construct sample freight routes between major origin-destination pairs over multimodal freight network system in Southern California
Research Approach

• Task 5. Estimate economic costs of CVT-induced freight routes
  • CVT network reliabilities for Southern California region will be translated into economic costs (for both mobility and resilience)

• Task 6. Preparing report and other deliverables
  • Presentation slides
  • Draft Report

Project scheduled for completion by February 2018
Research Approach

• Task 2. **Modeling mobility** and resilience indicators

**Formulation: Mobility Indicator** \( (\Theta_{n,k,t}) \)

\[
\Theta_{n,k,t} = \sum_{i=1}^{n} \frac{x_{i,k}}{(\tau_{i,t,k})^\beta} \sum_{i=1}^{n} \frac{x_{i,k}}{(\Gamma_{i,t,k})^\beta}
\]

- \( n \) = number of individual links
- \( n \) = number of nodes at each exit point diverging away from the main stream freight movement
- \( x_{i,k} \) = tonnage on link \( i \), for freight type \( k \)
- \( \tau_{i,t,k} \) = the travel time along the link at time \( t \), for freight type \( k \)
- \( \Gamma_{i,t,k} \) = the travel time along the link at time \( t \), for freight type \( k \) at free-flow speed
- \( \beta \) = decay parameter (needs to be calibrated for the link or the segment)
Research Approach

• **Task 2. Modeling mobility and resilience indicators**

**Formulation: Resilience Indicators** $(\psi_{i,k,t})$

- **$n$** number of individual links
- **$n$** = number of nodes at each exit point diverging away from the main stream freight movement
- **$x_{i,k}$** = tonnage on link $i$, for freight type $k$
- **$\tau_{i,t,k}$** = the travel time along the link at time $t$, for freight type $k$
- **$\Gamma_{i,t,k}$** = the travel time along the link at time $t$, for freight type $k$ at free-flow speed
- **$\beta$** = decay parameter (needs to be calibrated for the link or the segment)
Research Approach

• Task 2. Modeling mobility and resilience indicators

Parameter (β) values to be used for the indicators
(travel time data collection carried out for some representative interstates in Southern California)

<table>
<thead>
<tr>
<th>Interstate (approximately 11-mile segment)</th>
<th>β-value (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-10</td>
<td>0.1 - 1.5</td>
</tr>
<tr>
<td>I-710</td>
<td>0.2 - 1.0</td>
</tr>
<tr>
<td>I-110</td>
<td>0.1 - 1.1</td>
</tr>
</tbody>
</table>
Research Approach

• Task 3. Developing connected vehicles’ network reliability model for route guidance

Developing network reliability analysis based on percolation theory
Connected $k$-component

Reliability at Micro-level ($r_m$)

Reliability at Macro-level ($R_M$)
Research Approach

• Task 3. Developing connected vehicles’ **network reliability model** for route guidance

Network reliability at macro-level ($R_M(t)$) at time $t$, based on the percolation critical value:

\[
R_M(t) = \sum_{i=[n_p]+1}^{N} \binom{N}{i} r_m(t)^i (1 - r_m(t))^{N-i}
\]

$N = \text{number of connected } k\text{-components}$

$[n_p] = \text{threshold number of functioning connected } k\text{-components}$

$R(t)$ is the reliability of the connected $k$-component at the micro or macro-level.
Research Approach

\[ R_M(t) = \sum_{i=[n_p]+1}^{N} \binom{N}{i} r_m(t)^i (1 - r_m(t))^{N-i} \]

- **Modeling** \( r_m \)
  - **Exponential distribution:** \( r_m(t) = \exp(-\lambda t) \), where \( \lambda \) is the scale parameter.
  - **Uniform distribution:** \( r_m(t) = (b - t)/(b - a) \), where \( a, b \) are the lower and upper limits of the interval, respectively.
  - **Weibull distributions:** \( r_m(t) = \exp \left( - \left( \frac{t}{\lambda} \right)^k \right) \), where \( \lambda, k \) are the scale parameter and shape parameter, respectively.
Demonstration

\[ R_M(t) = \sum_{i=[n_p]+1}^{N} \binom{N}{i} r_m(t)^i (1 - r_m(t))^{N-i} \]
Application
Concluding Remarks and Future Research

- CVT has the potential to become very relevant and crucial for multimodal transportation.
- Understanding factors for mobility and resilience is critical for efficient multimodal freight operations.
- Very little is known about the influence of reliability of CVT network on the freight industry.
- Estimate economic costs of CVT-induced freight routes.
- CVT network reliabilities for Southern California region will be translated into economic costs (for both mobility and resilience).
Thank you