Development of Performance Measurement for Freight Transportation

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Outline

• Introduction

• Review of Literature and Practice
  – USDOT
  – State DOTs
  – Other Literature

• Preliminary Performance Measure Development
  – User Needs
  – Transportation Goals
  – Preliminary Freight Performance Measures

• Work Plan
Landmarks of Intermodal Freight Transportation

- ISTEA (1991)
- TEA-21 (1998)
- MAP-21 (2012)

  - Requests the national freight network to “incorporate concepts of performance, …, and accountability into the operation and maintenance of the national freight network”
  - Requires the U.S. Department of Transportation (USDOT) and all states to “establish performance measures for freight movement”
Project Objectives

• To develop a systematic, scalable, calculable, effective, and user-oriented performance measure system for intermodal freight transportation systems.

• Measures can be integrated into other models such as Intermodal Freight Simulation Model to answer the following questions:
  – For a transportation system, intermodal or single mode, how well it is designed and operated;
  – For a specific industry in a specific area, what kinds of modes or their combination should be chosen;
  – For local, state wide, national governments, what kind of intermodal transportation system is the best choice
  – To provide guidelines for performance measures-based intermodal transportation decision making.
2011 USDOT Performance Measures

- Safety
- Reduced congestion
- Global connectivity
- Environmental stewardship
- Security, preparedness, and response; and
- Organizational excellence.
## 2011 USDOT Performance Measures

### Safety

- Passenger vehicle occupant highway fatality rate per 100 million passenger vehicle miles traveled (VMT);
- Large truck and bus fatality rate per 100 million total VMT;
- Motorcyclist fatality rate per 100,000 motorcycle registrations;
- Non-occupant fatality rate per 100 million VMT;
- Number of commercial air carrier fatalities per 100 million persons onboard;
- Fatal accidents per 100,000 flight hours in general aviation;
- Rail-related accidents and incidents per million train miles;
- Transit fatalities per 100 million passenger-miles traveled;
- Number of natural gas and hazardous liquid pipeline incidents with death or major injury; and
- Number of hazardous materials transportation incidents with death or major injury.
2011 USDOT Performance Measures

• Congestion Reduction
  – Percentage of travel on the National Highway System (NHS) meeting pavement performance standards for “good” rated ride;
  – Percentage of deck area on National Highway System (NHS) bridges rated deficient
  – Percentage of total annual urban area travel occurring in congested conditions;
  – Average percent change in transit boardings per transit market (150 largest transit agencies);
  – Percent of transit bus fleets compliant with the Americans with Disabilities Act (ADA);
  – Percent of key transit rail stations compliant with the ADA; and
  – Percent of all flights arriving within 15 minutes of schedule at the 35 Operational Evolution Partnership airports due to National Airspace System related delays.

Mode-Specific
2011 USDOT Performance Measures

• Environmental stewardship, security, and organizational excellence
  – Number of areas in conformity lapse;
  – Number of hazardous liquid pipeline spills with environmental consequences;
  – Number of Exemplary Human Environmental Initiatives undertaken;
  – Median time in months to complete environmental impact statements for DOT funded infrastructure projects;
  – Percentage of DoD-required shipping capacity complete with crews available within mobilization timelines;
  – Percentage of DoD-designated commercial ports available for military use within DoD established readiness timelines;
  – Percent of DOT personnel with emergency management responsibilities who are prepared to respond to disasters and emergencies;
  – Percent of DOT agencies meeting annual response requirements;
  – Percent of major federally funded transportation infrastructure projects with less than 2 percent annual growth in the project completion milestone as reported in the finance plan;
  – Percent of finance plan cost estimated for major federally funded transportation infrastructure projects with less than 2 percent annual growth in project completion cost;
  – For major DOT aviation systems, percentage of cost goals established in the acquisitions project baselines that are met; and
  – For major DOT aviation systems, percentage of scheduled milestones established in acquisition project baselines that are met.
Measurements of DOT Administrations

- **Maritime Administrations**
  - Reduced congestion,
  - Global connectivity,
  - Environmental stewardship, and
  - Security, preparedness, and response.

- **Federal Highway Administration**
  - Truck travel times in freight-significant corridors to measure the performance of the freight transportation system
  - Border delay and crossing times for freight

- **Federal Transit Administration**
  - FTA has opportunities to improve performance accountability (GOA 2011)
  - MAP-21 requires FTA to define objective standards for measuring
    - Safety for all modes of public transportation, and
    - Condition of capital assets.
Measures of DOT Administrations

• Federal Railroad Administration reports rail service metrics and performance of intercity passenger train operations regarding finance, on-time, delays, other service quality, and public benefit.

• Seven Class-I railroad report three freight rail performance at www.railroadpm.org.
  – Cars on Line,
  – Train Speed (miles per hour), and
  – Terminal Dwell (Hours).

The railroads actually use different ways to calculate those measures and it is difficult to compare them on a railroad-by-railroad basis (Vantuono)
Measures Used by State DOTs (Missouri)

• MoDOT is using a comprehensive tool called *Tracker* to track 19 categories of performance
  – Uninterrupted Traffic Flow;
  – Smooth and Unrestricted Roads and Bridges;
  – Safe Transportation System;
  – Roadway Visibility;
  – Outstanding Customer Service;
  – Partner with Others to Deliver Transportation Services;
  – Advance Economic Development;
  – Innovative Transportation Solutions;
  – Fat Projects That Are of Great Value;
  – Environmentally Responsible;
  – Great Workplace, Great Employees;
  – Efficient Movement of Goods;
  – Easily Accessible Modal Choices;
  – Customer Involvement in Transportation Decision Making;
  – Accommodating Roadsides;
  – Best Value for Every Dollar Spent;
  – Advocate for Transportation Issues; and
  – Proactive Transportation Information.
# MoDOT Metrics for Uninterrupted Traffic Flow

<table>
<thead>
<tr>
<th>Metrics</th>
<th>Unit/Calculation</th>
<th>Relevant to Freight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average travel times on selected freeway sections</td>
<td>$10$-mile travel time (minutes) = $10$ miles/ Average Speed $\times$ Free flow speed</td>
<td>H</td>
</tr>
<tr>
<td>Average rate of travel on signalized routes</td>
<td>High: speeds at 80 percent of the speed limit; medium: 50 to 79 percent; low: less than 50 percent.</td>
<td>H</td>
</tr>
<tr>
<td>Average time to clear traffic incident</td>
<td>Minutes</td>
<td>M</td>
</tr>
<tr>
<td>Traffic impact closures on major interstate routes</td>
<td>Total closure minutes for events with an actual or expected duration of one hour or more closure at selected mile markers at major highways</td>
<td>H</td>
</tr>
<tr>
<td>Work zone (WZ) impacts to traveling public</td>
<td>Number of WZ with major and moderate impact. An impact is defined as the additional time added to the public’s normal travel: Minor: less than 10 minutes, moderate:10 to 14 minutes, and major: 15 minutes or greater.</td>
<td>H</td>
</tr>
<tr>
<td>Time to meet winter storm event performance objectives</td>
<td>Average time (hours) involved in road clearance during winter weather on continuous and non-continuous operations routes.</td>
<td>H</td>
</tr>
</tbody>
</table>
MoDOT Metrics for Uninterrupted Traffic Flow

<table>
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<tr>
<th>Metrics</th>
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</thead>
<tbody>
<tr>
<td>Percent of major highways in good condition</td>
<td>On high-speed routes (&gt; 50 mph), the International Roughness Index (IRI) is used to measure good conditions. For lower-speed routes (mostly urban areas) where smoothness is less critical, a condition rating is used in with the smoothness component.</td>
<td>H</td>
</tr>
<tr>
<td>Percent of minor highways in good condition</td>
<td>Smoothness is evaluated using the IRI. Pavements below the prescribed threshold are considered good. A condition rating of visual distress is also evaluated and if those criteria are met, the roadway is considered good.</td>
<td>H</td>
</tr>
<tr>
<td>Percent of vehicle miles traveled on major highways in good condition</td>
<td>An annual measure based on VMT estimation on major highways.</td>
<td>H</td>
</tr>
<tr>
<td>Percent of bridges in good condition</td>
<td>A bridge is considered “good” if it is not either “structurally deficient” or “functionally obsolete”</td>
<td>H</td>
</tr>
<tr>
<td>Percent of major bridges in good condition</td>
<td>A major bridge is one with a length greater than 1,000 feet.</td>
<td>H</td>
</tr>
</tbody>
</table>
# MnDOT Performance Metrics

<table>
<thead>
<tr>
<th>Category</th>
<th>Measure with Definition</th>
<th>Relevant to Freight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traveler Safety</td>
<td>Total traffic fatalities and serious injuries</td>
<td>H</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Percent of bridges whose conditions are good or satisfactory</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>Percent of bridges whose conditions are poor (structurally deficient or functionally deficient)</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>Percent of state highway miles in poor pavement condition</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>Percent of state principal arterials miles in poor pavement condition</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>Percent of state principal arterials miles in good pavement condition</td>
<td>H</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Frequency of achieving bare lane within target hours, all storms and routes</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>Percent of bridge safety inspections that were inspected within the required time period</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>Customer satisfaction with state highway maintenance from 1 to 10 based on a survey</td>
<td>H</td>
</tr>
<tr>
<td>National and Global Connections</td>
<td>Airline annual available seat miles on scheduled commercial flights</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Annual tonnage of shipments to and from MN Great Lakes &amp; river ports</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>Annual tonnage of shipments on Minnesota Railroads: from, to and through Minnesota</td>
<td>H</td>
</tr>
</tbody>
</table>
## MnDOT Performance Metrics

<table>
<thead>
<tr>
<th>Category</th>
<th>Measure with Definition</th>
<th>Relevant to Freight</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Statewide Connection</strong></td>
<td>Percent of major interregional routes can be driven within 2 mph of the corridor target speed</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>Percent of Minnesota population within 30 minute drive time of an airport with paved and lighted runway</td>
<td>H</td>
</tr>
<tr>
<td><strong>Twin Cities Mobility</strong></td>
<td>Percent of miles below 45 mph in AM or PM peak</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Average clearance time for metro urban freeway incidents</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>Annual rail and express bus transit ridership</td>
<td>I</td>
</tr>
<tr>
<td><strong>MN Metro and Regional Mobility</strong></td>
<td>Annual Greater Minnesota bus service hours</td>
<td>I</td>
</tr>
<tr>
<td><strong>Community Development and Transportation</strong></td>
<td>Percent of state highway intersections with Accessible Pedestrian Signals</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>Percent of commuter trips with bicycle commuting, walking and public transit in major metropolitan areas</td>
<td>I</td>
</tr>
<tr>
<td><strong>Energy and the Environment</strong></td>
<td>Annual billions of gallons sold in Minnesota</td>
<td>H</td>
</tr>
</tbody>
</table>
MnDOT Performance Scorecard

Minnesota 2011 Transportation Results Scorecard

<table>
<thead>
<tr>
<th>Measure</th>
<th>Score</th>
<th>Result</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic Safety</td>
<td>368</td>
<td>400 by 2010</td>
<td>509</td>
</tr>
<tr>
<td>Infrastructure Preservation</td>
<td>85.4%</td>
<td>64%</td>
<td>88.9% 88.5% 87.4% 86.9% 85.4%</td>
</tr>
<tr>
<td>Pavement</td>
<td>66%</td>
<td>5%</td>
<td>4.4% 4.6% 6.9% 6.2% 6.8%</td>
</tr>
<tr>
<td>Pavement</td>
<td>4.8%</td>
<td>2%</td>
<td>2.6% 3.4% 5.5% 3.7% 4.8%</td>
</tr>
<tr>
<td>Pavement</td>
<td>67.3%</td>
<td>70%</td>
<td>66.3% 67.9% 63.7% 70.2% 67.3%</td>
</tr>
</tbody>
</table>

Final 2011 data indicate 368 fatalities—the lowest number of fatalities in a generation. Annual fatalities are down by 141 since 2007. Comparison—3rd lowest state in 2010, with fatality rate 35% below U.S. average.

In 2011 bridges on principal state roads in Good or Satisfactory condition fell to 85.4%, which is still meeting target. The percent rated Poor increased slightly to 3.3%, but is projected to improve and be close to the 2% target in 2015. Comparison—Minnesota has the 4th lowest percentage of bridges rated structurally deficient or functionally obsolete—less than half the national average—according to 2011 rankings by Better Roads magazine.

State pavement condition declined in 2011 after improving slightly in 2010. Overall, 66 percent of state highway miles were in poor condition in 2011. Both principal arterial pavement measures fell short of their targets.

MnDOT’s Better Roads program will slow the deterioration of pavements by improving nearly 700 miles of poor roads. Additionally, increased pavement investment in response to the new federal transportation bill is predicted to result in 0.6 percent poor in 2016. This falls within the 5-9 percent range for poor pavement that represents an acceptable risk. MnDOT is committed to keeping poor pavements within this acceptable range, though this will take significant investment in the years to come. Another pavement quality measure, appearing in the Minnesota Dashboard, is discussed in the Pavement section.
# NCDOT Performance Metrics

<table>
<thead>
<tr>
<th>Measure</th>
<th>Definition</th>
<th>Relevant to Freight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatality Rate</td>
<td>Total number of statewide fatalities on NC roads per 100 million vehicle</td>
<td>H</td>
</tr>
<tr>
<td>Incident Duration</td>
<td>Average time it takes to clear a major accident (i.e. one that causes significant or unusual delays) from a North Carolina highway</td>
<td>H</td>
</tr>
<tr>
<td>Infrastructure Health</td>
<td>Bridge health index: Percent of bridges in good condition. A bridge is considered to be in good condition if the Level of Service (LOS) for the Deck, Sub-Structure and Super Structure are all greater than or equal to 6 (on a 1 to 9 scale). Pavement condition rating: Percent of lane miles in good condition. A good condition for pavement is defined as a Pavement Condition Rating (PCR) value of 80 or higher (on a 0 to 100 scale). Roadside feature condition score:</td>
<td>H</td>
</tr>
<tr>
<td>Delivery Rate</td>
<td>Percent of plans completed and bids opened on time</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Percent of right of way plans completed on time</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Percent of construction projects completed on schedule</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Percent of construction projects completed on budget</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Environmental compliance index.</td>
<td>M</td>
</tr>
<tr>
<td>Employee Engagement</td>
<td>Employee emotional and rational commitment indices derived from the employee engagement survey</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Employee discretionary effort index derived from the employee engagement survey</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Intent to stay index derived from the employee engagement survey</td>
<td>I</td>
</tr>
</tbody>
</table>
Organizational Performance

The N.C. Department of Transportation is committed to measuring and improving performance. The department's Organizational Performance Dashboard serves as an indicator of how well we are meeting our mission and goals. Check this page often for updates and real-time information.

Simply roll over a dial to see additional performance data for each goal.

- Fatality Rate: 1.24
- Incident Duration: 58 min.
- Infrastructure Health: 73%
- Delivery Rate: 62%
- Employee Engagement: 5.32

Incident Duration

Making our transportation network move people and goods more efficiently: This is defined as the average time it takes to clear a major accident (i.e., one that causes significant or unusual delays) from a North Carolina highway. The gauge is accompanied by performance information for Highways, Rail, Ferry and Public Transportation.

Click here for additional performance information

Our mission is connecting people and places in North Carolina — safely and efficiently, with accountability and environmental sensitivity.
### A Freight Performance Study by MnDOT (2008)

- **19** Categories with total **247** Performance Metrics under Them (some overlaps)

<table>
<thead>
<tr>
<th>Network and infrastructure</th>
<th>Safety or damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access</td>
<td>Capacity</td>
</tr>
<tr>
<td>Travel time</td>
<td>Reliability</td>
</tr>
<tr>
<td>Market share</td>
<td>Modal share</td>
</tr>
<tr>
<td>Modal costs</td>
<td>Freight productivity</td>
</tr>
<tr>
<td>Freight security</td>
<td>Shipment rates</td>
</tr>
<tr>
<td>Pricing</td>
<td>Agency cost</td>
</tr>
<tr>
<td>Carrier cost</td>
<td>Shipper cost</td>
</tr>
<tr>
<td>Externalities and community cost</td>
<td>Transportation indices</td>
</tr>
<tr>
<td>External factors</td>
<td></td>
</tr>
</tbody>
</table>

Too Many?
• Major Findings
  – A reporting framework is possible.
  – The impediments to creating a Freight System Report Card are numerous and there is no entity and no budget to develop a Freight System Report Card.
  – A coalition of interested parties will need to coalesce around the concept of producing a Freight System Report Card.

• 29 Metrics under 6 Categories
  Freight Demand      Freight Efficiency
  Freight System Condition    Freight Environmental Impacts
  Freight Safety      Adequacy of Investment in Freight System

Those metrics describe the facts of performance on each mode and lacks system-level performance measures for intermodal transportation.
Literature Review of Mobility

- **Mobility:** the ability to transport goods in an efficient way
  - Average speed (Shaw 2002, Bertini 2002)
  - Both speed and trip length (Report of Albany, NY, 2001)
  - Average origin-destination travel time per trip (Meyer 2001)
  - Colorado System 2000
    - Passenger Mobility Coefficient by using PMT/Average Speed/1,000,000
    - Freight Mobility Coefficient by using FTMT/Average Speed/1,000,000
    - Passenger Mobility Index is (PMT/VMT) × Average Speed
    - Freight Mobility Index is FTMT/Truck VMT*Average Speed
  - Congestion Volume to Capacity Ratio (V/C) greater than 0.85 (BRW, Inc 2000)
  - Number (or percent) of intermodal connectors improved (Bertini 2002)
  - Railway: Average Train Speed, Average Terminal Dwell Time (American Association of Railroads 2003)
Literature Review of Accessibility and Capacity

• Accessibility: the ease to reach major transportation facility
  – Percentage of urban population within $X$ mile of transit to evaluate the transit service accessibility (Bertini 2003, San Francisco Bay Area Report. 2001, Dumbaugh 2003)
  – Number of goods transferred and number of people accessing the system (Bertini 2003)

• Capacity of transportation system:
  – vehicle miles traveled (VMT), ton miles traveled (TMT) (BRW, Inc 2000, Bertini 2002)
  – Vehicle hours traveled hours traveled (Bertini 2002)
  – Railway: Total Freight Cars On Line (American Association of Railroads 2012)
Literature Review of Reliability

- Reliability: the delay caused by some unusual events or incidents

- Measures:
  - Transfer time between modes (Bertini, 2003, Czerniak 1996)
  - Delays per ton-mile, lost time or delay time, and congested highway miles divided by total highway miles (BRW, Inc 2000)
  - How ships know the schedule well and accurately estimate the dwell time (DOT 1999)

- Problem: How to define delay and “on time”? 
Literature Review of Safety

• From “Combined Performance Plan and Report”
  – Highway: fatalities per 100 million vehicle-mile of travel and number of accidents per 100 million vehicle-miles of travel
  – Airborne: fatal aviation accidents per 100,000 departures
  – Maritime: number of calls received for help by coast guard and percent of all mariners in imminent danger who are rescued.
  – Railway: train accidents per million train-miles and rail related fatalities per million train-miles

• Problems: hard to compare
Literature Review of Cost Effectiveness

- Cost is direct costs associated with transportation planning, construction and operation
    - Fuel consumption cost
    - Truck technology and drivers’ wages
  - Cost per vehicle hour (Hagler Bailly Services, Inc 2001)
  - Maintenance cost on facilities (the State of Florida 1998)
    - The higher the better?
Literature Review Infrastructure Condition

- Number of bridges per 100 miles (BRW Inc 2002)
- Number of deficient bridges per 100 mile (BRW Inc 2002)
- Lane-miles of high-level highway requiring rehabilitation (California, 1998)
- Percentage of miles of state trunk lines with surface condition classified as good and the number bridges rated as good (Michigan, 1999 and many state DOTs)

Is infrastructure condition a necessary performance measure?

It influences mobility, reliability, safety, comfortability
Literature Review of Economic Impact

- Number of direct and indirect jobs created (Indianapolis Study 2000, St. Louis Region MPO 1998)
- Contribution of investment to GDP growth presented (Hickling Lewis Brod, Inc 1998)
- Revenue per ton-mile by mode (Florida, 1998)
- The value of the freight that is moved from, to and within the region (St. Louis Region MPO 1998)
- Problems
  - Hard to compare
  - Hard to measure
Literature Review of Industry Productivity

• Industry productivity: the efficiency of the industry instead of the transportation system

• Measures in the literature
  – Vehicle miles per capita and revenue hours per employee. (Thompson, 2001)
  – Empty/loaded ratio for truck moves, annual miles per truck, and average length of haul by vehicle (FHWA)

• Not direct reflection of transportation system efficiency
Problems Identified from Reviews

- Problems of existing measures for freight transportation
  - Many are only applicable for a single mode
  - Not systematic: overlap and overlook
  - Not scientific: factors ≠ performance measures
  - Not user-oriented
  - Not all quantitative
  - High cost to calculate, track, and use
What is a Good Measurement Systems?

• It should be based on user needs. Transportation systems are built for their users rather than others.

• It should be applicable for all modes and their combinations.

• It should be scalable to compare systems of different sizes.

• It should be scientific and systematic. A good performance measure system should be a hierarchy with system and sub system measures. At the system level, there should be no overlaps or oversights.

• It should be as quantitative as possible.

• It should be cost effective to calculate, track, and use.
Freight Transportation User Needs

• Users: all agencies and participants in freight transportation systems, who have diverse purposes, preferences and requirements for the transportation facilities.
  – **Investors** include transportation investors and stakeholders (sometimes they are government agencies). Their major concerns would be how to develop a cost effective system and how to get the investment return as soon as possible.
  – **Industries** include public and private industries. Their major concerns are to transport the goods in a quick, safe, cheap, reliable and efficient manner.
  – **Society users’** major concerns are located in economic impact, community impact, and environment consideration.
Transportation Goals

Goals

• Mobility: less time for trips
  (Industry)

• Reliability: more predictable, less delay
  (Industry)

• Safety and security: less accidents, fatalities, risks
  (Industry, Society)

• Environmental impact: less amount of transportation related pollutants released into the environment, higher community livability near major transportation infrastructures, and less energy consumption
  (Society)

• Long-term cost efficiency: more cost efficient system, lower cost/benefit ratio and higher sustainability
  (Investors)

• Economic growth: more jobs and revenue created by transportation system
  (Society)

DOT Metrics

• Reduced congestion
• Global connectivity
• Safety
• Security, preparedness, and response
• Environmental stewardship
• Organizational excellence.
Proposed Measures: Mobility

• Mobility (M): Average travel time per TMR (Ton Mile Required), where distance is Geographic distance rather than traveling distance.

• The statistics can be obtained by

\[ M = \frac{\sum_{(i,j,n) \in R} p_{i,j,n} T_{i,j,n}}{\sum_{(i,j,n) \in R} p_{i,j,n} l_{i,j}} \]

• Why geographic distance?
  – User needs
  – Verified by some shippers

• Already includes the transfer time and considers vehicle occupancy
Proposed Measures: Reliability

- **Reliability** ($R$): the dependable levels of transportation service and coefficient of variation of travel time can be used to measure it. The statistics can be obtained by:

$$R = \frac{\sqrt{\sum_{(i,j,n) \in R} p_{i,j,n} l_{i,j} \left( \frac{T_{i,j,n}}{l_{i,j}} - M \right)^2}}{\sum_{(i,j,n) \in R} p_{i,j,n} l_{i,j}}$$

- **Nonrecurring delays** ($R_u$)

$$R_u = \sqrt{\sum_{(i,j,n) \in R} p_{i,j,n} l_{i,j} \left( \frac{T_{i,j,n}}{f_{i,j,n}} - \frac{T_{i,j,n}}{l_{i,j}} \right)^2}$$

- **Smaller $R$ means people can easily predict the total travel time and avoid the delay**
- **Security issues??**
Proposed Measures: Safety

- **Fatality \((S_F)\):** number of fatality per TMR
  \[
  S_F = \frac{\sum_{(i,j,n) \in R} F_{i,j,n}}{\sum_{(i,j,n) \in R} p_{i,j,n} l_{i,j}}
  \]

- **Injury rate \((S_I)\):** number of injuries per TMR
  \[
  S_I = \frac{\sum_{(i,j,n) \in R} I_{i,j,n}}{\sum_{(i,j,n) \in R} p_{i,j,n} l_{i,j}}
  \]

- **Property damage \((S_P)\) cost per TMR
  \[
  S_P = \frac{\sum_{(i,j,n) \in R} D_{i,j,n}}{\sum_{(i,j,n) \in R} p_{i,j,n} l_{i,j}}
  \]

- Accident detection and response efficiency influence the outcomes of accidents, but they are already covered by mobility and reliability.
Proposed Measures: Environment Impact

- Transportation related pollutants released \((P)\): Tons of mobile source emissions from transportation systems per TMR

\[
P = \frac{\sum_{(i,j,n) \in R} p_{i,j,n}}{\sum_{(i,j,n) \in R} p_{i,j,n} l_{i,j}}
\]

- Community livability \((L)\): Percent of people affected by transportation systems
  - noise
  - or other issues?
Proposed Measures: Direct Cost Efficiency

- The direct cost includes vehicle operation cost, construction, operation, maintenance and disposal cost for transportation facilities
  - Vehicle Operation Cost ($VC$): vehicle operation cost mainly includes cost of fuel consumption, cost for vehicle insurance, cost for vehicle maintenance, cost for vehicle aging per TMR, and other cost.

\[
VC = \sum_{(i,j,n) \in R} (GC_{i,j,n} + VI_{i,j,n} + VM_{i,j,n} + VA_{i,j,n} + VO_{i,j,n})
\]

- Transportation Facility Cost ($FC$): the cost of transportation facility per TMR. (money flow diagram and interest issues)
Proposed Measures: Economic Growth

• Transportation system investment can improve business sale and employment of the region
  – Economic growth ($EG$): the direct business sale increasing directly caused by one million dollar transportation investment, which includes initial capital investment and operating and maintenance investment.

  \[ EG = \frac{TEG}{TI} \]

  – Regional Employment Improvement ($J$): Number of job year opportunities created by a transportation system per 1 million dollar investment.
Work Plan

• Further modify metrics for freight transportation
• Investigate data availability for calculating metrics
• Study the calculation procedures for the metrics
• A case study to demonstrate the usage of proposed performance measurement system
Questions and Answers

Thanks