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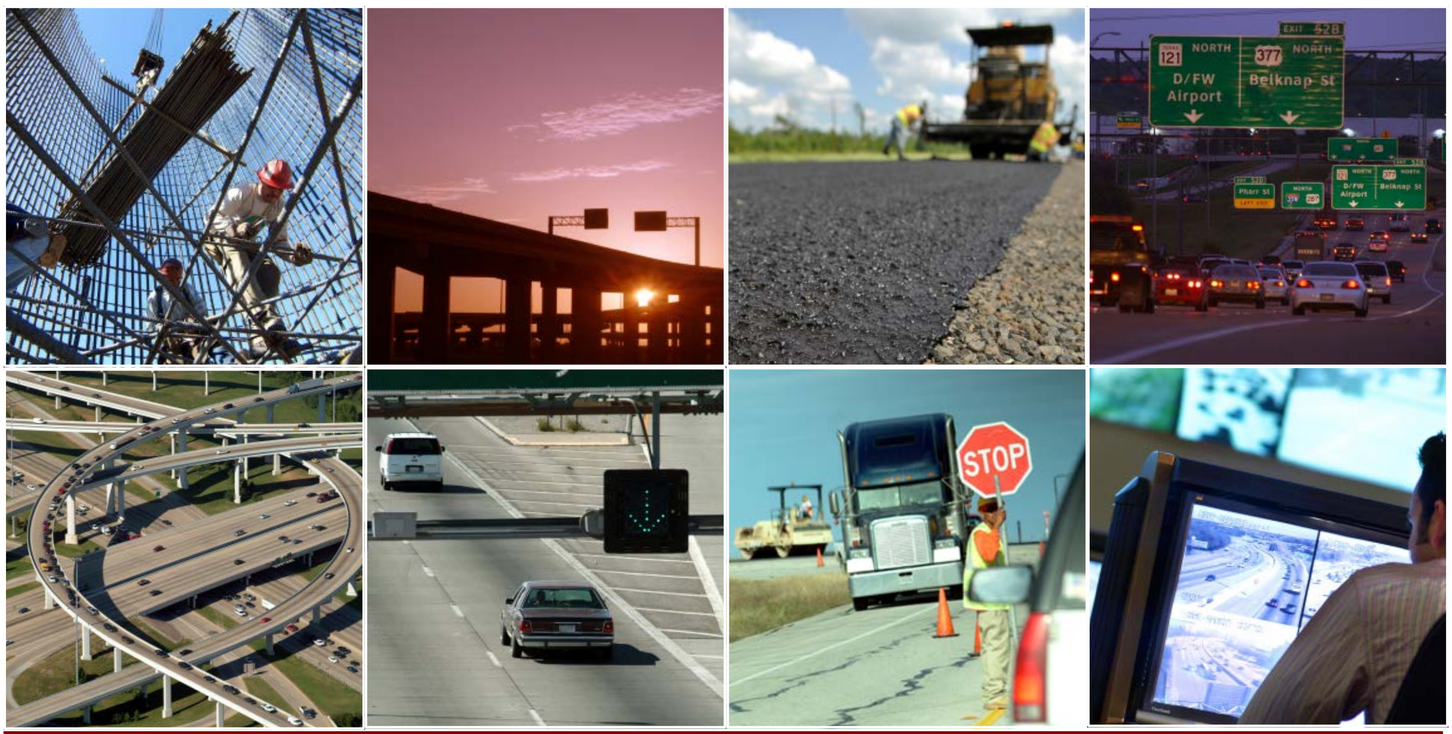


TECHNICAL MEMORANDUM

# Freight Multimodal Performance Measures

Task 4 - Synthesis Development (Synthesis #2 of 5)

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## EXECUTIVE SUMMARY

The Moving Ahead for Progress in the 21st Century Act (MAP-21) directs state DOTs to perform multimodal freight performance evaluations to efficiently monitor their freight systems *(1)*. These freight systems face consistently increasing demand to meet the goals of the National Export Initiative *(2)*. To better gauge the effectiveness of their overall freight system, agencies need to implement performance measures which can be applied to systems consisting of multiple modes and their intermodal connections. This technical memorandum discusses some suggested and widely used multimodal freight performance measures, identifies some of the challenges involved, and describes applicable solutions. The key findings of this technical memorandum are listed below, and more discussion is provided in the body of the memo.

### Key Points

- The recommended freight multimodal performance areas include mobility, travel time reliability, safety, environmental stewardship, cost efficiency and economic growth. Specific measures in these areas have been defined in the body of the memo and a few key examples have been provided for each. These performance measures have been used frequently by agencies and planning organizations, and are well-documented in the literature.
- A few other performance measurement areas such as flexibility to respond to market changes, asset management, global connectivity and organizational excellence are used on a contextual basis, though less often than those previously mentioned.
- An emerging performance measure is transportation system resiliency, which refers to the system's ability to withstand, respond to, and recover from disruptions.
- The relative importance of freight metrics is dependent upon the goals and objectives of users and stakeholders. From a planning agency's point of view, using a combination of such metrics enables balanced performance measurement capturing these varied areas.
- Because multimodal systems consider intermodal connections between multiple components, each having unique characteristics, using metrics which are applicable across modes is suggested. For example, using travel time-based mobility and reliability measures, and indices like the travel time index or planning time index address this challenge by negating the effect of trip lengths (and times) across the different modes involved.
- Freight-related data are maintained independently by different organizations for different purposes. Therefore, the data sources for freight performance measures can be voluminous and disjointed. There is a logistical complexity associated with integrating, tracking and keeping some of the measures updated for practical utility.

## INTRODUCTION

Multi-modal freight transportation system performance evaluation has gained increased attention with intermodal transportation system developments across the United States as well as enactments of the Intermodal Transportation Efficiency Act (ISTEA) and the Transportation Equity Act for the 21st Century (TEA-21). All state DOTs are also directed to perform freight evaluations per MAP-21 to improve their freight network operations *(1)*. Under MAP-21, national freight policy objectives include economic competitiveness, productivity and efficiency; reduced congestion; safety, security and resilience of freight movement *(1)*. The goal of promoting exports aggressively, as set by the National Export Initiative *(2)*, is likely to cause demand to grow beyond capacity in many regions across the United States, contributing to elevated congestion and decreased reliability throughout the surface transportation system, impacting freight shipments *(3)*. Increased freight growth and increased transportation system congestion levels make it imperative for state DOTs and metropolitan planning organizations (MPOs) to evaluate the impacts and performance of freight transportation systems. This synthesis highlights freight multi-modal performance measures as well as some challenges related to systematic performance monitoring of freight transportation.

## THE CHALLENGE IN FREIGHT MULTIMODAL PERFORMANCE MEASUREMENT

The multi-faceted (and sometimes conflicting) priorities and effects among economic, environmental and social elements make freight performance more challenging to measure compared to similar impacts from highway users *(4)*. Although single mode and micro-level studies use simulation techniques to study network performance for respective modes, very few simulation models and research studies have focused on the multi-modal transportation environment and evaluating system-wide performance *(5-6)*. This has largely been because of the high scale of complexity and variability that needs to be addressed while evaluating flow and capacity related issues between multiple connections within the freight system that includes highways, rail, seaports and airways. The existing traffic simulation techniques use capacity and speed-flow relationships for a single mode, such as highway links, ports and airports, or rail links, and are unable to incorporate intermodal connections even though connections between and within modes constitute a high portion of the total freight flow time. Similarly, an aggregate network model was developed for the state of Mississippi in 2004 which could not consider node interactions for different modes *(5)*. The intermodal connection nodes are often the bottlenecks for freight networks.

## CURRENT PERFORMANCE MEASURES

In addition to mobility (reducing transportation time and delay), which is a major concern for most transportation users, other performance measure areas such as reliability, safety and security, environmental impact, and economic development are often adopted as metrics for freight system performance evaluation. Computer simulation is one typical way to evaluate system performance and identify bottlenecks because experimenting with traffic networks and connections is more practical in a simulated environment *(7)*.

Some of the most frequently employed measures of freight system performance (by topic area) are listed in Table 1 and briefly described below:

**TABLE 1 Areas of Performance Measurement**

| Measure Area | Typical Characteristics | Examples |
|---|---|---|
| Mobility | Effectiveness in moving goods and services | • Total delay<br>• Travel Time Index<br>• Delay per mile<br>• Average travel time per ton mile<br>• Average terminal dwell time |
| Reliability | Variability in travel time from hour-to-hour, day-to-day, year-to-year, etc. | • Planning Time Index<br>• Travel time variability (standard deviation, coefficient of variation)<br>• System Resiliency |
| Safety | Reduction in crash rates, injuries, fatalities; improving crash detection and response | • Fatality rate<br>• Injury rate<br>• No. of fatal aviation and rail-related crashes per assigned reference units |
| Environmental Stewardship | Environmental effects of freight systems; reduction in amount of transportation-related pollutants | • Energy consumption rate<br>• Pollutant released rate |
| Direct Cost Efficiency | Reduction in direct costs of the freight transportation system | • Vehicle operating cost<br>• Infrastructure construction, maintenance and disposal cost |
| Economic Growth | Promoting local or regional economic growth and employment opportunities | • No. of direct and indirect jobs created<br>• Total revenue; revenue by mode<br>• Value of freight movement to and within the region |

### 1. Mobility

Mobility is an indicator of the effectiveness of the freight transportation system in moving goods and services. Total delay or delay per mile ("all vehicles" or truck) are typical mobility measures used when ranking congestion. An example of this is the *100 Most Congested Roadways* list created by the Texas A&M Transportation Institute (TTI) for the Texas DOT *(8)*. In this list, segments of roadway are ranked by delay per mile, allowing the values for various roadways to be normalized by their differing lengths. Another example is TTI's *2015 Urban Mobility Scorecard* where a cost is associated with urban area truck delay *(9)*.

In the literature, freight mobility has also been defined as the average travel time (ton-hour) per ton mile *(5)*. Ton-mile is the product of number of tons of freight involved in the trip and the geographical distance between the origin-destination (O-D) pair. Geographical distance is used instead of the traveling distance because freight users have modal options for moving goods and thus the traveling distance will differ with mode chosen. Mobility measures can be adjusted by ton-mile weighting and the value of goods carried to reflect the associated revenue generated. Another method is using twenty-foot equivalent unit (TEU) for weighting (by volume) *(10)*. These traditional types of weighting are similar to the use of vehicle-miles of travel (VMT) for mobility analysis.

One of the most common microeconomic considerations is the reduction in travel time and associated direct cost savings as well as indirect savings from logistical reorganization of freight systems wherein warehousing costs are lowered due to faster and more reliable transportation *(11-12)*. In addition to the average speed, the average terminal dwell time is also used for railroads. It should be noted that the overall value of travel time as well as travel reliability (discussed next) depends on the type and value of commodities or services being moved (e.g. both these values are higher for perishable goods and time sensitive shipments than otherwise) *(13)*.

**2. Reliability**

Reliability remains one of the most significant factors for freight system users because shippers and freight users depend on reliable travel times to remain competitive *(14-15)*. The value of reliability also depends on whether the shipper or receiver of the commodity or service is using a just-in-time inventory system *(16)*. A common way to quantify reliability is using the planning time index measure - a ratio of conditions at the 95$^{th}$ percentile travel time relative to uncongested traffic. Therefore, a PTI of 1.50 means a traveler needs to allow 30 minutes for a trip that takes 20 minutes in uncongested conditions to ensure arriving on time for important trips *(8-9)*. Reduced reliability impacts production supplies and may persuade shippers to carry more inventories as a cushion against repeated supply chain disruptions, thereby increasing costs in the long run. An emerging concept in performance measurement related to reliability is that of resilience of a transportation system which refers to its ability to withstand, respond to, and recover from disruptions by either efficient mobilization of existing resources or having robust networks with alternate route and capacity available for use during disruptions *(17)*.

The variability of transfer time between modes is also often used as a reliability metric. Index values (e.g., planning time index) allow negation of effects of trip lengths and thus facilitate easier comparisons within and between corridors (and modes) as well as identification of bottlenecks *(10)*. Two types of delays are frequently addressed in transportation - recurrent delays and nonrecurring delays. Recurrent delay is regular and more predictable, while nonrecurring delay is unanticipated (incidents, weather).

**3. Safety**

The safety aspect of freight transportation is almost always considered a performance metric by most public and private agencies, states and Metropolitan Planning Organizations (MPOs). Safety is typically assessed by fatality rate and injury rate. While fatality rate is the number of fatalities per ton-mile, injury rate is the number of injuries (mild to severe) per ton-mile *(4-5,18)*. These metrics are aimed at measuring the reduction in crash rates, injuries and fatalities. This aspect of performance measurement also considers increasing traffic security and reducing crime rates, improving crash detection and response, and increasing public and homeland security. Depending on the mode, this measure can be quantified as:

- Passenger vehicle fatality rate per 100 million vehicle-miles traveled (VMT);
- Large truck and bus fatality rate per 100 million ton-miles;
- Number of fatal aviation crashes per 100,000 departures;
- Rail-related crashes and fatalities per million train ton-miles;
- Number of natural gas and hazardous liquid pipeline crashes with death or major injury; and
- Number of hazardous materials transportation incidents with death or major injury.

**4. Environmental Stewardship**

This measure accounts for the environmental effects of (freight) transportation systems. Environmental stewardship is measured by energy consumption rate (average unsustainable energy consumption in British Thermal Unit [BTU] per ton-mile) and pollutant released rate (tons of auto [mobile] source emission from transportation system per ton-mile). This criterion evaluates the reduction in the amount of transportation-related pollutants, promotion of community livability near major transportation infrastructures, and decreases in energy consumption.

## 5. Direct Cost Efficiency

The direct cost for the transportation system includes the vehicle operating cost (fuel consumption, vehicle insurance and maintenance, vehicle aging per ton-mile, etc.), infrastructure construction cost, and maintenance and disposal cost for the transportation facilities. The effectiveness of the freight transportation system in allocating these different costs efficiently and minimizing them in the long run is captured under direct cost efficiency.

## 6. Economic Growth

This metric evaluates the objectives of promoting local or regional economic growth and increasing local or regional employment opportunities. The number of direct and indirect jobs created, revenue per ton-mile by mode, total value of freight movement to and within the region, etc. are included as measures to assess economic development.

## ADDITIONAL FREIGHT PERFORMANCE MEASURE DEFINITIONS

This section describes a few other metrics used by other researchers and agencies.

Belella (2005) *(4)* categorized freight measures as reliability (measure for delivery performance), responsiveness (measure of origin to destination travel speed), flexibility (measure of the agility of a system to respond to market changes that maintain or improve competitive advantages), costs (measure of overall cost of moving freight), asset management (measure of an organization's effectiveness in managing assets to support demand satisfaction), safety (measure of achieving a safe condition through danger, risk and injury reduction), and security (measure of the ability to mitigate security risks and threats).

Though less frequently used than other mobility measures, travel speed is also used as an indicator *(19)*.

In the case of maritime operations, global connectivity is also identified as an additional performance measure.

The Florida Department of Transportation (FDOT) identifies four dimensions of mobility, namely quantity, quality, accessibility and utilization *(20)*.

- For freight networks, quantity refers to how much freight is moved (includes truck-miles traveled; combination truck, aviation, rail and seaport tonnage; value of freight; seaport TEUs, etc.)
- Quality encompasses travel experience and implies travel reliability (sometimes also defined as percentage of freeway trips traveling at greater than or equal to 5 mph below the posted speed limit). This also comprises aviation (departure within 15 minutes of scheduled time) and rail departure reliability, truck hours of delay, etc. Freight travel

time variability can be incorporated using the planning time index (ratio of $95^{th}$ percentile travel time and uncongested travel time).

- Accessibility measures the ease of interconnectivity (e.g., aviation, rail and port connectivity with highways). Consequently, aviation, rail and seaport highway adequacies give level-of-service (LOS) measures of the overall connection travel time and speed of inter-modal connections. Active rail access and seaport active rail access metrics account for active rail services to intermodal logistic centers and seaports.
- Utilization factors in the relative demand and supply of transportation facilities and services (for example, percent of miles severely congested estimated using total roadway miles operating at LOS F during peak hour divided by total highway miles).

A 2011 National Cooperative Freight Research Program freight performance measures report *(18)* includes safety (e.g., highway fatality rate, rail incidents per million train miles, number of fatalities per 100,000 take-offs in general aviation); congestion reduction; global connectivity; environmental stewardship; security, preparedness and response; and organizational excellence. Infrastructure condition is also considered a performance measure in some cases because it has an effect on mobility, reliability and safety aspects of the overall freight system.

Freight fluidity is an evolving concept adopted by agencies dealing with freight movement. It has two broad aspects – performance and quantity. The “performance” component focuses on how fluid the supply chains, comprised of multiple modes, are in terms of mobility, travel time reliability and resiliency. The “quantity” component incorporates both the weight (tonnage, volume) and the value of the commodity being shipped to weight performance measures through the entire supply chain. Freight fluidity indicators enable agencies to evaluate the total transit time and travel time reliability of goods along end-to-end networks using data elements from all modes that are part of the supply chain *(17)*.

## CHALLENGES IDENTIFIED IN EXISTING PERFORMANCE MEASURES FOR FREIGHT TRANSPORTATION

A few important challenges observed in existing measures for multi-modal freight transportation system include:

1. Some of the measures can be applied to only a few modes, and in some cases only to a single mode. There is a need for these measures to be applicable to all modes and their combinations for system-level performance measurement. For example, safety is defined distinctly for different modes - for air transportation it is measured by number of fatalities per 100,000 take-offs, while for highways it is the number of fatalities per 100 million VMT or truck-miles of travel (TMT), and likewise for maritime transportation.

2. Some measures are subjective and qualitative rather than quantitative (e.g., measures based on perceived satisfaction of customers, employees and other stakeholders). “Employee satisfaction and customer satisfaction are the most common qualitative key performance measures” *(18)*.
3. Sources of data for freight performance measures are voluminous and disjointed as freight data sets are maintained independently by different organizations for different purposes. There is a logistical complexity associated with integrating, tracking and keeping some of the measures updated for practical utility.
4. Some of the important freight system performance functions suffer from lack of complete data. Closing such data gaps is another challenge. As the National Cooperative Freight Research Program (NCFRP) report 10 notes, “Systematic data regarding multimodal performance measures are practically nonexistent” *(18)*.
5. Some of the measures should be made more scalable to facilitate comparison across systems of varying sizes and complexity.
6. Complete data, including information about the commodity being carried, origin-destination, route, its weight and total value are difficult to obtain. Availability of such “perfect” data can make multi-modal freight performance measurement very efficient, informative and effective.

**CHARACTERISTICS OF AN EFFICIENT FREIGHT MULTIMODAL PERFORMANCE MEASUREMENT SYSTEM**

1. Performance measures should be user-oriented and sensitive to stakeholder needs and goals. The diverse users of any freight transportation system include industry, investors and the public (which uses the freight system and is affected by its externalities directly or indirectly).
2. The measures should be applicable to a combination of modes (intermodal connections), not to only one or a few selected modes. Using travel time-based mobility and reliability measures, and indices like the travel time index and planning time index address this challenge to a great extent. Similar metrics are desirable for measures such as safety which currently has different metrics based on mode.
3. At the macroscopic level of the transportation system, the freight performance measurement should be made more systematic to include all the contributing factors while avoiding double counting.
4. The metric should be quantitative and cost efficient to measure, track and update.

## CONCLUSIONS

Performance measurement in freight transportation helps better investment decision-making and assessment of operation of the system. Because the complete freight system comprises several modes, nodes and links, and each mode has slightly unique transportation characteristics and problems, devising a comprehensive measurement system that considers all modes involved and their intermodal connections is a challenge. Also, the weights assigned to several performance metrics for investment and performance measurement purposes depend on the priorities and long-term vision of respective agencies, their stakeholders, and decision-making bodies.

Overall, some freight multimodal performance measures have been identified and described here, most of which are consistently used by several planning organizations and state DOTs. These performance measure areas include mobility, travel time reliability, safety, environmental stewardship, cost efficiency and economic growth. These aspects have been briefly defined and some currently used key metrics for each of these have been discussed.

Integrating, tracking and updating performance measures based on multimodal data for evaluation is one of the major challenges because the freight data sets are maintained by different organizations independently. Also, freight performance measures should be made applicable to all modes involved and scalable to systems of varied size and complexity. Using mobility and reliability measures based on travel time helps fulfils some of these requirements.

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