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Benchmarking Transportation Safety Performance via Shift-Share Approaches

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Benchmarking Transportation Safety Performance via Shift-Share Approaches

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The measurement of safety performance is a critical task for transportation agencies to monitor the quality of services and evaluate operation efficiency. This article presents and compares safety performance between and among four passenger transportation modes in the United States—highway, transit, railroad, and aviation—using national data from 2002 through 2010. The research utilizes data collected and reported by transportation agencies to meet federal reporting requirements and does not involve the collection of additional data. After a brief review and comparison of transportation-safety performance definitions, the authors evaluate three different types of metrics: number, ratio, and rate, which are applied to all four modes. This article highlights the approach used to compare the share of fatalities/injuries of a particular mode to its share of personal (for highway mode) or passenger (for transit, rail, and aviation) miles traveled compared to the overall multimodal passenger transportation systems. The “shift-share” method is a viable approach to achieve consistent apples-to-apples comparisons. The study shows that aviation and rail are the safest modes for travel between cities, and transit is safer than automobiles for local travel.

Keywords safety performance comparison, accidents, shift share, intermodal comparison

1. Introduction

Public transportation, such as bus, light rail transit, or subway, often carries a large number of patrons. When an accident occurs in transit systems, it often garners high-level attention and long-lasting impact. For example, the New Jersey Transit (NJ Transit) train derailment in Penn Station, New York, in August 2011, not only occupied the front pages of the local newspapers in the tri-state area but also accumulated a large number of web posts (Star-Ledger Staff, 2011). No injuries resulted from the NJ Transit derailment at the height of the morning rush hour on the nation’s busiest rail corridors, but the incident created a commuting nightmare as it also affected AMTRAK and LIRR riders. On the other end of
the spectrum, more than 33 thousand people were killed in motor vehicle crashes in 2009 alone, an average of 93 people each day or one every 16 min. In comparison, the combined fatalities of railroad and transit together are 938 in the same year.

Despite the much safer performance, public transit has not been cast in a positive light when it comes to safety measures. When compared to other modes, particularly automobiles, the safety performance of public transportation is often distorted due to inadequate unit conversions or calculation bases. The criteria and measures used in the current statistics often result in an “apples-to-oranges” comparison. This arises, in part, because of the differences in how safety performance is defined and measured among transportation modes and because of the inherent differences in the operating environments of the different modes.

In addition, some of the comparisons of aggregate national safety statistics and performance measures of different transportation modes can be misleading and may, in fact, distort the safety performance record of a particular mode.

The disparity between the safety performance and public perceptions of various transportation modes may have hampered the viability of transit services. Given the discrepancies and misperceptions of existing safety performance measures, the public transit industry is in an urgent need of recognizing, addressing, and improving a safety performance comparison among transportation modes. To develop near-term, practical solutions to existing problems, the authors have conducted comprehensive evaluations of safety performance definitions, metrics, and approaches used by all four modes: highway, transit, railroad, and aviation. This article highlights the “shift-share” approach to benchmark transportation-safety measures and compares the safety performance among different passenger transportation modes.

2. Literature Review

Our literature search has revealed uneven coverage of the safety performance measures and research. That is, there is a large number of research papers, data sources, and methodologies for highway safety/crash analyses, yet very limited research and data sources exist for transit safety performance measures.

2.1. Key Factors that Affect Accident Rates or Injury Severity

Many researchers have focused their attention on various factors such as roadway design, weather, time of day or week, and drivers’ demographic, social economic, health, or mental status. For example, Abdel-Aty, Ekram, Huang, and Choi (2011) studied crashes related to visibility obstruction due to fog and smoke. Chen and Chen (2011) evaluated the injury severity of truck drivers in single and multivehicle accidents on rural highways.

In the areas of transit safety research, most authors have focused their attention on particular programs (Hau, 2012), certain types of equipment (Read et al., 2011), and particular groups of riders (Marin-Lamellet, 2011). There is very limited comparison among system metrics, such as operating environments, risk exposures, types of operations, or technologies, not to mention various submodes under the general category of public transportation.

2.2. Data Source and Method Evaluation

A limited number of studies has evaluated different types of data sources and documented their applications in evaluating crash injuries. For example, Tarco and Azam (2011)
evaluated the selectivity bias using linked police–hospital data in pedestrian injury analyses. Others (Savolainer, Mannering, Lord, & Quddus, 2011) have evaluated methodologies, such as multilevel mixed-effects regression models, disaggregated level injury severity, and data envelopment analysis.

Containing a large amount of accident data, highway safety research has used various complex models and analysis methods, such as negative binomial Lindeley distribution (Lord & Geedipally, 2011), Bayesian hierarchical approach (Ahmed, Huang, Abdel-Aty, & Guevara, 2011; Schultz, Thurgood, Olsen and Reese, 2010), or joint-probability approach (Pei, Wong, & Sze, 2011). Similar approaches have been extended to bus mode using Motor Carrier Management Information System (MCMIS) data (Blower & Matteson, 2010; Strathman, Wachana, & Callas, 2010) but not to other transit modes, such as rail or ferry, most likely due to the nonexistence of similar data.

2.3. System Comparison

A few studies (Haji, 2005) suggested a set of methodologies to combine different indicators of road safety into a single index. For example, the Road Safety Design Index (RSDI) is a simple and quick composite index, which may become a significant measurement in comparing, ranking, and determining road safety levels in different countries and regions worldwide. Other studies have initiated the process to develop safety performance functions using reliability-based risk measures (Ibrahim & Sayed, 2011) or performance-based track geometry inspection (Li et al., 2004). However, the comparison or system evaluation is not extended to multimodal systems, such as highway and rail or highway and air.

A recent study (Jasmin & Liu, 2013) focused the comparison of safety performance measures between subway and light rail transit (LRT) modes at the national aggregations. Starting with clear definitions of each safety category, the authors analyzed the safety data from the National Transit Database in recent years to estimate the impact and implications of various safety performance measures. A series of comparisons between LRT and subway in various fatality, injury, and property damage categories demonstrated that accident rates may be unstable and easily distorted when the operational base is small. With increased operations, the accident rate may become more predictable even if the simple numbers of accidents/incidents may still appear random.

3. Safety Performance Definitions

The objective of this research is to develop an approach for meaningful comparison of safety performance metrics between and among passenger transportation modes. To accomplish that objective, the first step was to examine the similarities and differences among definitions and terms used to measure safety performance for various passenger transportation modes.

Based on a review of published journal papers, research reports, and ongoing projects, as well as an examination of various data sources, the following key safety concepts and terms were defined, highlighting similarities and differences for different modes:

- accident/incident
- fatality
- injury
- property damage

As highlighted in Table 1, the definitions of accident, fatality, injury, and property damage vary among different transportation modes. Of these, accident and fatality show
Table 1
Highlight of key definitions by passenger modes

<table>
<thead>
<tr>
<th>Modes/Definition</th>
<th>Highway</th>
<th>Transit</th>
<th>Railroad</th>
<th>Aviation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accident/Incident/Crash</strong></td>
<td>Occurrence that produces unintended injury, death, or property damage</td>
<td>A moving vehicle collision with a vehicle, object, or person (except suicides) and derailment/leaving roadway</td>
<td>Operation of a railroad resulting in death, injury, or reportable damages</td>
<td>Fatal or serious injury to any person (occupant or non-occupant) or substantial damage to aircraft as a result of the operation of an aircraft</td>
</tr>
<tr>
<td><strong>Fatality</strong></td>
<td>Death within 30 days</td>
<td>Death within 30 days</td>
<td>Death within 30 days for passengers or 365 days for employees</td>
<td>Death within 30 days (7 days until 2006)</td>
</tr>
<tr>
<td><strong>Injury</strong></td>
<td>Medical treatment away from the scene</td>
<td>Medical attention away from the scene</td>
<td>Medical treatment</td>
<td>Hospitalization for more than 48 h, bone fracture, internal organ damage, or second- or third-degree burn</td>
</tr>
<tr>
<td><strong>Property damage</strong></td>
<td>Varies by state: $500 to $1,500</td>
<td>&gt; $25,000</td>
<td>&gt; $9,200 (adjusted periodically)</td>
<td>Total or partial destruction, impairment</td>
</tr>
</tbody>
</table>
the most commonality. The most consistent definition is fatality: death as a result of operating in the respective mode of transportation within 30 days of the accident. The diverse definitions of injury and the wide range of reportable thresholds for property damage make comparisons difficult for those two measures among modes. Therefore, this research does not compare injury and property damage beyond their definitions.

One common thread observed in the definition of the accident/incident is the “in action” characteristics. For example, the Federal Motor Carrier Safety Administration (FMCSA; FMCSA, 2011) reported “commercial motor vehicle operating on a public road,” Federal Transit Administration (FTA) defines a “moving vehicle,” Federal Rail Administration (FRA) indicates “on-track equipment,” and aviation concerns itself with aircraft in flight. Although most modal administrations use accident and incident interchangeably, FRA defined train incident as any event involving the movement of on-track equipment that results in a reportable casualty but does not cause reportable damage above the current threshold established for train accidents. The differences among modes lie in the thresholds for reporting and may be altered by the requirements for reporting to various agencies or institutions.

4. Safety Performance Comparison

The measurement of safety performance is essential, as it shows the efficiency and robustness of operations of each mode. Meaningful performance indicators are needed to measure the safety performance of each mode and compare the safety performance between and among transportation modes. This section (1) presents safety performance measures used by highways, transit, railroad, and airplanes and (2) compares safety performance between and among modes that transport people. This research used data and information that are currently being collected and reported for the various transportation modes; it did not require the collection of new or different data or information.

Although there are many safety performance measures, in general they belong to one of three categories: a number; a ratio, share, or percentage; or a rate. The following section presents the disparity in numbers for each mode and the proposed shift-share approach to benchmark multimodal transportation safety measures using personal miles travelled (PMT) for highway mode and passenger miles travelled for transit, rail and aviation mode, as the base.

4.1. Disparity in Numbers

The simplest safety performance measure is a number, which is the sum, count, or aggregate of safety performances—for example, the total number of crashes in the United States in 2011 or the total number of transit injuries in the past decade. An important starting point for the comparison of the safety performance of different transportation modes is to present and compare the annual total number of accidents and fatalities experienced by each mode.

As shown in Figure 1, the total number of accidents and fatalities for the four passenger modes is dramatically different. Most accidents occur on the highways—an average of six million per year from 2002 to 2010. Aviation has the smallest number, with annual accidents in the double digits. Passenger railroad has the second-smallest number of accidents: in the hundreds each year. The total number of accidents for transit is higher than aviation and railroad but much lower than highways.

Figure 2 shows that the total number of fatalities for the four passenger modes follows a similar pattern. That is, highway has the most, aviation the least, and railroad and transit fall in the middle. The past decade shows a clear downward trend in highway fatalities.
Starting at 43,000 in 2002, the total annual highway fatalities dropped below 40,000 in 2008 and below 33,000 in 2010; the annual average number of highway fatalities is about 40,000 for the period 2002–2010. Passenger railroad has the lowest annual fatalities, in the single digits for most years except 2005. The total annual fatalities for commercial airlines...
are generally in the double digits but also can be zero, as in 2002, 2007, 2008, and 2010. The total annual fatalities for transit are in the hundreds, with an average of 188 per year.

4.2. Misrepresentation of Rates

Among the many rate-based measures for quantifying and ranking safety on the roadways, most states use the following:

- Crash rate: number of crashes per 100 million vehicle miles travelled (MVMT)
- Severity rate: number of weighted crashes, by severity, per 100 MVMT
- Critical severity rate: ratio of severity rate per stretch of roadway to all crash severity rates occurring in the same roadway functional class.

The most common indicators used to measure highway safety on an annual basis are:

- Fatalities per 100 MVMT
- Fatalities per 100,000 population
- Fatalities per 100,000 registered vehicles
- Fatalities per 100,000 licensed drivers.

Safety performance measures based on MVMT work fine when compared within the highway modes or when applied to the severity of various accidents. However, MVMT become problematic when comparing highway and transit, trains, and airplanes due to the obvious differences in the capacities of the various vehicles. Since the focus of this research is on passenger transport, passenger or PMT converts different sizes of vehicles, trains, and airplanes into a uniform measure, making it a better parameter for reflecting the efficiency of each mode in moving passengers.

As presented in Figure 3, the numbers of accidents per 100 MPMT for all passenger modes vary. The accident rates for highway remain the highest, consistently above 100 crashes per 100 MPMT. The accident rates for aviation remain the lowest, at fewer than 10 per 100 billion PMT (BPMT).

![Figure 3](image-url)
Figure 4. Fatalities per 100 million passenger mile traveled (MPMT) for different modes, 2002–2010.

Equipped with safety performance measures using the same base unit, 100 MPMT, for different modes, the authors were able to derive an apples-to-apples comparison of accidents and fatalities for highway, transit, railroad, and aviation. As shown in Figure 4, the fatality rates per 100 MPMT vary significantly among passenger modes, even if the numbers within each mode remain fairly consistent over time. That is, the highway fatality rates were the highest and commercial air carriers the lowest. Fatality rates for railroad fluctuate from year to year due to their small numbers; still, the rates are generally low, similar to aviation’s. The fatality rates for transit fall between those ranges, higher than aviation and railroad but much lower than highway.

4.3. True Pictures of Ratio, Share, or Percentage Measures

Another way to measure the safety performance of a transportation mode is to use a ratio, share, or percentage, which defines the proportional relationship among various safety performance metrics. Using existing data collected for all four modes, this research derived the accident share, fatality share, and PMT share of each mode. An apples-to-apples comparison can be accomplished by using PMT shares as a benchmark.

Pooling the average annual accidents occurring from 2002 to 2010 for the four passenger transportation modes, the research identified the proportion or share of accidents attributed to each mode. As demonstrated in Figure 5a, the predominant portion of all the passenger accidents occurred on the highways, 99.61%, and the smallest share in aviation, at 0.001%. Transit represented 0.39% and rail 0.003% of all accidents.

Similarly, as shown in Figure 5b, the highway share of total passenger transportation fatalities was the highest, at 99.48% for 2002 to 2010. A slight change in rank is the switch between railroad and aviation, that is, railroad has the smallest share of fatalities among all four passenger modes, at 0.02%, whereas aviation has the second-smallest share for fatalities, 0.04%. Again, the transit share of total fatalities, at 0.47%, was slightly higher than the shares of aviation (0.04%) and railroad (0.02%) but much lower than that of highway (99.48%).

As shown in Figure 5c, the highway share of PMT was 85% of total PMT in the United States. Aviation accounted for the second most PMT, with a share of 14%. Transit carried 0.72% and rail just 0.27% of the total PMT during the period 2002 to 2010.
Figure 5. Average annual accident and passenger miles travelled (PMT) shares by passenger modes, 2002–2010. Data source: Bureau of Transportation Statistics (2012b).
5. Benchmarking Safety Performance with PMT

To accomplish the apples-to-apples comparisons of safety performance among passenger modes, the research compared the shares of PMT to the shares of accidents and fatalities as shown in Table 2.

Highway represents 85% of PMT but contributes 99.61% of accidents and 99.48% of fatalities. The accident share for highway is 14.2 percentage points higher than its PMT share. The fatality share for highway is 14 percentage points higher than its PMT share.

Transit represents 0.72% of PMT while contributing to 0.39% of accidents and 0.47% of fatalities. The accident share for transit is 0.33 percentage points lower than its PMT share. The fatality share for transit is 0.25 percentage points lower than its PMT share.

Railroad represents 0.27% of PMT while accounting for 0.003% of accidents and 0.02% of fatalities. Both the accident and fatality shares of railroad are about 0.25 percentage points lower than its PMT share.

Aviation represents 14% of PMT but contributes to only 0.001% of accidents and 0.04% fatalities. Accident and fatality shares for aviation are much lower than its PMT share. The differences are around 13.6 and 13.5 percentage points for accident and fatality, respectively.

Another way to present this information is through a benchmarking process, which was derived by applying a “shift-share” analysis technique often used in economics (Berke, Godschalk, Kaiser, & Rodriguez, 2006). Borrowing the shift-share concept, this research took PMT shares of different passenger transportation modes as the basic, or constant, shares. If all modes are equally safe, then the accident and fatality shares of each mode should be similar or equivalent to its share of PMT. The difference between the basic share (PMT share) and shift share (accident or fatality share) is called the “shift term” and can be used to compare the safety performances of the different modes. A positive shift term indicates that this particular mode contributes more than its fair share of accidents or deaths. A negative shift term means that the mode contributes fewer accidents and fatalities than its fair share measured in PMT.

As shown in Figure 6, highway is the only mode that has a higher share of accidents and fatalities than its share of PMT. Aviation is the safest mode, as its accident and fatality shares are much lower than its PMT share. Similarly, transit and rail

![Figure 6](Benchmarking safety performance with passenger miles travelled (PMT).)

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<table>
<thead>
<tr>
<th>Mode</th>
<th>PMT Share</th>
<th>Compared to PMT</th>
<th>Accident Share</th>
<th>Compared to PMT</th>
<th>Fatality Share</th>
<th>Compared to PMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highway</td>
<td>85.4%</td>
<td>—</td>
<td>99.6%</td>
<td>14.2%</td>
<td>99.5%</td>
<td>14.0%</td>
</tr>
<tr>
<td>Transit</td>
<td>0.72%</td>
<td>—</td>
<td>0.39%</td>
<td>−0.33%</td>
<td>0.47%</td>
<td>−0.25%</td>
</tr>
<tr>
<td>Railroad</td>
<td>0.274%</td>
<td>—</td>
<td>0.003%</td>
<td>−0.27%</td>
<td>0.015%</td>
<td>−0.26%</td>
</tr>
<tr>
<td>Aviation</td>
<td>13.574%</td>
<td>—</td>
<td>0.001%</td>
<td>−13.6%</td>
<td>0.039%</td>
<td>−13.5%</td>
</tr>
</tbody>
</table>
are much safer than highway; their accident and fatality shares are less than their PMT shares.

6. Summary

To accomplish the goal of apples-to-apples comparisons of the transportation safety performance between and among passenger transportation modes, this research reviewed the definitions of safety variables by different modes and evaluated a number of data sources in detail. This investigation helps to answer questions such as “Who collects and reports safety-related data by mode?” and “How readily available or accessible are safety-related data?”

The researchers investigated three different ways to compare the safety performance of four passenger transportation modes: highway, transit, railroad, and aviation. After comparing the accidents and fatalities of these modes using the total numbers, ratio or shares, and rates based on 100 MPMT of each mode, the researchers concluded that accident and fatality rates based on 100 MPMT afford the most consistent platform for apples-to-apples comparisons. The “shift-share” method is presented here to highlight and stimulate alternative approaches in evaluating and comparing the safety performance of different passenger transportation modes.

The comparisons of safety performance during 2002 to 2010 for highway, transit, railroad, and aviation were presented in the report using easy-to-interpret tables and figures. The key conclusions from the safety performance comparisons are highlighted below.

- Highway is the least safe travel alternative for passengers: On average, there were about six million highway accidents and more than 40,000 deaths per year. The highway accidents and fatalities accounted for more than 99% of the accidents and fatalities of all passenger transportation modes. Because highway travel represented 85% of the PMT by all four passenger modes, its shares of accidents and fatalities were much higher than its share of PMT. On average there were 128 accidents and 0.85 fatalities every 100 MPMT along the U.S. highways. These were the highest rates of accidents and fatalities of any passenger mode.

- Transit is far safer than highway travel but less safe than railroad and airline travel for passengers: Although on average there were more than 23,000 annual accidents and 188 annual fatalities by transit, this represented only 0.39% of the total annual accidents and 0.47% of the total annual fatalities by all passenger modes. Transit was safer because its share of PMT, 0.72%, was much higher than its share of accidents and fatalities of all passenger modes. On average, there were 57 accidents and 0.54 fatalities for 100 MPMT by transit in the United States.

- Railroad is one of the safest modes of passenger travel: Between 2002 and 2010 there were on average 207 accidents and only six fatalities per year on passenger railroad, which includes commuter rails and AMTRAK. The railroad shares of total accidents and fatalities of all passenger transportation modes were 0.003% and 0.02%, respectively. Railroad was one of the safest modes because its share of PMT—0.27% of the total PMT by all passenger modes—was much higher than its shares of accidents and fatalities. On average there were 1.5 accidents and 0.04 fatalities for 100 MPMT by passenger railroad in the United States.

- Aviation is the safest mode of all passenger travels: Between 2002 and 2010, there were on average 35 accidents and 16 fatalities per year by U.S. commercial airlines
involving passengers. This represented only 0.001% of the total passenger accidents and 0.04% of the total passenger fatalities by all passenger modes. Aviation was the safest mode because the aviation represented 14% of the total PMT by all passenger modes. The aviation share of PMT is much higher than its shares of accidents and fatalities. On average, there were only 0.005 accidents and 0.002 fatalities for 100 MPMT by airplanes in the United States.

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