Project # C-07-10

BRIDGE VEHICLE IMPACT ASSESSMENT

Task 1: Problem Background Investigation
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1.1 INTRODUCTION

Bridges in New York State are experiencing close to 200 bridge hits a year. From the analysis of bridge hits data provided by the NYSDOT, it has been observed that these accidents could be attributed to numerous factors, including improperly stored equipment on trucks, violation of vehicle posting signs, illegal commercial vehicles on parkways, etc. According to the Federal Highway Administration (FHWA), over 600,000 bridges are registered in the National Bridge Inventory (NBI). By a wide margin, most bridges that collapse do so during floods. Overweight vehicles, usually crossing a bridge in violation of posted weight limits, are the second biggest cause of bridge collapses. According to Federal Highway Administration, a 3rd leading cause of bridge failure or collapse is collision damage when a vehicle or a vessel hits a bridge.

Impact of vehicles with bridge components may result in failure of the bridge system and loss of lives. A tractor cargo-tank semitrailer loaded with 9,200 gallons of propane (a liquefied petroleum gas) drifted across the left lane onto the left shoulder, struck the guardrail and the tank hit a column of the Grant Avenue overpass over Interstate 287 on July 27, 1994 in White Plains, New York. During this accident, the driver was killed, 23 people were injured, and an area with a radius of approximately 400 feet was engulfed by fire. According to the National Transportation Safety Board (NTSB), the design of the highway geometries and appurtenances, which did not accommodate an errant vehicle, were contributing factors, in addition to the driver fatigue [HAR9502 (1994)]. The Alexandria Avenue bridge on George Washington Memorial Parkway in Alexandria, Virginia was hit by a 58-passenger motorcoach on November 14, 2004, even though there were low vertical clearance warning signs indicating that the bridge had a 10-foot, 2-inch clearance in the right lane. Of the 27 student passengers, 10 received minor injuries and 1 sustained serious injuries. The National Transportation Safety Board determined that the probable cause of this accident was the bus driver’s failure to notice and respond to posted low clearance warning signs due to cognitive distraction resulting from conversing on a hands-free cellular telephone while driving [HAR0604 (2004)]. A bridge on I-80 route in Big Springs, Nebraska failed when a bridge pier was struck by an errant truck on May 23, 2003 [ENR (2003)]. One person was killed and the Memorial Day traffic was severely disrupted because of the accident. In 1996, an unknown overheight vehicle struck the center span of a 3-span prestressed concrete (P/C) bridge carrying I-680 over County Road L34 near Beebeetown, Iowa [Russo et al (2003)]. Due to concerns about the remaining strength of the two most severely damaged beams, unknown effect of the damage on the load distribution patterns in the remaining structure, and concerns regarding the durability and effectiveness of any proposed repair, the beams were replaced. Above examples highlight the significant risk to highway bridges and motorists using them from vehicular collisions.

1.2 LITERATURE REVIEW

Although bridge collisions have been a common occurrence, few studies have focused on systematic investigation on causes of occurrence and mitigation approaches. The most prominent research study on collision of overheight vehicles with bridges has been by Fu (2001) and Fu et al. (2003). This study quantifies the problem of over-height vehicle collision using bridge collision data for bridges in Maryland. Fu (2001) and Fu et al. (2003) found that 1,496
bridges were susceptible to over-height vehicle collision out of the total Maryland Bridge Inventory of 5,056 structures. It has been observed that the frequency of overheight accidents reported in Maryland increased by 81% between 1995 and 2000, as shown in Figure 1. Figure 2 compares the number of bridge hits recorded in Maryland as they relate to vertical clearance. It is observed that the bridge hits frequency has peaks at 14.5 and 16.5 feet. Above 16.5 feet, the number of bridges struck drops off sharply. The two distinct peaks in Figure 2 indicate the existence of two different populations of bridges: those designed for a standard vertical clearance around 14.5 feet, and those designed for a clearance around 16.5 feet. In order to study this trend, Fu (2001) studied bridges hit by separating them into two groups: those crossing Interstate, U.S., and Maryland routes; and those crossing County, Municipal, or other routes. They found that typically the bridges with 16.5 foot of vertical clearance were constructed over the Interstates and State routes, while the bridges with 14.5 foot of vertical clearance were more commonly constructed over local roads. Of the 1496 bridges susceptible to impact by overheight vehicles statewide, 309 (20%) have been struck. Scrapes were sustained by 144 of these damaged bridges, minor damage was sustained by 107 bridges, and 58 required considerable repair. Figure 3 shows frequency of bridges hits for different vertical clearances and damages. It is observed that the maximum number of bridges requiring repairs also had vertical clearances of 14.5 feet and 16.5 feet.

Figure 1: Frequency of Recorded Bridge Hits in Maryland From 1995 to 2000.
Figure 2: Frequency of Recorded Bridges Hit as Related to Vertical Clearance.

Figure 3: Frequency of Recorded Bridge Hits as Related to Vertical Clearance and Damage Extent.

Fu (2001) also carried out a detailed survey of 29 states on the severity of the bridge hit problem. The state survey shows that 19 states (out of 29 responding) consider overheight collisions to be a significant problem. However, very few states collect data on the bridge hits. Figure 4 shows the map of USA with states considering overheight collision a serious problem shown by red (dark shading), and states not considering overheight collision a problem by green.
It is observed that the states considering overheight collision a problem are: California, New Mexico, Texas, Louisiana, Mississippi, Florida, Georgia, Ohio, Kentucky, Indiana, New York, New Jersey, Maryland, Delaware, Illinois, Iowa, Alaska, Hawaii and Maine.

The nationwide survey by Fu (2001) has documented many observations that are important for the bridge hits problem in New York. These observations are:

- Standard bridge clearances on the National Network\(^1\) range from 16 to 17 feet. Standard clearances range from 14 to 17 feet on bridges off the National Network.
- Some states post the actual vertical clearance on warning signs, while other states under-report the clearance by up to twelve inches. For example, New York State posts at 1 feet under when the bridge has a vertical clearance less than 14 feet. This can have negative effects as truckers are likely to ignore clearance signs knowing that clearance are under-reported, depending on the state.
- Most states allow vehicle heights up to 13.5 feet without a permit; a few states allow up to 14.5 feet.
- There is a wide disparity in penalties for overheight violations, with fines ranging from $20 to $1000 between different states.
- Although 17 states maintain records on overheight collisions, only 6 states maintain computerized records. States with a maximum number of overheight collisions (California, Connecticut and Illinois) are among those that maintain computerized records.

\(^1\) The National Network includes Interstate Highways and sections of the Federal-Aid Primary System on which large dimension trucks designated under the Surface Transportation Assistance Act (STAA) are authorized to travel.
18 states out of 29 responding to the survey (62%) feel that overheight collisions are a significant problem, 11 out of 29 states (38%) do not.

On specific actions taken by each state to reduce the frequency of overheight collisions, nine states (31%) reported installing more signs posting clearances on or in advance of bridges. Most felt that these were effective in reducing accidents. Seven states (24%) responded that they had increased vertical clearances by grinding pavement or raising overpasses, and that this was very effective in reducing overheight collisions. In fact, Georgia has a program in place to raise all existing Interstate bridges to clearances over 16’ 6”. Only three states use overheight detection systems.

Hilton (1973) investigated general accidents involving highway bridges in Virginia to characterize bridges that had been the scene of frequent accidents. “Inadequate vertical clearance” was listed as a key contributing factor. Shanafelt and Horn (1980) reported on damage evaluation and repair methods for prestressed concrete bridge members through a countrywide survey. In response to the survey, state bridge engineers listed overheight loads as the leading cause of damages (81%) to prestressed concrete bridges. Other causes were overweight loads, fire, salt, and water freezing. Shanafelt and Horn (1984) released a similar report on damaged steel bridge members over a 5 year period. They found that 95% of damaged steel bridges were caused by overheight vehicles.

A study by the University of Kentucky in 1990 [Harik et al (1990)] analyzed U. S. bridge failures over a 38 year period (1951-1988). Each collapse was classified by its cause. Of the 79 bridge failures considered in the study, 11 were precipitated by truck collisions (14%).

Some states have recorded a significant rise in the frequency of bridges being hit by overheight vehicles. In 1988, the Michigan Department of Transportation reported a 36% increase in overheight collisions over a one year period [MRC (1988)]. The Mississippi State Highway Department installed overheight warning systems on some rural bridges after an increase in bridge damage by overheight logging trucks [Hanchey and Exley (1990)]. A 1992 study by the Texas Department of Transportation [Feldman et al (1998)] revealed a rise in the occurrence of overheight impact damage to prestressed concrete bridges. They have developed guidelines for assessing the degree of impact damage to prestressed concrete bridge girders and developing repair procedures. These guidelines are drawn from case studies of prestressed concrete bridges damaged by overheight vehicles in Texas. Of the damaged girders inspected, 61% were assessed as having minor damage, defined as isolated cracks, nicks, shallow spalls, or scrapes. Moderate damage, defined as cracks or spalls large enough to expose undamaged prestressing tendons, was found in 25% of the girders. Severe damage, consisting of damaged tendons, significant concrete section loss, or lateral misalignment, made up the remaining 14% of bridges.

Bedi (2000) has examined the reduction in load-carrying capacity of a wide-flange steel girder distorted by a vehicle impact. The girder was modeled with a finite element analysis program. Typical impact damage was simulated by imparting a lateral deformation to the lower half of the cross section. The deflection under vertical loading was compared to that of the undistorted cross section. Under loading, the deformed section underwent further distortion and tended to twist. It was found that the reduction in strength was more than double of that predicted by the section properties alone. These results suggest that the damage to steel girders struck by overheight vehicles may be more severe than previously thought.
El-Tawil et al (2004) performed inelastic transient finite element simulations to investigate the demands generated during collisions between vehicles and bridge piers. Two different bridge/pier systems were used in the simulations. The approach speeds for the trucks range from 55 to 135 kph. Their simulation results show that current collision design provisions could be unconservative and there may be a population of bridge piers that are vulnerable to collapse because of accidental or malicious impact by heavy trucks.

Damages to railway bridges by vehicles passing under such bridges have been investigated extensively in the United Kingdom. Martin and Mitchell (2004) have carried out extensive investigation of various factors leading to vehicular collisions at bridges owned by “National Rail” and developed measures to reduce such damages. Their detailed investigation has identified three main causes of bridge hits in the U.K.:
- Drivers not knowing the height of their vehicles/cargo
- Lack of provisions of alternative routes around low bridges, and lack of planning of routes by haulers
- Inadequate signing at and on the approach to low bridges

In addition to the causes cited above, they have also identified several other factors contributing to bridge strike (hits) in the United Kingdom, including lack of signs, distraction, positioning of signs, driver cognizance and bumpy road conditions. They have observed that almost 75% of the hits occur at plate girder bridges. They have investigated and proposed several approaches to reduce bridge strikes, such as:
- Driver education
- Accurate vehicle height measurements
- Alternative route symbols
- Infra-red detection systems
- Database of low bridges
- Enforcement cameras
- Driver training and behavior observation by simulation
- In-cab alerting systems (GPS)
- Improvement in signing

Horberry et al. (2002) have experimentally evaluated a new design of markings for low bridges to prevent bridge hits. In order to carry out the study, they constructed a full size bridge capable of having its overhead clearance adjusted. Subjects (test divers) sat in a truck cab as it drove towards the bridge and were asked to judge whether the vehicle could pass safely under the bridge. The objective of their study was to investigate the effectiveness of new markings versus old markings\(^2\) (See Fig. 5) in preventing a truck impacting a bridge. In their experiment, they measured the effectiveness by asking the subject drivers at 100 m, 30 m and 8 m from the bridges with two markings whether they would safely cross under the bridge or not. Figure 6 shows the outcome of the study. In Figure 6, A, B and C represent decision making by the drivers at distances 100 m, 30 m and 8 m. The mean score of 1 represents that the drivers thought they will definitely hit the bridges. It is observed from Fig. 6 that the new markings helped drivers achieve scores closer to 1 than those by the old markings. Hence, the type of bridge marking influenced the level of caution associated with decisions regarding bridge navigation, with the new marking design producing the most cautious decisions at all distances.

\(^2\) These markings aren’t in the Federal MUTCD and are commonly used in the United Kingdom.
away from the bridge structure. Additionally, the distance before the bridge at which decisions were given had an effect on the level of caution associated with decisions regarding bridge navigation (the closer to the bridge, the more cautious the decisions became, irrespective of the marking design).

![Design of Markings Used in Experimental Study by Horberry et al. (2002); (a) Old Marking, (b) New Marking.](image1)

Figure 5: Design of Markings Used in Experimental Study by Horberry et al. (2002); (a) Old Marking, (b) New Marking.

![Effects of Two Markings in Decision about Bridge Heights from 100 m (Case A), 30 m (Case B) and 8m (Case C).](image2)

Figure 6: Effects of Two Markings in Decision about Bridge Heights from 100 m (Case A), 30 m (Case B) and 8m (Case C).

Mattingly (2003) has investigated the use of overheight warning systems to mitigate overheight vehicle crashes into bridges through a nationwide survey of State DOTs. The prime focus of the survey has been on early warning detection warning systems (EWDS), e.g., laser systems, infrared systems, etc. Out of forty-nine State DOTs surveyed, 29 State DOTs responded to the survey. Thirty-eight percent of the responding states (i.e., 11 states) indicated the use of EWDS. Table 1 below shows types of EWDS used by these 11 states, their manufacturers and initial costs. Although there is a lack of definitive effectiveness of EWDS based on this survey, the use of these devices certainly results in reduction of bridge hits. Figure 7 shows the perception on overall effectiveness of EWDS based on survey results in Table 1. It is observed from Figure 7 that eight out of eleven states using EWDS believe their systems reduce overheight vehicles striking bridge components. Among three states reporting “slight reduction” in 4th column of Table 1, two states actually used passive systems (chains or headache bar). Based on this survey, laser and infrared systems appear to successfully reduce bridge impacts. However, these systems still suffer from operational issues. For example, DOTs experience false detections from antennas, debris, birds, and snow deposits on the top of trucks. Additionally, some DOTs experience hunters sighting their weapons on receivers (aiming and/or
shooting the receivers), and occasionally the laser moves and comes out of alignment with the detector. The one state that used battery power for its system encountered significant problems. However, states that use laser and infrared detection systems appear to value the reduction in impacts regardless of the small operational difficulties that they experience. Table 2 shows options available to Alaska DOT on various types of EWDS. Later tasks on this project will focus on the use of EWDS and their reliability through more focused vendor surveys, DOT survey and several site visits of states using them.

Table 1: Survey of States by Mattingley (2003) on Early Warning Detection System.

<table>
<thead>
<tr>
<th>State</th>
<th>Manufacturer</th>
<th>WEDS Used</th>
<th>System Affect on Impacts</th>
<th>Initial Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kansas</td>
<td>Elwood</td>
<td>Laser system</td>
<td>Reduction</td>
<td>$500 + labor</td>
</tr>
<tr>
<td>Iowa</td>
<td>In House</td>
<td>Chains</td>
<td>Slight reduction</td>
<td>N/A</td>
</tr>
<tr>
<td>New York</td>
<td>In House</td>
<td>Headache bar</td>
<td>Slight reduction</td>
<td>N/A</td>
</tr>
<tr>
<td>Oregon</td>
<td>IRD</td>
<td>Laser system</td>
<td>Reduction</td>
<td>$32,000</td>
</tr>
<tr>
<td>Idaho</td>
<td>IRD</td>
<td>Laser system</td>
<td>Reduction</td>
<td>$65,000</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>IRD</td>
<td>Laser system</td>
<td>Reduction</td>
<td>Unavailable</td>
</tr>
<tr>
<td>Louisiana</td>
<td>IRD</td>
<td>Laser system</td>
<td>Reduction</td>
<td>Unavailable</td>
</tr>
<tr>
<td>Mississippi</td>
<td>Unavailable</td>
<td>2 EWDS</td>
<td>Slight reduction</td>
<td>Unavailable</td>
</tr>
<tr>
<td>Maryland</td>
<td>Unavailable</td>
<td>Light beam</td>
<td>Reduction</td>
<td>50,000</td>
</tr>
<tr>
<td>California</td>
<td>IRD, Trigg</td>
<td>Laser system</td>
<td>Reduction</td>
<td>10,000-20,000 + Labor</td>
</tr>
</tbody>
</table>

Figure 7: Effectiveness of EWDS through State’s Survey by Mattingly et al. (2003).
Table 2: Comparisons of Options Presented to Alaska DOT to Reduce Bridge Strikes [Mattingly et al. 2003]

<table>
<thead>
<tr>
<th>Solution</th>
<th>Power Req'd</th>
<th>Initial Cost</th>
<th>Assessed Effectiveness</th>
<th>Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warning signs and lights</td>
<td>Yes</td>
<td>Low</td>
<td>Unknown</td>
<td>Unknown</td>
</tr>
<tr>
<td>Passive-rigid</td>
<td>No</td>
<td>Low-Med.</td>
<td>Slight reduction</td>
<td>Possible damage to truck and other nearby vehicles</td>
</tr>
<tr>
<td>Passive-nonrigid</td>
<td>No</td>
<td>$2,25K</td>
<td>Slight reduction</td>
<td>Inaudible over road noise for drivers</td>
</tr>
<tr>
<td>Laser/Infrared w/signs</td>
<td>Yes</td>
<td>$7-70K</td>
<td>Reduction</td>
<td>False positives</td>
</tr>
<tr>
<td>Enforcement/Penalties</td>
<td>No</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Unknown</td>
</tr>
<tr>
<td>Police Escort</td>
<td>No</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Still prone to human error</td>
</tr>
</tbody>
</table>

1.3 REVIEW OF NYSDOT BRIDGE HITS DATABASE

NYSDOT provided a bridge hits database containing information on 1345 reported bridge hits. The database contains the following fields: BIN (Bridge Identification Number), Span, Region, County, Carried Over, Crossed, Date of Collision, Damage, Comments, Collision Class, and Collision Rating. Several of the records only had feature carried over and feature crossed, without any BIN information. The New York State DOT bridge inventory database was used to augment other relevant tables, such as AADT, vertical clearance under, necking, feature carried under, etc. into the bridge hit database so that a detailed study on the effects of different factors on bridge hits could be carried out. Bridge hit data from the New York City region was provided by Dr. Yanev of NYCDOT. This data was integrated with the NYSDOT database to provide a detailed statistical analysis. The database doesn’t include hits on bridges owned by the New York State Thruway Authority. The combined database has a total of 1431 records. The research team also searched the Fatality Analysis Reporting System (FARS) and the Federal Motor Carrier Safety Administration (FMCSA) databases to identify additional information on bridge hits. However, the search of these two databases didn’t yield any new bridge hit data.

A detailed analysis of bridge hits in New York State using this database is presented below.

1.3.1 Bridge Hits by Year

Figure 8 shows a histogram that details the number of reported bridge hits in New York between 1993 and 2008. It is observed from Figure 8 that the number of reported annual bridge hits increased from 69 to 219 during 2001 to 2005, and was steady during 2005 to 2007. The number has declined sharply during 2008 (based on the partial data for 2008). The increase in bridge hits during 2001 to 2005 may be linked to the increased construction activity because of the real estate boom during this period. Increase in bridge hits data may also be attributed to better record keeping practice that NYSDOT started implementing during 2001 to 2005.

1.3.2 Bridge Hits by NYSDOT Regions

Figure 9 shows a GIS map of New York State with the 11 NYSDOT Regions. Bridge hits in

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3 Necking is defined as the difference between curb-to-curb width and the approach width.
each of the Regions are shown as blue dots, as well as number written below the region name. Figure 10 shows the histogram of number of bridge hits by NYSDOT Regions. It is observed from Figure 9 and 10 that Regions 8, 10, 5 and 11 have 641, 267, 179 and 120 bridge hits and these four Regions account for approximately 85.4% of the total bridge hits in the state between 1993 and 2008 periods. In fact, bridge hits in Region 8 (Poughkeepsie) are significantly higher than other Regions because of significant agricultural and commercial activity in the area as well as Region 8’s proximity to New York City. For Regions 8 and 10, there are more bridge hits in areas close to New York City. Similarly, there are more bridge hits near the Canadian border in Region 5.

Figures 11(a) and 11(b) show histograms of bridge hits by NYSDOT Regions with and without parkways. Figure 11(a) show histograms of Regional bridge hits and hits on bridges with parkways under for Regions 4 (Rochester), 5 (Buffalo), 8 (Poughkeepsie), 10 (Hauppauge) and 11 (New York City). It is observed from Figure 11(a) that the presence of parkways contribute significantly to bridge hits. In fact, 196 out of 267 hits in Region 10 are on bridge over parkways. On the other hand, number of hits on bridges in Regions without parkways is significantly lesser with Region 1 (Albany) having 66 hits, as shown in Figure 11(b).

Figures 12(a) and 12(b) show the number of bridges hit multiple times and the total number of multiple hits (i.e., number of bridges hit multiple times multiplied by the number of hits on each bridge) by NYSDOT regions. It is observed that Regions 8, 10 and 5 have 67, 35, & 14 bridges, respectively, that have been hit multiple times. In Region 8, 67 bridges have been impacted a total of 527 times, i.e., the multiple hit per bridge frequency is approximately 7.87. This frequency is 5.66 and 9.93 for Regions 10 and 5, respectively. Higher multiple hit per bridge in Region 8 is attributed to higher number of parkways passing through Region 8.
Figure 9: Number of Reported Bridge Hits in each NYSDOT Region (1993 to 2008).

Figure 10: Number of Recorded Bridge Hits in Each NYSDOT Region during 1995-2008.
Figure 11: Number of Recorded Bridge Hits during 1995-2008 in NYSDOT Regions; (a) Regions with Parkways, (b) Regions Without Parkways.
Figure 12: NYSDOT Multiple Bridge Hit Demographics.
1.3.3 Bridge Hit by County

Figure 13 shows histograms for the number of reported bridge hits by county. Figure 13(a) shows the histogram for all reported bridges hits. It is observed from Figure 13(a) that Westchester County has the maximum number of reported bridge hits and is followed by Nassau, Erie, Suffolk and Rockland counties. Figure 13(b) shows the number of multiple bridge hits by county. Note that a majority of bridge hits recorded in the five counties noted above are a result of bridges being impacted multiple times. In fact, in Westchester, Erie and Nassau counties, 32 bridges have been impacted 595 times (44% of all recorded hits in the New York State) out of a total of 815 bridge hits recorded in these counties (See Figure 13(c)).
1.3.4 Feature Carried on the Bridge

Figure 14 shows a histogram of the number of reported bridge impacts plotted as related to the type of roadway the bridge is over. Note that bridges carrying local roads (County, Town, City, Village) have been subjected to a total of 488 impacts. Bridges carrying state highways had 359 recorded impacts and bridges carrying railroads had 230 recorded impacts.

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Figure 13: Number of Recorded Bridge Hits by County; (a) Considering All Bridges Hits; (b) Considering Multiple Bridge Hits Only; (c) Considering Multiple Bridge Hits by 55 Most Hit Bridges.
1.3.5 Feature Carried Under the Bridge

Figure 15 plots the number of recorded bridge hits as related to the type of roadway the bridge is over. It is observed that, of 1431 recorded bridge hits, 546 hits occurred on bridges over parkways, 322 on bridges over state highways, 139 on bridges over city streets, 137 on bridges over interstates and 137 on bridges over non-navigable waterways. Since trucks are not allowed on parkways, the large number of hits on parkways clearly indicates the presence of unauthorized trucks on parkways. A high number of hits on bridges over state highways and city streets may be a result of many impacts to railroad and other low clearance bridges.

![Figure 15: Number of Bridge Hits by Feature Carried Under the Bridge.](image)

<table>
<thead>
<tr>
<th>Feature Carried Under Codes</th>
<th>Hit Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>State Highway:</td>
<td>121</td>
</tr>
<tr>
<td>Expressway:</td>
<td>42</td>
</tr>
<tr>
<td>Interstate:</td>
<td>18</td>
</tr>
<tr>
<td>Parkway:</td>
<td>20</td>
</tr>
<tr>
<td>County Road:</td>
<td>9</td>
</tr>
<tr>
<td>Town Road:</td>
<td>7</td>
</tr>
<tr>
<td>City Street:</td>
<td>5</td>
</tr>
<tr>
<td>Non-Navigable Waterway:</td>
<td>3</td>
</tr>
</tbody>
</table>

1.3.6 Bridge Hits by Superstructure Design Type

Figure 16 shows the number of reported bridge hits by the superstructure design type. Note that bridges with frame type superstructure have been experiencing the highest number of recorded impacts. A large number of these bridges are over parkways or carry railroad traffic. Other design types that are impacted frequently are rolled beam with multi-girder, plate girder with multi-girder, deck arch with closed spandrel and plate girder-thru with floor beam.

1.3.7 Bridge Hits by Bridge Component Hit

Figure 17 shows components of bridges that are impacted most frequently during recorded bridge hit events. The histogram in Figure 17 is based on limited observed data in the NYSDOT bridge hits database. It is observed that frame and girders are the most frequently hit components, which are similar to those in Figure 16. Deck arch and piers are the next most hit components.
Figure 16: Number of Recorded Bridge Hits as Related to the Superstructure Design Type.

Figure 17: Number of Recorded Bridge Hits as Related to Bridge Element Type (Based On Limited Observations).

1.3.8 Bridge Hits by Maximum Vertical Clearance Under

Figure 18 plots the number of recorded bridge hits as they relate to the maximum vertical clearance under the bridge. Note that a majority of bridge impacts occurred on bridges with a maximum vertical underclearance in the range of 12 to 15 feet with peaks at 13 and 13.5 feet. Several bridges with vertical clearance greater than 15 feet have also been hit. Figure 19 plots the number of bridge hits as they relate to the maximum vertical clearance for bridges hit multiple times. It is observed that the peaks in Figures 18 and 19 are at identical vertical
clearances and the frequencies of hits in Figure 19 are more than 95% of those in Figure 18. This clearly shows that the vertical clearance is one of the most dominant factors responsible for bridges being hit multiple numbers of times. This fact must be accounted for when considering any modifications to the collision vulnerability assessment procedure for bridges in New York.

Figure 18: Maximum Number of Recorded Bridge Hits for the Maximum Vertical Under-Clearance.

Figure 19: Maximum Number of Recorded Bridge Hits for the Maximum Vertical Under-Clearance (Bridges with Multiple Hits).

1.3.9 Bridge Hits by Minimum Vertical Clearance Under

For a highway bridge, minimum vertical clearance is defined as the minimum clearance
between the lowest permanent overhead obstruction and a point on the pavement which is directly below it. Figure 20(a) plots the number of reported bridge hits as they relate to the minimum vertical clearance. Note that the frequency of bridge hits is the most prominent for minimum vertical underclearance less than 15 feet. The largest incident of bridge impacts has been noted at about a minimum vertical clearance of 10.5 feet. Figure 20(b) plots the number of reported bridge hits as they relate to the minimum vertical clearance for bridges that have been hit multiple times. Note that the trend and distribution of hit frequencies in Figure 20(b) are almost the same as those in Figure 20(a). This observation implies that the minimum vertical clearance contributes to the increased risk bridges being hit multiple times.

Figure 20: Number of Recorded Bridge Hits as Related to the Minimum Vertical Clearance: (a) For All Bridge Hits, (b) For Bridges with Multiple Hits.
1.3.10 Bridge Hits by Posted Vertical Clearance Under

Table RC06 of the NYSDOT bridge inventory database provides information on vertical clearance posting for the roadway passing under the bridge. If the roadway is not posted, this item is left blank. Figure 21 plots the number of reported bridge hits for the reported “Posted Vertical Clearance Under”. It is observed that the incidence of bridge hits has been observed to mostly occur mostly for vertical clearances in the range of 9 to 12.5 feet with a peak number amount of impacts between 9 to 10 feet. Based on a recent site visit to bridges in the Buffalo area by the PI, bridges in these clearance ranges seem to be hit multiple times because of their proximity to areas of extensive trucking activity. Most of these bridges are also railroad bridges or bridges over parkways with low vertical clearances.

![Figure 21: Number of Reported Bridge Hits as Related to Minimum Vertical Clearance for Bridges with Multiple Recorded Hits.](image)

1.3.11 Bridge Hits by Vehicle and Cargo Types

Figure 22 plots the number of reported bridge hits as related to the vehicle type. Note that the maximum numbers of hits are caused by trailer and trucks with some accidents caused by construction vehicles. Figure 23 plots the number of reported bridge hits as related to the vehicle cargo type. Vehicles carrying construction equipment, fence posts, garbage and modular homes have been found to be hitting bridges frequently. It should be noted that the histograms are based on a limited number of recorded comments in the NYSDOT bridge hits database.

1.3.12 Bridge Hits and Associated Bridge Safety Assurance (BSA) Ratings

The New York State Department of Transportation (NYSDOT) BSA ratings are used to identify bridges according to their vulnerability to collisions. The procedure for determining BSA classifications and ratings can be found in the NYSDOT Collision Vulnerability Manual located at https://www.nysdot.gov/divisions/engineering/structures/manuals/collision.
Based on the collision vulnerability analysis, bridges are classified into High (H), Medium (M), Low (L) and not vulnerable (N) vulnerability classes. Figure 24 shows a histogram of the number of reported bridge hits as related to the vulnerability classes. Note that a large number of bridges in class N (not vulnerable) have been hit by vehicles. These bridges are most likely on parkways. Likewise, 292 bridge hits have been on bridges classified as L (Low).

NYSDOT assigns Collision Vulnerability Ratings of 1 to 6 based on their detailed collision vulnerability assurance assessment procedure. These ratings are assigned with a goal to prioritize safety/capital retrofit/inspection programs and are assigned as follows: Safety Program Watch:1, Safety Program Alert:2, Capital Program Action:3, Inspection Program Action: 4, No
Action: 5 and Not Applicable: 6. Figure 25 shows a histogram of the number of reported bridge hits as related to the Collision BSA Rating.

![Histogram of Bridge Hits by Collision BSA Rating](image)

Figure 24: Number of Reported Bridge Hits as Related to the NYSDOT BSA Collision Vulnerability Class.

Figure 25: Number of Reported Bridge Hits as Related to the NYSDOT BSA Collision Rating.

Note that a majority of the bridges that have been hit have been assigned a collision rating of 6 (not applicable). This may be because parkways are not allowed to have truck traffic, although a large number of bridges on parkways have been hit. Also note that a significant number of bridges with collision ratings of 4 and 5 have been hit. A large number of bridges with these ratings may be railroad bridges. Hence, the current CVA procedures have to be reviewed and revised so that bridges susceptible to collision are assigned appropriate ratings.
1.3.13 Bridge Hits by Necking

Necking is defined as the difference between curb-to-curb width and the approach width beneath a bridge. Hence, a negative value of necking will indicate a smaller curb-to-curb width at the structure as compared to the approach width. Figure 26 (a) shows the number of reported bridge hits as related to necking. Figure 26 (b) shows the number of reported bridge hits as related to necking for bridges that have been hit multiple times.

![Histograms showing bridge hits related to necking](image)

Figure 26: Number of Reported Bridge Hits as Related to Necking: (a) Histogram Using All Reported Bridge Hits, (b) Histogram Using Multiple Bridge Hits Only.

It is observed from Figures 26(a) and 26(b) that bridge hits are mostly concentrated near zero necking, since necking is usually zero. Although hits occur in the case of both negative and positive values of necking, more hits seem to occur in negative necking region. The trend for
multiple hits in Figure 25(b) is almost the same as that in Figure 26(a). Figure 26(b) also shows that there are more hits on bridges with negative necking.

1.3.14 Bridge Hits as Related to AADT

Average Annual Daily Truck Traffic (AADTT), calculated by multiplying AADT by the percentage of trucks, under a bridge can directly be linked to the number of bridge hits. For this purpose, AADT data for feature under the bridge from the RC13 table has been used since the percentage of truck traffic is not available from this table. Figure 27(a) shows a histogram of AADT for all bridges in New York. Figure 27(b) shows the histogram of number of recorded bridge hits by AADT.

![Histogram of AADT](image)

![Histogram of Bridge Hits](image)

Figure 27: Number of Recorded Bridge Hits as Related to AADT: (a) Histogram Using All State Bridges Over Roadways, (B) Histogram Using Bridge Hits Only.

It is observed from Figures 27 (a) and 27(b) that AADT data for all bridges and hit bridges follow the same pattern, except for a slightly different pattern for AADT > 50,000 in case of
bridge hits in Figure 27(b). Bridges with high AADT for feature carried under seems to have much smaller instances of hits.

1.3.15 Bridge Hits as Related to Total Horizontal Clearance, Left Clearance and Right Clearance

Total horizontal clearance is the clearance between under-bridge components (e.g., curbs, non-mountable medians, railings and any other items which restrict horizontal clearance) which provide the least restrictive horizontal clearance. Figures 28(a) and 28(b) show the total number of recorded bridge hits and the number of multiple bridge hits, respectively, as a function of total horizontal clearance.

Figure 28: Number of Recorded Bridge Hits as Related to Total Horizontal Clearance: (a) Histogram Using All Recorded Bridge Hits, (b) Histogram Using Bridge Hits Multiple Times Only.
It is observed from Figure 28 that although bridges with total horizontal clearance between 20 to 75 feet have been hit, bridges with total horizontal clearance between 25 to 45 feet have been hit the most.

Figure 29 (a) shows the number of recorded bridge hits as related to the minimum horizontal clearance left. It is observed that the number of hits increases significantly if the minimum horizontal clearance left is less than 4 ft. Figure 29(b) shows the number of recorded bridge hits as related to the minimum horizontal clearance right. It is observed that a majority of hits occur when the minimum horizontal clearance right is less than 10 ft. It is also observed that the number of hits becomes suddenly high for minimum right clearance in the range of 25 to 30 feet. This may be related to a particular bridge being hit multiple times.

Figure 29: Number of Recorded Bridge Hits as Related to Left and Right Horizontal Clearance: (a) For Left Horizontal Clearance, (b) For Right Horizontal Clearance.
Overall, although horizontal clearance seems to be correlated to the frequency of bridge hits, this correlation may simply be because of the fact that the minimum right clearance is typically less than 10 feet for most low height highway and railroad bridges. This correlation will be investigated in detail using more detailed statistical models.

1.4 CONCLUSIONS

This report presents a detailed review of all relevant and available literature on bridges hits around the world in order to identify factors that may be considered in developing mitigation strategies for bridge hits in New York. It is observed from the analysis of the NYSDOT bridge hits database that a majority of bridge hits are by overheight vehicles. Several overhead detection devices that have been found to be effective by other states are available and will be investigated in detail in later tasks. From the analysis of bridge hits in New York, it is observed that NYSDOT regions 8, 10, 5 and 11 have the highest incidence of hits in the state. Among the counties in New York State, Westchester, Erie, Nassau, Suffolk and Rockland counties have the highest incidence of hits. In fact, only 32 bridges contribute to 595 hits (44% of total hits in the New York State) out of a total of 815 bridge hits in Westchester, Erie and Nassau counties. Among the factors contributing to increased bridge hits are feature carried under, superstructure design type and maximum and minimum vertical clearance under. Analysis of the bridge hits data shows that a majority of bridges that have been hit were rated ‘not vulnerable’ to collision or have not been considered candidates for a collision vulnerability analysis. Detailed work will be carried out in future tasks to identify previously unaccounted for factors that contribute to collision vulnerability in the state so that the methodologies used by NYSDOT to determine bridge collision vulnerability can be updated.

1.5 REFERENCES