DEVELOPMENT OF AN INSPECTION CHECKLIST

FOR RISK ASSESSMENT OF BRIDGES IN NEW JERSEY

by

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ABSTRACT OF THE THESIS

DEVELOPMENT OF AN INSPECTION CHECKLIST FOR RISK ASSESSMENT OF BRIDGES IN NEW JERSEY

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In the aftermath of the September 11th tragedies, transportation infrastructure has become one of the most visible targets since its destruction could result in substantial human casualties, economic losses, and socio-political damages. Improving bridge security is very important in helping various governmental agencies protect and design structures to better withstand extreme blast loadings. Although many bridge owners have developed their own prioritization methodologies, there is still a need for a better approach to prioritize and assess all bridges not only in New Jersey but in the whole United States. This research focuses on bridges located in New Jersey only, however the analysis and results could be applied to bridges in other states.

The studies include an analysis on risk management and vulnerability assessment by developing a checklist that will provide identification of critical bridges for security hazards and guidelines for bridge security design in order to reduce their vulnerability to attacks. The analysis will first start by identifying bridges in New Jersey and the different

types available. Second, identifying security hazard levels and threats along with their probability of occurrence. Third, discussing bridge vulnerability assessment and developing a comprehensive easy to use security checklist that will categorize bridges according to the likelihood that a bridge will be targeted. Finally, taking different prevention measures that could secure the bridges. Examples were conducted by applying the checklist on various types of bridges to check its validity. However, the questions from the checklist and some other information have been omitted from this paper. For more information please contact New Jersey Department of Transportation or refer to the Simple Bridge Security Inspection Report (Nassif 2006).

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Lastly but not least, I am grateful for my family, specifically my parents Tony Issa and Claude Issa, my brother Tony Jr. and my sister Rachel, because without their support none of this would have been possible.

DEDICATION

Dedicated to
my loving sister who will forever be in my heart
Nidale Issa

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CHAPTER 1. INTRODUCTION

Transportation infrastructure is one of the most visible targets for man-made attacks. Its destruction could result in substantial human casualties, economic losses, and socio-political damages. The Blue Ribbon Panel (Bridge and Tunnel Security 2003) was formed from renowned engineering experts who contributed their time to guide government leaders, infrastructure owners, and the engineering community on how to improve the security of bridges and tunnels. They expect that the ordinary cost of construction to replace a major long-span bridge on a busy interstate highway corridor in the United States would be $1.75 billion (Bridge and Tunnel Security 2003). Over the past few years, transportation agencies have become increasingly interested in evaluating and managing the risk associated with man-made or terrorist threats to the bridges they own and operate. The objective of this study is to establish a general risk assessment checklist that will provide identification of critical bridges for security hazards and guidelines for bridge security design in order to reduce their vulnerability to attacks.

Before attempting to develop a bridge security assessment checklist, security hazard levels and performance objectives needed to be established. These hazard levels need to take into account the probability of occurrence of an attack (blast and impact loadings), the associated risks and the magnitude of these loading, the permissible extent of damage, and the expected condition of the bridge after an attack. It is essential for any successful bridge security system to have risk management and a vulnerability assessment plan.

Risk management and vulnerability assessment for bridge security should include the following:

1. Bridge Identification (Critical Bridges, Other Bridges).
2. Security Hazard Level or Threat Identification and its Probability of Occurrence.
3. Bridge Vulnerability Assessment (Performance Criteria and Acceptable Damage Levels).
4. Bridge Security Prevention Measures.
5. Response Schemes (Coordination and Planning).

A flow chart showing the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) recommendations for vulnerability assessment is shown in Figure 1.

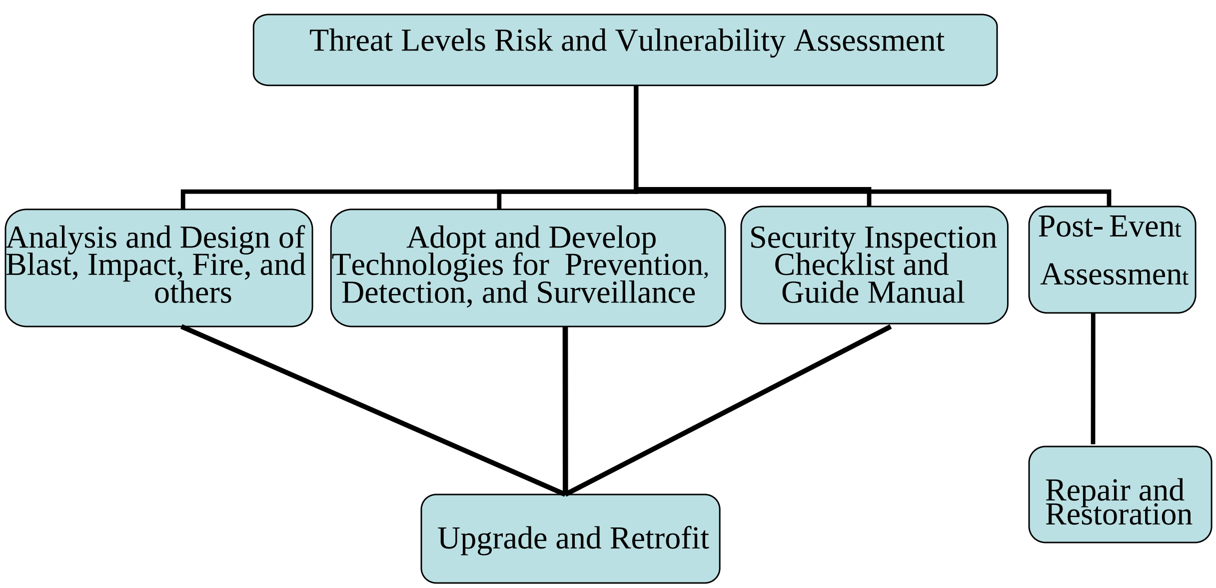


Figure 1: Flow Chart for Risk and Vulnerability Assessment (FHWA and AASHTO 2003)

In order to establish these security hazard levels and performance criteria a quantitative assessment of the probability of occurrence, vulnerability, and importance of the bridge need to be defined. The probability of occurrence of a security hazard or an attack can be attributed to many factors. These factors include history of previous of attacks, data available from security agencies, nature, visibility, importance of the bridge, accessibility, and many others. Therefore, the predictability of such an attack is a complicated process that involved many parameters. The other factor for risk assessment is the vulnerability of the bridge. Bridge vulnerability depends on many factors and can be estimated by conducting bridge security inspection using the National Bridge Inventory (NBI). Among these factors are the type of threat attacks and the magnitude of the explosive devices used in the attack. The development of security hazard levels and performance objectives is essential to properly design bridges for various security threat levels.

Once these security hazard levels and performance criteria are established, bridge components that are vulnerable to blast and impact need to be identified based on standoff distance, strength, ductility, allowable movement, and other available protection measures. Many bridges in New Jersey have design and construction details that may not be adequate to resist forces from blast loads and maintain integrity during such an event. Therefore, it is important to identify these security deficient bridges, evaluate the extent of possible damage, and establish a program to reduce their security risk.

To establish risk levels and the probability of attacks on bridges and to define the acceptable level of service required following such an attack on a bridge, a risk management plan for security hazards need to be developed. The plan will be coordinated with NJDOT Bureaus of Structural Engineering and Transportation Security Office of Homeland Security, and Law Enforcement Agencies. This should include development and implementation of a comprehensive risk and loss characterization for the New Jersey bridges. In addition, identifying and modeling a variety of attack (blast/impact load) scenarios to determine the risk and consequences of these events. Data needs to be collected on all bridges in New Jersey such as geometry, traffic volume, location, height, material type, bridge use, cost, proximity to police and fire stations, etc…

In addition to security hazards, bridges are also exposed to other natural hazards such as earthquakes, vessel impact, flooding, scour, and fire. Since most of these hazards require risk assessment and management plans similar to bridge security, it is more rational and cost effective to use a multi-hazard approach for designing and retrofitting bridges to withstand these hazards.

CHAPTER 2. LITERATURE REVIEW

The American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA) assembled a blue-ribbon panel (Bridge and Tunnel Security 2003) of engineers, researchers, contractors, and owners and operators of infrastructure to discuss how to protect the nation's bridges and tunnels. The panel had provided recommendations and guidelines to assist State Department of Transportation (DOT) implement transportation infrastructure security. The guideline divided the security program into seven approaches:

1) **Overall Strategy of Bridge and Tunnel Security** – it includes a broad range of issues that must be addressed to ensure that adequate measures are taken to protect the asset and the people and goods that utilize the asset.
2) **Framework for Planning, Design, and Engineering** – it considers determining the damages and identifying critical bridges/tunnels through prioritization and risk assessment.
3) **Prioritization and Risk Assessment –** this will identify the likely targets and select methods to defeat the attack. There is also a need to determine the financial impact to deter and provide defense compared to the facility and social cost from the loss and allocate available funds appropriately.
4) **Threats –** different types of threat need to be considered in order to identify the design loads.

5) **Damage** – considers anything that would result in replacement of the facility or major repairs, closure of the facility for more than a month, or any catastrophic failure resulting from an attack.
6) **Countermeasures** – grouped into actions or technologies to deter attack, deny access, detect presence, defend the facility, or design structural hardening to minimize consequences to an accepted level.
7) **Codes and Specifications** – touches on how to employ hardening design, how to quantify blast-related demand, and how to determine the capacity of components exposed to high-pressure transients.

They also recommended the use of the National Bridge Inventory (NBI) maintained by FHWA for prioritization and risk assessment. NBI contains data about bridges including location, structure type, span characteristics, average daily traffic volume, military significance, and others. According to FHWA (The Blue Ribbon Panel on Bridge and Tunnel Security 2003), there are about 600,000 bridges in the United States. This raised the panel a question on how to decide which bridges are more at risk and which ones should receive attention first. They then formulated a risk factor, which is a function of occurrence – that is the likelihood that a basic threat will occur against a given structure, vulnerability of the structure – how much of it might be damaged or destroyed and what effect that destruction would have, and importance of the structure which measures the consequences to the region or the nation in the event that the structure is destroyed or rendered unusable.

Similar findings were also described by Rowshan et. al (2003) by highlighting five steps for conducting a highway vulnerability assessment: 1) Identify Critical Assets, 2) Assess Vulnerabilities, 3) Assess Consequences, 4) Identify Countermeasures, and 5) Review Security Operational Planning. They also derived critical asset and vulnerability factors to help in prioritizing highway infrastructures. Additionally, they developed three levels of countermeasures: 1) Deterrence, 2) Detection, and 3) Defense. They also suggested that the countermeasures need to be linked to their associated cost and recommended that the State DOT develop a plan for training their staff on how to implement bridge security. There is a need for a detailed checklist for security inspection based upon which vulnerability assessment as well as mitigation plans can be planned.

Anderson et. al (2005) used a model called the Inoperability Input-Output Model (IIM) to calculate the losses and describe the impact from an attack. The term inoperability stands for the level of the system's dysfunction. The model was developed by Nobel Prize-winning economist Wassily Leontief. In this study it is assumed that the bridges are completely inoperable which means there is 100% loss and it will take one year to recover. This therefore results into two major types of losses: 1) transportation loss – taken from the average daily traffic data published by Virginia DOT and 2) workforce loss – the amount of hours of work missed by individuals if they could not use the bridge. After calculating the losses, six characteristics were introduced to help develop risk: prevention, detection, hardening, preparedness, response, and recovery. Risk management techniques were used to identify and quantify risks to three bridge-tunnels (selected as examples for this study) and measure the costs and benefits.

Eytan (2003) reported on the Israeli experience in dealing with man-made attacks and the data gathered from the observed damages to structures from real-life terrorist attacks in order to develop and implement protective measures to strengthen existing structures. The following outline summarizes the Israeli experience:

1. Progressive structural collapse:

- Adding a shield cover around the column with an air gap.
- Strengthening the existing column.
- Providing stand-off.

2. Prevent the dislocation of slabs by the blast:

- Strengthening existing slabs for uplift loads by adding steel plates/meshes, concrete layers or sheets made of various materials.
- Strengthening the connections between slabs and supporting beams/columns/walls mainly for uplift loads.
- Adding shielding slabs mainly made of steel plates/meshes.

3. Prevent injuries from glass shards:

- Strengthening the existing glazing.
- Adding an inner “catching” system.
- Replacing the existing glazing by blast resistant glazing.
- Adding an inner energy absorbing catching system.

4. Mitigate impact from masonry wall debris:

- Adding on the inner face of the wall a hand-placed layer of plastic material.

- Adding sheets on inner face of the wall.
- Adding on the inner face of the wall an additional wall.
- Replacing the existing masonry wall by a blast resistant wall.

5. Mitigate direct blast effect:

- Additional shielding blast walls.
- Strengthening internal partition walls.
- Additional blast resistant partitions.

6. Mitigate impact from non-structural elements debris:

- Strengthened false/acoustic ceilings.
- Internal finishes such as plasters, gypsum boards.
- Fixtures on walls and ceilings.
- Furniture.

The author has also developed a Security Protection and Hardening Risk Analysis (SEPHRA) which consists of five stages:

Stage 1 – Threat analysis: defined threats on the structure are analyzed including their probability of occurrence.

Stage 2 – Damage analysis: the damages/injuries are assessed for each of the defined threats.

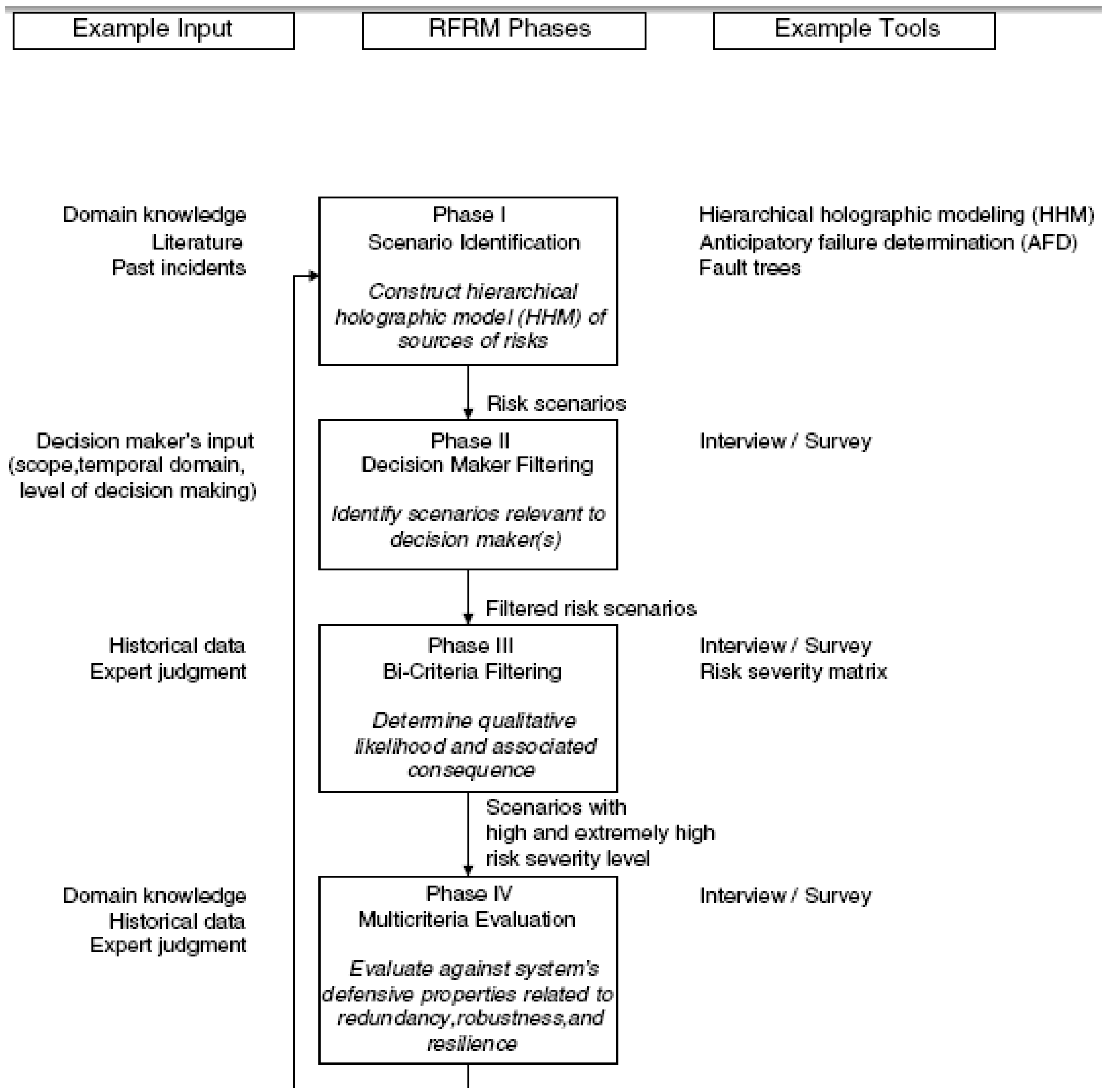
Stage 3 – Risk assessment: the risk to the structure and people is assessed, using the results of stages 1 and 2

Stage 4 – Countermeasures cost effectiveness analysis: various countermeasures are defined, their cost is estimated and their effectiveness in reducing the risk is assessed.

Stage 5 – Countermeasures optimization: plots of assessed damages/injuries versus the cost of protective hardening measures allow the definition of the optimal cost effective countermeasures.

According to the author, the Israeli experience is that implementing retrofit protective hardening measures is feasible, cost effective and risk reducing.

Leung et. al (2004) presented a two level risk assessment system: (1) system level, and (2) asset-specific level. This will help experts and decision makers within the transportation organization to determine which assets should be considered critical and therefore need to be protected. The process of this framework is called the Risk Filtering, Ranking and Management (RFRM) method (Figure 2). It builds on Hierarchical Holographic Modeling (HHM) to identify risks, then filters and ranks the sources of risks, allowing experts to focus on the most critical. The prioritized risks are further evaluated in the risk management phase. Finally, the process is reviewed and improved if necessary. Below is a flow chart of the procedure that is divided into eight phases:



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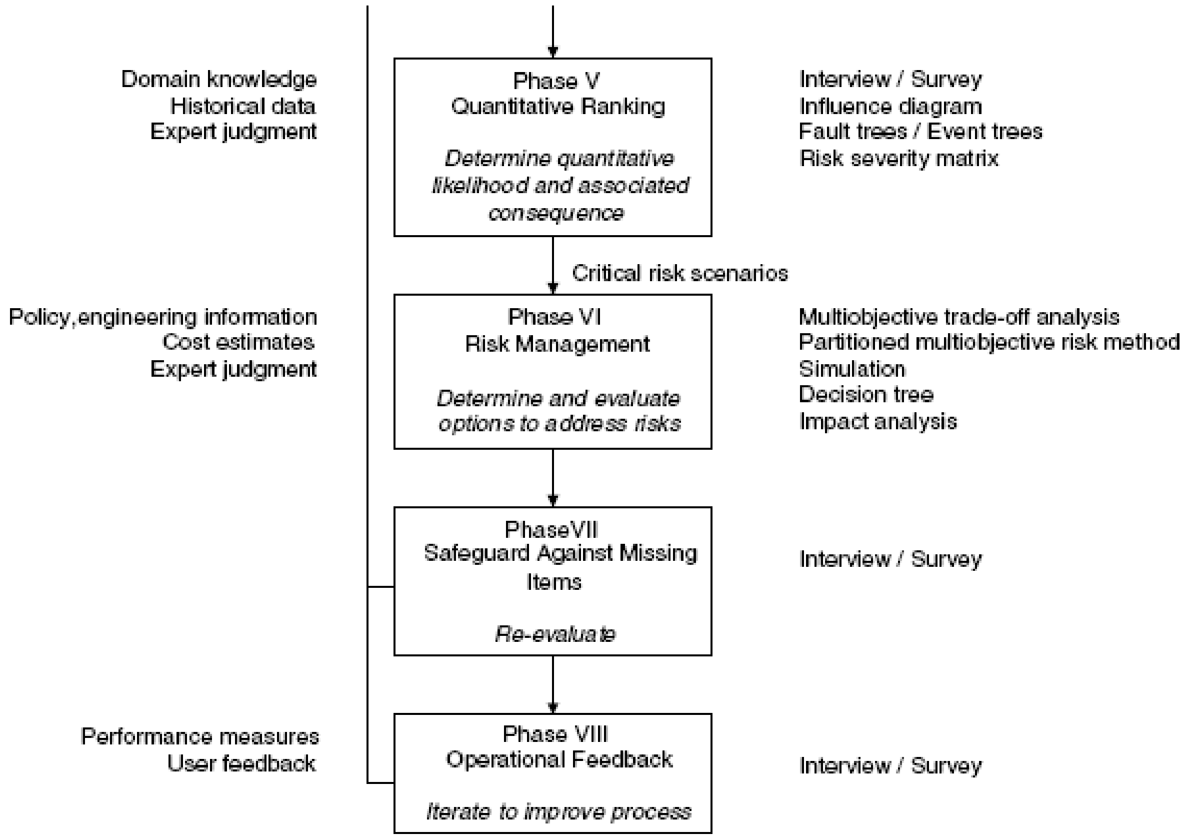


Figure 2: Risk Filtering, Ranking, and Management (RFRM) Method (Leung 2004)

The main goal and purpose of the National Infrastructure Protection Plan (NIPP) is to:

> "Build a safer, more secure, and more resilient American by enhancing protection of the Nation's critical infrastructure and key resources (CI/KR) to prevent, deter, neutralize, or mitigate the effects of deliberate efforts by terrorists to destroy, incapacitate, or exploit them; and to strengthen national preparedness, timely response, and rapid recovery in the event of an attack, natural disaster, or other emergency" (NIPP 2006).

Figure 3 illustrates the type of protections needed to manage risks and actions that should be implemented.

Figure 3: Protection Flow Chart (NIPP 2006)

Blast-resistant design has traditionally been considered only for essential government buildings, military structures, and petrochemical facilities. Recently, increased attention has been given to bridges. However, engineers have not considered security in the design process. More research will be done to enhance physical security, improve structural response, or mitigate the consequences of an attack. Barrier protection for impact is considered in highway design and for protection of piers in navigable waterways. Nevertheless, these are intended for accidental collision and not malicious attacks.

According to Müllers and Vogel (2005), the vulnerability of flat slab structures made out of reinforced concrete is very important to investigate because the collapse of such a building can lead to fatal consequences. Even though this addresses buildings and not bridges, the analysis is very similar because it deals with column failure. Column failure is hazardous since it could end in a progressive collapse. Hence, investigations are made and key parameters, such as failure time, physical non-linearity, geometrical non-linearity, damping and/or strain-rates are identified with the aid of simple mechanical model. It was assumed that the failure time would be close to zero. A non-linear structural behavior was considered and damping and strain-rate effects were neglected for calculations of forces. This resulted in three methods for column failure design of a structure: a displacement based design analyzed by energy balance, a capacity design according to seismic design methods, or a non-linear dynamic finite element analysis. From that model, it was concluded that the column failure time influences the effect of actions in the remaining structure significantly.

Winget et. al (2005) indicated that developing an understanding of the principles of blast wave propagation and its potential effects on bridge structures is the first step that should be taken before engineers can begin to design bridges to withstand blast loads and terrorist attacks. A project manager or a security professional should perform a preliminary risk assessment to determine which threats the bridge may face. Once the potential threats have been identified, measures can be implemented to mitigate those risks. These measures can be used to displace the threat to less attractive targets, increase the likelihood of terrorists being detected and identified, keep casualties to a minimum, improve emergency response time, increase public confidence, improve structural response, or a combination of these events (Jenkins 2001). Longer span members are generally more resilient to localized blast loads because they tend to be more massive, stronger, and more flexible than shorter spans and therefore can usually absorb more blast energy through larger deformations (James Ray, personal communication, June 2002).

In their paper, Winget et. al (2005) mentioned that the most common analysis method used in practice is a single- or multiple-degree-of-freedom, uncoupled, nonlinear dynamic analysis. BlastX version 4.2.3.0 (BlastX 2001) was used to generate loads. To calculate the reduced area of the columns due to local blast damage, empirically based spall and breach equations developed by Marchand and Plenge (1998) were used. To predict the local breaching damage for counterforce scenarios on small diameter piers, the rule of thumb in FM 5-250 (Department of the Army 1992) was used, which indicates the amount of TNT per foot for concrete to be breached. To calculate the flexural response of the piers to vehicle blast loads, SPAn32 version 1.2.7.2 (SPAn32 2002) was used.

After the analyses were made, the results showed that bridge geometry can significantly affect the blast loads that develop below the deck. For bridges with deep girders, confinement effects can greatly enhance the blast loads acting on the girders and tops of the piers. In some cases effects may result in more damage than an explosion occurring on top of the deck. Higher clearances result in lower average loads on the piers due to the larger volume of space under the bridge and the increased average standoff distance to a given point on the pier. Explosions occurring near sloped abutments could possibly result in more damage than an explosion at midspan due to the confinement effects at the abutments. In addition, round columns will experience lower loads due to the increased angle of incidence from the curved surface.

Prior to September 11, 2001, the Department of Defense and other agencies of the U.S. Government had developed a number of engineering design documents that provided guidance for protection of government assets against terrorist and criminal acts (Betts 2005). Including in these documents, Table 1 which describes the levels of protection associated with 1) Potential Structural Damage, 2) Potential Door and Glazing Hazards, and 3) Potential Injury. Table 2 discusses the standoff distances at which construction can resist the minimum explosive weights and achieve the minimum levels of protection.

Table 1: Qualitative Levels of Protection (Betts 2005)

Level of Protection	Potential Structural Damage	Potential Door and Glazing Hazards	Potential Injury
Below AT standards	Severely damaged. Frame collapse/massive destruction. Little left standing	Doors and windows fail and result in lethal hazards	Majority of personnel suffer fatalities
Very Low	Heavily damaged - onset of structural collapse: Major deformation of primary and secondary structural members, but progressive collapse is unlikely. Collapse of non-structural elements.	Glazing will break and is likely to be propelled into the building, resulting in serious glazing fragment injuries, but fragments will be reduced. Doors may be propelled into rooms, presenting serious hazards.	Majority of personnel suffer serious injuries. There are likely to be a limited number (10% to 25%) of fatalities.
Low	Damaged - unrepairable. Major deformation of non-structural elements and secondary structural members and minor deformation of primary structural members, but progressive collapse is unlikely.	Glazing will break, but fall within 1 meter of the wall or otherwise not present a significant fragment hazard. Doors may fail, but they will rebound out of their frames, presenting minimal hazards.	Majority of personnel suffer serious injuries. There may be a few (<10%) fatalities.
Medium	Damaged - repairable. Minor deformations of non-structural elements and secondary structural members and no permanent deformation in primary structural members.	Glazing will break, but will remain in the window frame. Doors will stay in frames, but will not be reusable.	Some minor injuries, but fatalities are unlikely.
High	Superficially damaged. No permanent deformation of primary and secondary structural members or non-structural elements.	Glazing will not break. Doors will be reusable.	Only superficial injuries are likely.

Table 2: Minimum Standoff Distances (Betts 2005)

Location	Building Category	Standoff Distance or Separation Requirements			
		Applicable Level of Protection	Conventional Construction Standoff Distance	Effective Standoff Distance[1]	Applicable Explosive Weight[2]
Controlled Perimeter or Parking and Roadways without a Controlled Perimeter	Billeting	Low	45 m (148 ft)	25 m (82 ft)	I
	Primary Gathering Building	Low	45 m (148 ft)	25 m (82 ft)	I
	Inhabited Building	Very Low	25 m (82 ft)	10 m (33 ft)	I
Parking and Roadways within a Controlled Perimeter	Billeting	Low	25 m (82 ft)	10 m (33 ft)	II
	Primary Gathering Building	Low	25 m (82 ft)	10 m (33 ft)	II
	Inhabited Building	Very Low	10 m (33 ft)	10 m (33 ft)	II
Trash Containers	Billeting	Low	25 m (82 ft)	10 m (33 ft)	II
	Primary Gathering Building	Low	25 m (82 ft)	10 m (33 ft)	II
	Inhabited Building	Very Low	10 m (33 ft)	10 m (33 ft)	II

(1) Even with analysis, standoff distances less than those in this column are not allowed for new buildings, but are allowed for existing buildings if constructed/retrofitted to provide the required level of protection at the reduced standoff distance.
(2) See UFC 4-010-02 for the specific explosive weights (kg/pounds of TNT) associated with designations - I and II

Mays and Smith (1995) introduced in their paper the standoff distances of an explosion that will produce internal flying glass in a building. This is illustrated below in Table 3.

Table 3: Stand-off Distances to Produce Internal Flying Glass
(Mays and Smith 1995)

Device	Stand-off (in m) to shatter 4mm annealed glass
Small package	10
Small briefcase	14
Large briefcase	20
Suitcase	26
Car	60
Small van	120
Large van	140
Small truck	160
Large truck	200

Princehorn et. al (2005) compared in Table 4 the effects of a blast and earthquake on a reinforced concrete or steel structures. Analyses concluded that earthquake designs typically focus on the performance of upper levels of buildings, whereas blast-resistant designs should focus on the lower stories that are subjected to higher force levels.

Table 4: Comparison of Blast and Earthquake Effects on Reinforced Concrete or Steel Structure (Princehorn and Laefer 2005)

Blast	Earthquake	Implications
Adjacent structures are susceptible. Floor slabs and beams most vulnerable to upward pressure and may shatter. Weaker columns may be destroyed, but larger, heavily loaded columns are often not initially shattered.	Damage to brittle vertical supporting elements, while floor slabs and beams usually have minimal initial damage.	Seismic column designs may be applied to blast designs, but seismic beam and floor slab design would be inappropriate.
Pressures radiate from point of detonation and decay rapidly with distance and time. As shock wave passes over building, pressure direction may change.	Affects entire structure and damage occurs because of mismatches in the strength/ stiffness ratio of structural members. Irregularities focus the damage on more vulnerable areas (softer and higher stories, and longer columns). Shaking matches earthquake duration; may exceed 60sec.	Blast resistance should focus on lower and exterior portions of the building, whereas seismic intervention is focused on upper levels and is more uniform in impacting all structural components.
Shattered floors reduce lateral support that can lead to adjacent columns buckling and then the collapse of bays in the structure. If columns are shattered, floor collapse is inevitable.	High lateral loads can compromise or damage vertical supports. Without enough vertical support, relatively undamaged floors will fall onto one another, causing a pancake type collapse.	Hardening lateral elements are higher priority in blast design. Seismic design requires lateral loads to be transferred/absorbed without significantly mitigating vertical structural components.
Secondary collapse is possible especially if rescue operations require removal of collapsed slab structures that have become the temporary lateral bracing to the remaining, free standing columns.	Aftershocks will cause additional lateral loading, which may readjust load paths, causing a secondary collapse.	Progressive collapse analysis is typically performed for seismic designs and can, therefore, be applied to blast designs.

Unlike natural disasters, man-made attacks are unpredictable. “To manage risk, one must measure it” (Haimes 2002). To calculate the likelihood that such an act would take place at a certain time and place is beyond possibilities. However, to simplify things, different approaches were taken to calculate risk. Haimes (2002) introduces a model of homeland and terrorist networks (Figure 4) as a system. Its outputs are the same as the four sources of risk that constitute the input to the homeland system. These sources are:

- Risk to human lives and to individual property, liberty, and freedom;
- Risk to organizational-societal infrastructures, and to the continuity of government operations, including the military and intelligence-gathering infrastructures;
- Risk to critical cyber-physical infrastructures; and
- Risk to economic sectors.

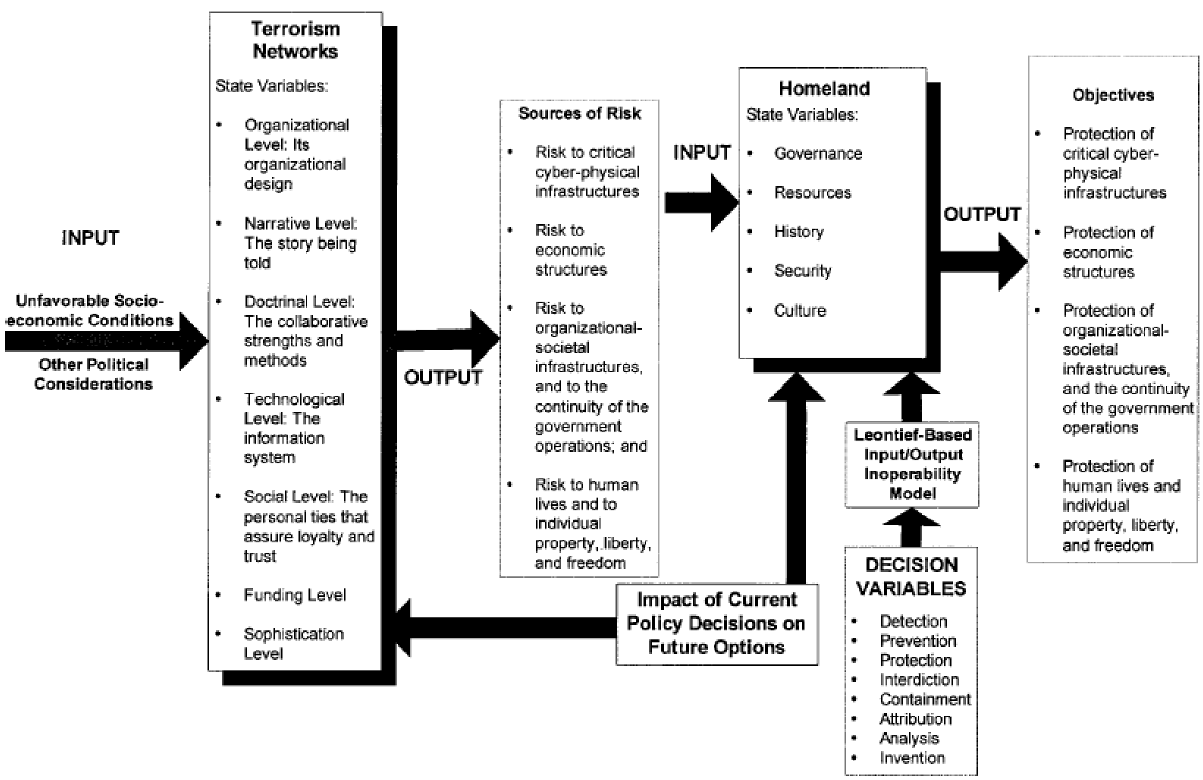


Figure 4: Model of Homeland and Terrorist Networks System (Haimes 2002)

Probabilistic Risk Assessment (PRA) is typically characterized as the quantification of the likelihood and severity of an adverse outcome. PRA-based prioritization techniques are well developed for natural and accidental hazards (Basoz 1995), but not to hazards related to man-made destructions. Even though there are differences between security and natural hazard risk, the PRA-based approach could be used to quantify risk and provide information needed to make rational and cost-effective risk management decisions.

King et al. (2005) measures risk by decomposing it into three components. O (Occurrence), V (Vulnerability), and I (Importance) and quantifying these components. Risk is written as the product of the three components as follows:

$$\text{Risk} = O \times V \times I$$

According to King, occurrence (O) is the hazard model used to characterize the probability of an initiating event occurring. There are no extensive historical databases for security related hazards due to their subjective and dynamic nature. For this reason, occurrence is taken as the relative likelihood of occurrence rather than a probability in some future time period. Vulnerability (V) is the damage or fragility model used to characterize the outcome or consequences of the event’s occurrence. Importance (I) is used to characterize the criticality or the social and economic impact of a facility’s operation on the region, the owner, and the society at large.

The majority of the publicly available security risk assessment methods can be characterized as one of the following three general types (Kings and Isenberg, 2005):

1) Scoring/screening techniques;

2) Event and fault tree approaches; and

3) Scenario-based analyses.

Scoring techniques are most often used for cursory evaluation of a large range of facilities and screening or prioritizing a sub-set for further assessment or mitigation considerations. An example of a scoring/screening method is the AASHTO Guide to Vulnerability Assessment for Critical Asset Identification and Protection (AASHTO, 2002). Figure 5 shows a scatter plot of Criticality versus Vulnerability that is used to identify the facilities with the highest risk.

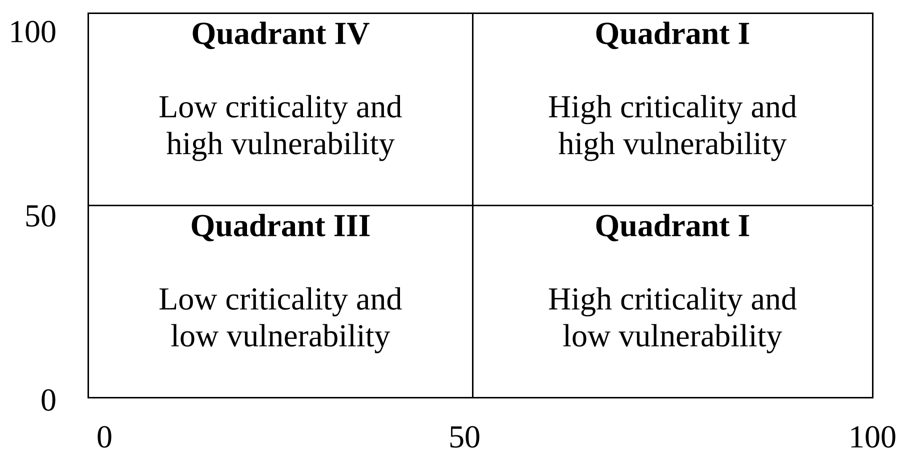
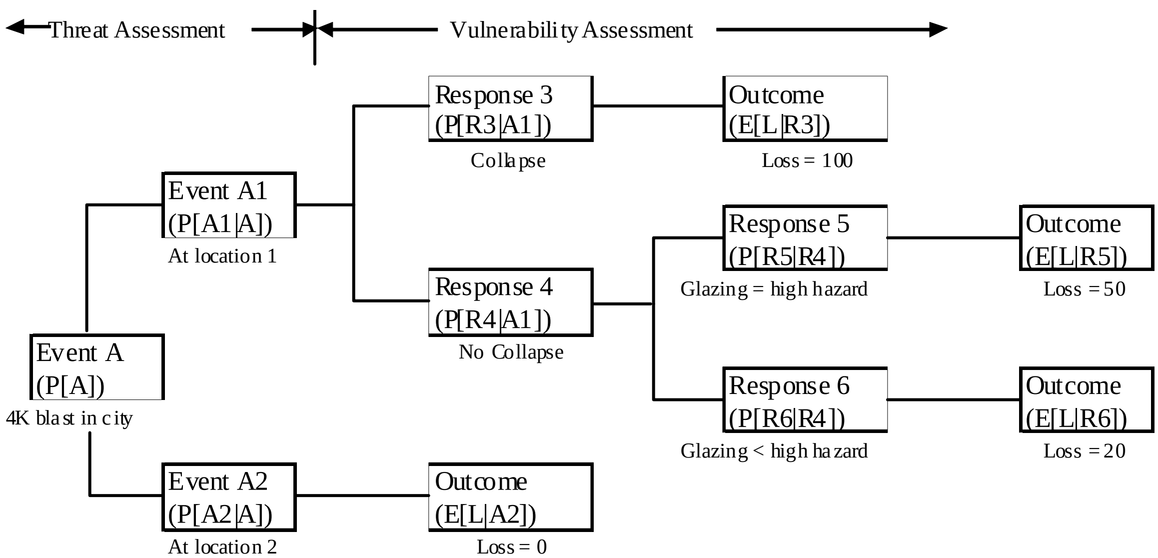


Figure 5: Criticality and Vulnerability Scatter Plot (AASHTO 2002)

Event tree analysis and fault tree analysis are quantitative risk assessment techniques often used to evaluate risk for natural or accidental hazards to individual facilities. However, they could be used for security risk assessment since they provide a means for modeling of the basic components of risk. Figure 6 show an example of an event tree analysis for a security risk application.



$$\begin{aligned} \text{Risk} = E[\text{Loss}] = \; & P[A]xP[A1|A]xP[R3|A1]x100 \\ & + P[A]xP[A1|A]xP[R4|A1]xP[R5|R4]x50 \\ & + P[A]xP[A1|A]xP[R4|A1]xP[R6|R4]x20 \\ & + P[A]xP[A2|A]x0 \end{aligned}$$

Figure 6: Event Tree Analysis Applied to Security Risk (King 2005)

In the scenario-based analysis, the basic components of risk are modeled explicitly following the above risk equation. The basic steps in the method are discussed in the sub-sections below.

Importance

- Vehicles Directly Impacted: a function of average daily traffic, length, deck, width, average traffic speed, and feature crossed.
- Anticipated Economic Loss: a function of average daily traffic, time for complete replacement, and cost of complete replacement.
- Vehicle Detour Miles: a function of average daily traffic, detour length, and usage type.
- Defense/Emergency/Evacuation Route: a function of usage type and feature crossed.
- System Redundancy: a function of priority and redundancy.
- Attached Utilities: a function of the type and number of utilities.

Occurrence

- Level of access for attack.
- Level of security against attack.
- Visibility or attractiveness of facility as a target.
- Capability of aggressor to initiate attack.

Vulnerability

- Expected damage to the bridge (% of total replacement value cost)
- Expected downtime or closure of the bridge (number of days)
- Expected casualties (number of people)

Ray et. al (2007) describes in his paper a risk-based methodology that was developed to facilitate prioritization of a threat mitigation strategies on individual bridges and the risk associated with each of their own individual structural components. A general equation, which is normally used for natural hazard risk assessment, was used for mitigation prioritization of individual bridge components.

$$\text{Risk} = OVI$$

Where,

O = occurrence – measures the relative likelihood of a basic threat actually occurring against a given component;

V = vulnerability – captures the relative vulnerability of a given component given the occurrence of the basic threat;

I = importance – measures the importance of an individual component to the bridge.

In this case, risk is not an actual probability. Instead, it’s a measure of the subjective expectation of a total bridge collapse from a given threat against a given component. The location of some components and the type of threat applied to a certain component may make them more critical to the survival of the structure than others. The following points will be discussed further more in the chapters ahead:

- Analysis of different types of possible threats.
- Analysis of different types of critical components of a single bridge.
- Effect of certain bridge components subjected to a specific type of threat.

On the other hand, in the context of Homeland Security and the National Infrastructure Protection Plan (NIPP) (U.S. Department of Homeland Security 2006), risk is defined as the expected magnitude of loss (e.g., deaths, injuries, or economic damage) due to a terrorist attack, natural disaster, or other incident, along with the likelihood of such an event occurring and causing that loss. With this definition, risk is a function of consequence, vulnerability, and threat:

$$\text{Risk} = f\,(C,V,T)$$

Where,

C = consequence: the loss of human lives and the negative effects on public health and safety and the economy that can be expected if a bridge was destroyed or disrupted by a terrorist attack, or other incident;

V = vulnerability: the likelihood that a bridge will be susceptible to destruction, by terrorist or other intentional acts;

T = threat: the likelihood that a bridge will suffer an attack or incident. The estimate of this is based on the analysis of the intent and the capability of an adversary.

The DHS Homeland Infrastructure Threat and Risk Analysis Center (HITRAC) conducts integrated threat analysis for all CI/KR sectors. Figure 7 shows how HITRAC develops analytical products by combining intelligence expertise based on all source information and threat assessments.

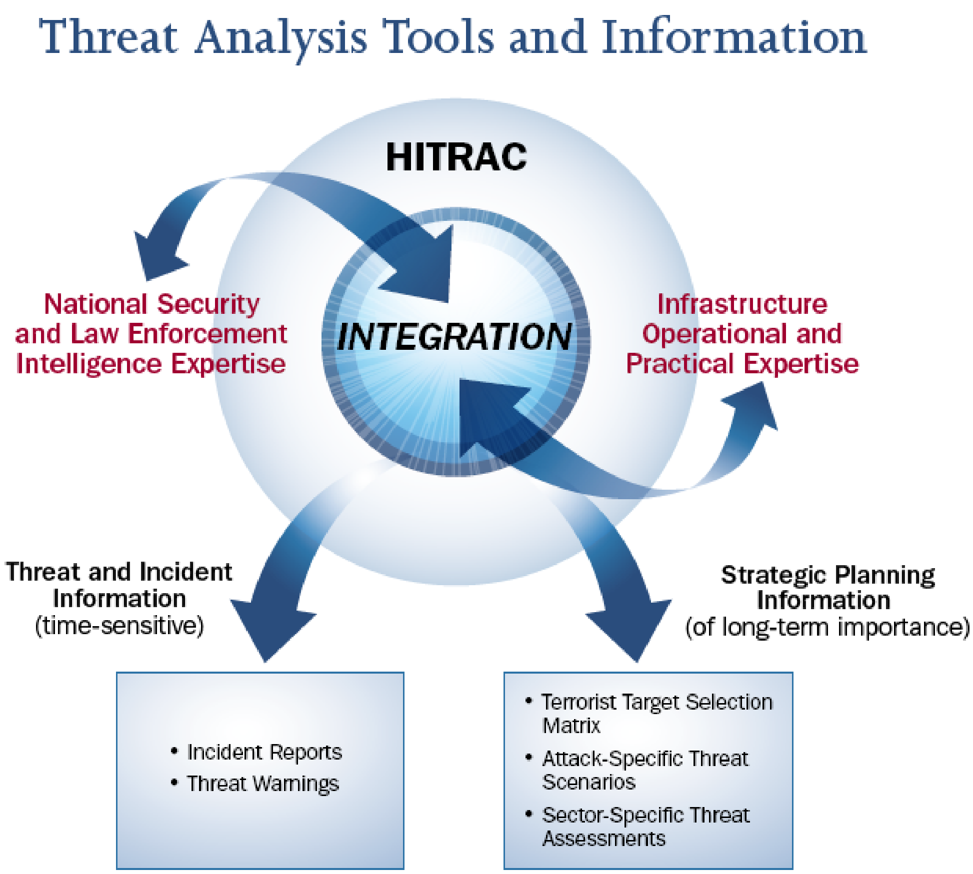


Figure 7: Threat Analysis (NIPP 2006)

Furthermore, Jaeger et. al (1998) introduces the risk equation based on Sandia’s approach (Sandia is the national laboratory at the Security Systems and Technology Center in Albuquerque, New Mexico).

$$Risk = (P_A)\ (1-P_E)\ (C)$$

Where,

P_A is the likelihood of occurrence which comes from the analysis of the threat.

P_E is the system effectiveness which is the product of two parts: P_I (the probability of interruption) indicates how effective the protective system is in interrupting an adversary attack, and P_N (the probability of neutralization) is a measure of how well the response forces do in force-on-force conflicts with the adversary given interruption.

C is the consequence that considers impact, criticality, and cost.

CHAPTER 3. BRIDGE TYPES

Squire Whipple (1804-1888), one of America's first bridge engineers, wrote that "a bridge is a structure for sustaining the weights of carriages and animals in their transit over a stream, gulf or valley" (Whipple 1986). There are six main types of bridges: beam bridges, cantilever bridges, arch bridges, suspension bridges, cable-stayed bridges and truss bridges. In addition, movable bridges will be discussed because there are many of them in New Jersey.

1. Beam Bridges (also known as girder bridges)

From approximately 1915 through 1955, the most common type of highway bridges built throughout much of the United States was the steel girder bridge. 85% of bridges in New Jersey are Girder Bridge which is equivalent to 1.2% of throughout the United States. The girder is a form of a beam bridge in which the deck slab is supported by certain types of beams or girders. According to the New Jersey Historic Bridge Survey, the Edison Bridge, built between 1938 and 1940 across the Raritan River, is an example of a large scale continuous deck-girder bridge. The bridge is composed of twenty-nine spans for a total length of 4,391 feet.

The Scudder Falls Bridge (Figure 8), a ten-span bridge with two-span continuous steel-plate girders, was built in 1959. Each of its two end spans is 150 feet long and the eight middle spans are 180 feet long each, for a total length of 1,740 feet.

The bridge carries Interstate 95 across the Delaware River between Ewing Township, New Jersey, and Lower Makefield, Pennsylvania, and crosses over the Pennsylvania Canal.

Figure 8: Scudder Falls Bridge (Little 2008)
(http://www.ibtta.org/files/PDFs/Little_Roy.pdf)

2. <u>Cantilever Bridges</u>

The cantilever bridge was a popular type in New Jersey in the first half of the twentieth century. The bridge can be built from both sides of the crossing simultaneously, either meeting or having a final center span put into place to link the two extended spans. One of the advantages of a cantilever bridge is that it can span wide spaces and can be built without the need of foundation piers, which can disrupt the flow of a river.

The Pulaski Skyway (Figure 9), which crosses the Hackensack and Passaic rivers and connects Newark and Jersey City across the Meadowlands, is said to be 6.2 miles (DeLony 1992). The bridge has two main 550-foot cantilever spans with through trusses, and four 350-foot side cantilever spans with deck trusses. It clears the water with an elevation of at least 135 feet. However, its peak point over the Hackensack River is at 200 feet high. Cunningham (1966) records that the construction on the Pulaski Skyway began in 1930 and was completed in 1932 at a cost of $20-21 million. The bridge used 88,461 tons of structural steel.

Figure 9: Pulaski Skyway, Hackensack River (Wikipedia 2008)
(http://en.wikipedia.org/wiki/Pulaski_Skyway)

3. Arch Bridges

An arch bridge is a bridge with abutments at each end shaped as a curved arch. Gravity holds the elements of the bridge in place as they are pressed against each other by the downward force, which is distributed along the path of the arch to the ground. The arch bridge was useful for spanning distances greater than was possible with simple beam bridges. Arch bridges could be made of stone, concrete, or steel. There are about 0.05% of Arch bridges in New Jersey.

The North Branch Viaduct, described by the New Jersey Transit Historic Bridge Survey as a “stunning example of stone bridges”, is a five-arch, 228-foot stone bridge built in 1852. It was built across the North Branch of the Raritan River to extend the Central New Jersey's lines to Phillipsburg. It carries two tracks at a width of 27 feet, and each span is 40 feet in length.

The seven-span Paulinskill Viaduct (Figure 10) at Hainesburg, New Jersey, was the second of the great bridges constructed as part of the Lackawanna Cutoff. Constructed from 1908 to 1910, it was the largest reinforced concrete railroad viaduct in the world at that time, more than 1,100 feet long and 115 feet above the valley.

Figure 10: Paulinskill Viaduct (Wikipedia 2007)
(http://en.wikipedia.org/wiki/Paulins_Kill_Viaduct)

A good example of a steel arch bridge is the Bayonne Bridge (Figure 11). Until the opening of the Lupu Steel Arch Bridge in Shanghai, China, in 2003, the Bayonne Bridge was the second-longest steel arch bridge in the world (1,675 feet, center span). Constructed between 1928 and 1931 at a cost of $16 million, it was honored as the "Most Beautiful Structure of Steel of 1931" by the American Institute of Steel Construction. The Bayonne Bridge is a through arch, also called "overhead", because the deck is suspended from a trussed arch by wire rope hangers. It connects Bayonne, New Jersey with Staten Island, New York, spanning the Kill Van Kull.

Figure 11: Bayonne Steel Arch Bridge (Wikipedia 2008)
(http://en.wikipedia.org/wiki/Bayonne_Bridge)

4. Suspension Bridges

A suspension bridge is a type of bridge where the main load-bearing elements are hung from suspension cables. The suspension cables must be anchored at each end of the bridge, since any load applied to the bridge is transformed into a tension in these main cables. The main cables continue beyond the pillars to deck-level supports, and further continue to connections with anchors in the ground. The roadway is supported by vertical suspender cables or rods, called hangers.

Darl Rastorfer calls the George Washington Bridge “the most significant long-span suspension bridge of the twentieth century.” Built between 1927 and 1931, the GWB (Figure 12) connects Fort Lee, New Jersey, and New York City across the Hudson River. It has two towers at 604 feet high and a higher clearance at mid-span above mean high water (213 feet). Unlike the Walt Whitman and Benjamin Franklin bridges, the George Washington Bridge has four cables. Each cable is 36 inches in diameter, made up of 61 strands of 26,474 individual wires. At the time it was built, the main span, at 3,500 feet, was twice the length of any existing suspension bridge span. The total length anchorage to anchorage is 4,760 feet.

Figure 12: George Washington Bridge (Wikipedia 2008)
(http://en.wikipedia.org/wiki/George_Washington_Bridge)

Other important suspension bridges in New Jersey are the Benjamin Franklin Bridge connecting Camden, NJ to Philadelphia, the Delaware Memorial Bridge, and the Walt Whitman Bridge connecting to an industrial area south of Camden.

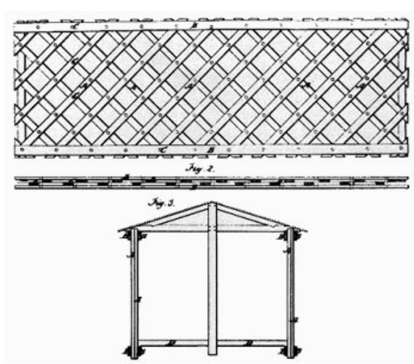
5. <u>Cable-Stayed Bridges</u>

Similar to the Suspension Bridge, the Cable-Stayed Bridge consists of one or more towers with cables supporting the deck. The earliest known example of a true cable-stayed bridge in the United States is E.E. Runyon's, still existing, steel bridge with wooden stringers and decking in Bluff Dale, Texas built in 1890. According to the National Bridge Inventory there are no Cable-Stayed bridges in New Jersey.

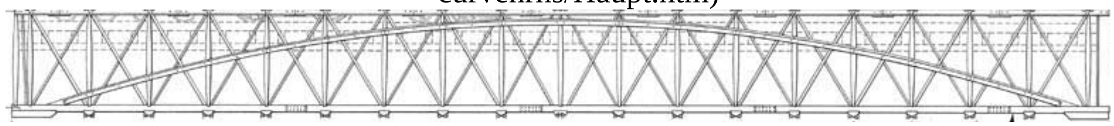
6. <u>Truss Bridges</u>

A truss bridge is a bridge composed of vertical, horizontal and diagonal members connected in a way where tensile and compressive forces act against each other. There are numerous types of truss bridges. Some of the more prevalent types of trusses are listed below:

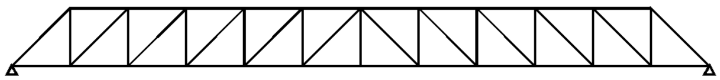
a) The Town truss (Wikipedia 2008, http://en.wikipedia.org/wiki/Truss_bridge)



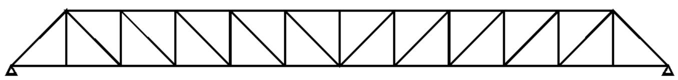
b) The Haupt truss (Behe 2008 http://www.trainweb.org/horseshoe curvenrhs/Haupt.htm)



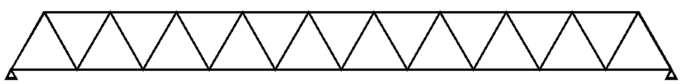
c) The Howe truss (Wikipedia 2008, http://en.wikipedia.org/wiki/Truss_bridge)



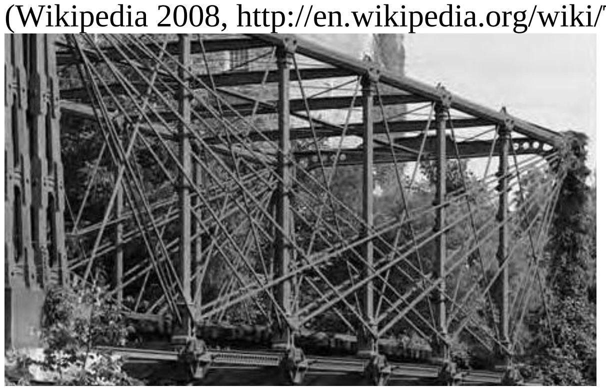
d) The Patt truss (Wikipedia 2008, http://en.wikipedia.org/wiki/Truss_bridge)



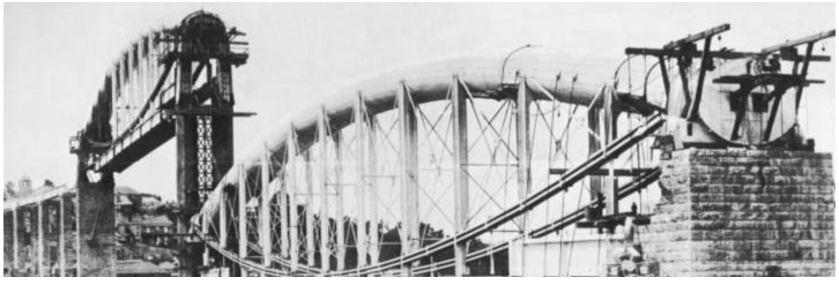
e) The Warren truss (Wikipedia 2008, http://en.wikipedia.org/wiki/Truss_bridge)



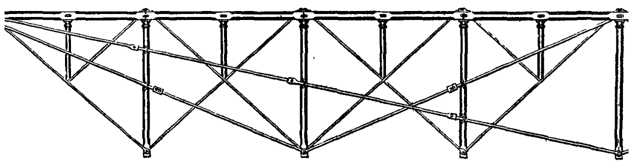
f) The Bollman truss
(Wikipedia 2008, http://en.wikipedia.org/wiki/Truss_bridge)



g) The Lenticular truss
(Wikipedia 2008, http://en.wikipedia.org/wiki/Truss_bridge)



h) The Fink truss (Wikipedia 2008, http://en.wikipedia.org/wiki/Truss_bridge)



The Betsy Ross Bridge (Figure 13) was built to connect Pennsauken, New Jersey, to Philadelphia. The bridge stands 135 feet over the mean high water, cost $103 million and required 29,326 tons of structural steel for itself and its approaches. The main span is 729 feet, and each of the two side spans is 364.5 feet. The Betsy Ross Bridge is a Warren truss bridge, with a width of 105 feet, where the truss descends below the level of the deck.

Figure 13: Betsy Ross Bridge (Wikipedia 2008)
(http://en.wikipedia.org/wiki/Betsy_Ross_Bridge)

7. Movable Bridges

Out of the United States, there are about 6.5% of movable bridges in New Jersey only. Movable bridges change position in a whole or in part to allow traffic to pass below or around them. The three basic types of a movable bridge are the bascule, swing, and lift bridges.

A familiar kind of Bascule Bridge is the drawbridge, in which a single leaf or each of two opposing leaves has a counterbalance at one end. When the counterbalance is allowed to sink, the free end rises on a horizontal axis. A double-leaf bascule has two ends that rise to allow marine traffic to pass. The Oceanic Bridge (Figure 14), a 2,712 foot, 57 span steel double-leaf bascule bridge across the Navesink River between Rumson and Middletown, was built in 1939.

Figure 14: Oceanic Bridge on the Navesink River
(http://en.wikipedia.org/wiki/Image:Oceanic_bridge_viewing_towards_Rumson.JPG)

The swing bridge rotates ninety degrees on a vertical axis on a central pivot pier, allowing marine traffic to pass on either side. The movable span is supported either by a center bearing on a vertical pin or pivot, or by a rim bearing on a circular girder. Three steel swing bridges for vehicular traffic operate on the Passaic River in Newark. They are: the Jackson Street Bridge (built between 1897 and 1898), Clay Street Bridge seen in Figure 15 (built in 1980), and Bridge Street Bridge (built in 1913).

Figure 15: Clay Street Bridge
(http://members.aol.com/Schoonmaker2000/BlogPix/RailBDsk.jpg)

The lift bridge operates like an elevator with the entire span rising vertically between towers. William Middleton discusses in his book that lift bridges were preferred for railroad traffic, “particularly where long clear spans were required.” He explains how they work: “The weight of the lift span was counterbalanced by weights attached to each end through cables running over sheaves at the top of each tower. Lift spans reached some prodigious dimensions” (Middleton, 1999). The Delair Lift Bridge (Figure 16) is a 500-foot lift bridge with a main span of

165 feet and camelback trusses. It was built in 1895-1896 by the Pennsylvania Railroad Company across the Delaware River at Delair, New Jersey, to accommodate Pennsylvanians traveling to resorts on the Jersey shore, including Atlantic City. It has a vertical clearance of 135 feet and a total length of about 4,400 feet.

Figure 16: Delair Lift Bridge (Feldman 2001)
(http://www.trainweb.org/railpix/njtpix/D-delair1-5-31-01.jpg)

According to the interim report on bridges published on August 9, 2007 by the New Jersey Department of Transportation, there are about 6,433 highway carrying bridges over 20 feet long in New Jersey's Bridge Inventory. Figure 17 shows the distribution of NJ bridges owned by different sectors.

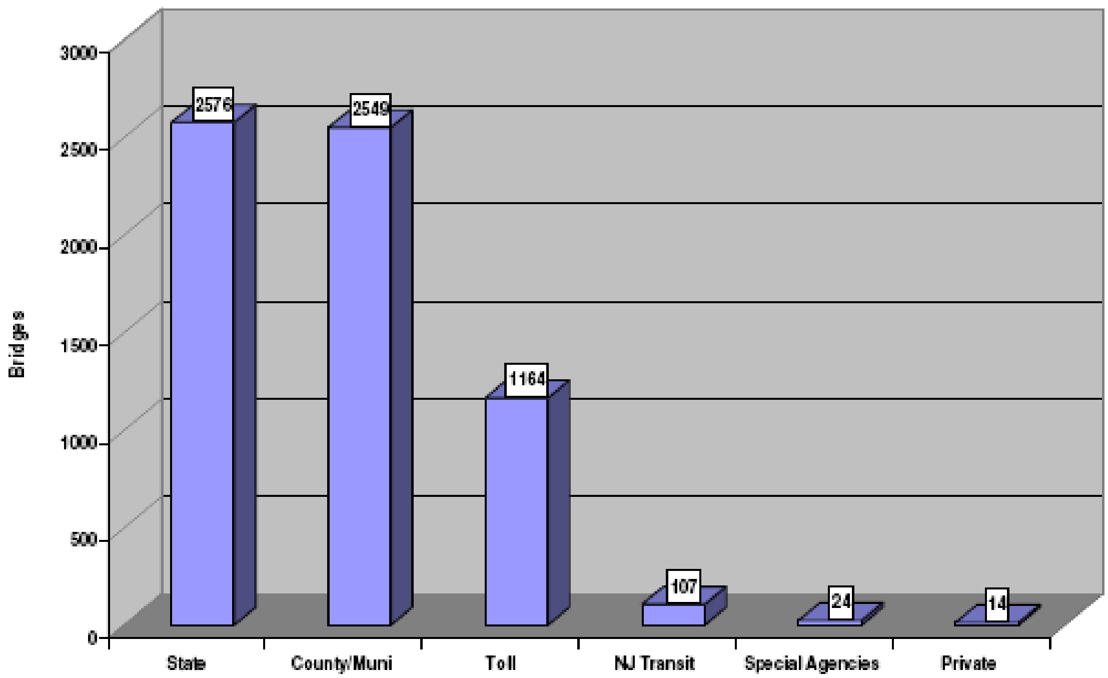


Figure 17: Number of bridge owned by different sectors (Kolluri 2007)

The interim report provides an overview of the condition of New Jersey's bridges. The majority (5,125 bridges) are owned by the New Jersey Department of Transportation (NJDOT), county and municipal governments. The report concludes that 66% (4,196) of New Jersey's bridges are neither structurally deficient nor functionally obsolete. 23% (1,502) are functionally obsolete; 6% (396) are load posted which limit the weights of trucks using the bridges. Structurally deficient bridges are those that are restricted to light vehicles, require immediate rehabilitation to remain open, or are closed. Functionally obsolete bridges are those with deck geometry (e.g., lane width), load carrying capacity, clearance, or approach roadway alignment that no longer meet the criteria for the system of which the bridge is a part. Moreover, Figure 18 shows the different material types of bridges in New Jersey and the percentage of bridges per material. Figures 19 & 20 show the percentage of bridges in New Jersey by types in Relation to the state and the nation. A detailed table can be found in Appendix A.

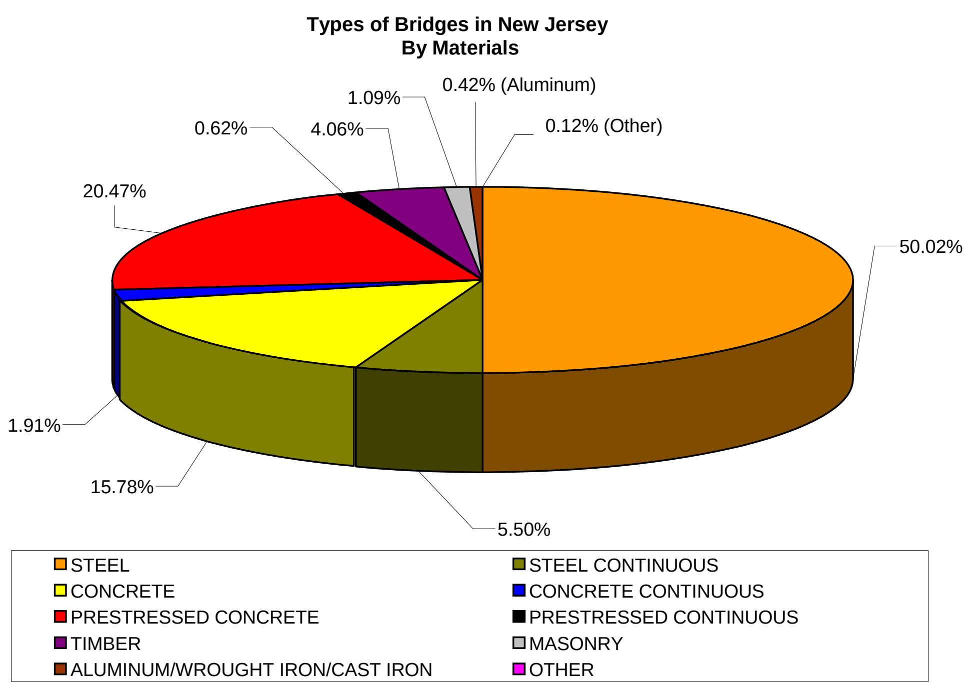


Figure 18: Percentage of Bridge Materials in NJ

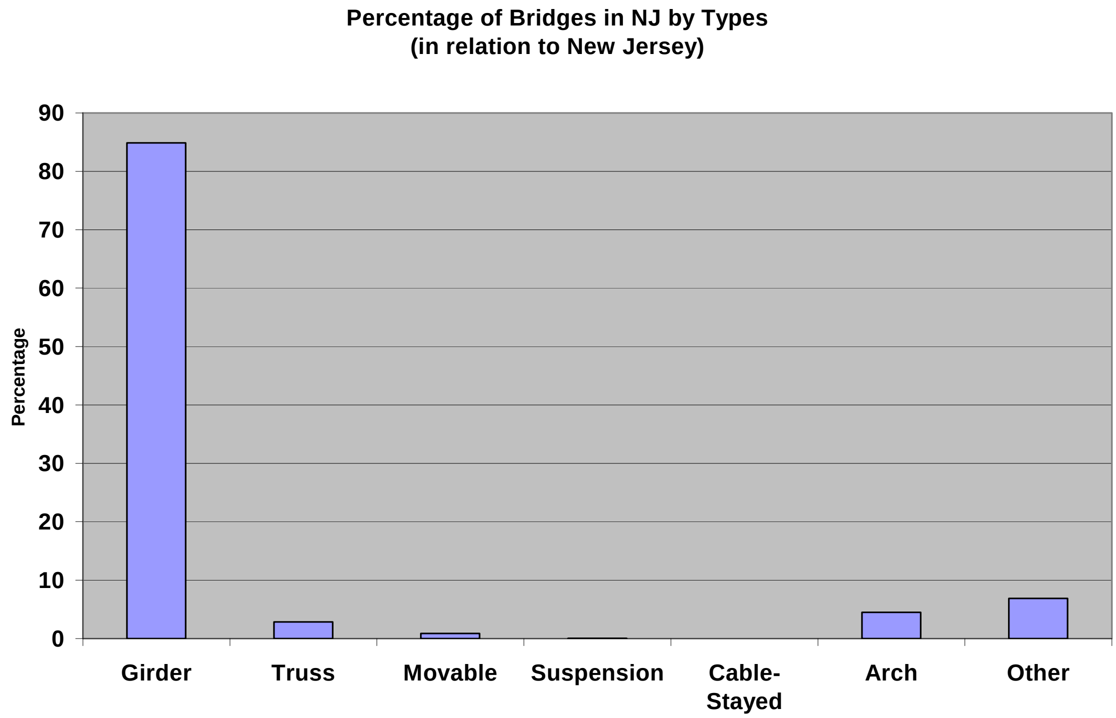


Figure 19: Percentage of Bridges in NJ by Types in Relation to New Jersey

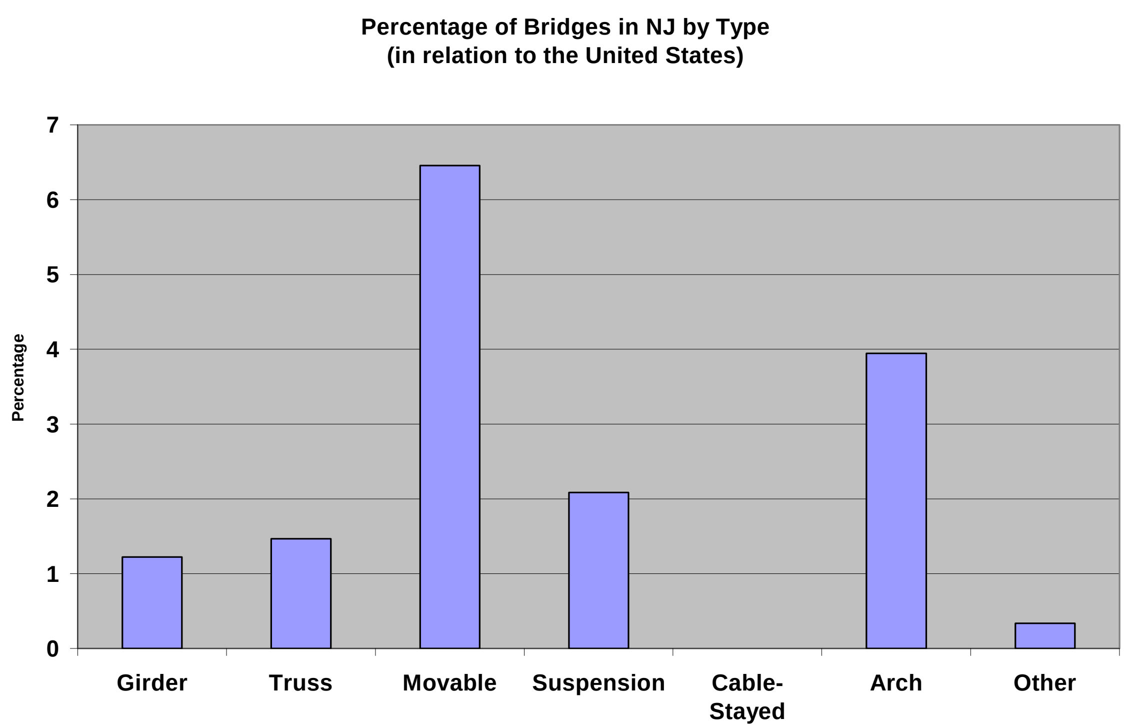


Figure 20: Percentage of Bridges in NJ by Types in Relation to the United States

CHAPTER 4. HAZARDS AND THREATS

Critical infrastructures are being targeted to achieve important types of effects such as creating physical destruction and disruption, creating fear among civilians and causing interruption of our every day business life. A wide array of tactics and techniques are in being used in conducting an attack. There are unlimited possibilities as to the types of threats that could be brought against bridge structures. However, it is impossible to design all bridges to withstand all possible combinations of attacks that may occur. Below is a list of the most likely tactics and threats:

1. **Vehicleborne Improvised Explosive Device** (VBIED): These include both landborne vehicles (i.e. truck bombs) that would be deployed against components reachable by land and waterborne vehicles (i.e. boat bombs) that would be deployed against any components reachable by water.

2. **Hand Emplaced Improvised Explosive Device** (HEIED): These include contact explosive devices such as satchel demolition charges and shaped charges that are commonly used by military engineers and civilian demolition experts to precisely cut/sever structural member.

3. **Non-Explosive Cutting Device** (NECD): These include any non-explosive devices such as saws, grinders, and torches that can be used to cut/sever structural members.

4. **Vehicular Impact** (VI): Similar to the VBIEDs, these include both landborne and waterborne vehicles depending on the location of the component of concern.

5. **Fire**: Size of fire and duration can cause structural members to lose both their stiffness and strength. Thus, fire caused by a ruptured tanker truck on the deck of a bridge, adjacent to key components or in the water adjacent to piers or towers, is of great concern.

The Federal Highway Administration (FHWA) presented in table 5 a summarized version of threats and their potential magnitude.

Table 5: Magnitude of Threats (FHWA 2003)

Threat Type	Largest Possible	Highest Probability
Conventional explosives	Truck*: 20,000 lbs Barge: 40,000 lbs	Car bomb*: 500 lbs
Collision to structure (i.e., the size of a vehicle that could collide with a structure)	Truck: 100,000 lbs GVW Water Vessel: depends on waterway	Truck: H-15 Water Vessel: (see AASHTO spec. LRFD on vessel impact)
Fire	Largest existing fuel or propane tank Largest fuel vessel or tanker	Gasoline truck (3S-2) Fuel barge
Chemical/biological HAZMAT	These threats exist; however, the panel is not qualified to quantify them. Therefore, other experts should assess these threats in this way.	

* Largest possible conventional explosive – for a truck, based on largest truck bomb ever donated internationally by a terrorist act. For a barge, based on the assumption that it is the largest explosive that could pass by unnoticed by current security at place at major waterways.

In order to reach a certain level of satisfaction, terrorists will study the behavior of a bridge; which components are more critical if subjected to a blast, how much explosive loads need to be placed next to a certain component to cause enough destruction, etc. Winget et. al (2005) studied the components of a bridge subjected to blast loads. Results from his study have shown that bridge geometry can significantly affect the blast loads that develop below the deck. For bridges with deep girders, confinement effects can greatly enhance the blast loads acting on the girders and tops of the piers and in some cases may result in more damage than an explosion occurring on top of the deck. The clearance can also have a large impact on the results, as increasing the distance from the explosion to the deck can result in more damage to the girders. However, higher clearances result in lower average loads on the piers due to the larger volume of space (less confinement) under the bridge and the increased average standoff distance to a given point on the pier. Explosions occurring near sloped abutments could possibly result in more damage than an explosion at midspan due to the confinement effects at the abutments. Finally, round columns will experience lower loads due to the increased angle of incidence from the curved surface.

Table 6 shows the critical components of various bridge types that are vulnerable to the above mentioned threats and blast loadings.

Table 6: Critical Components of Various Bridge Types

	Girder Bridge	Truss Bridge	Suspension Bridge	Cable-Stayed Bridge	Arch Bridge	Slab Bridge
Girders	X					
Splices	X					
Hangers	X					
Deck	X	X	X	X	X	X
Pier	X	X	X	X	X	X
Abutment	X	X	X	X	X	X
Seating	X	X			X	X
Top Chords		X				
Bottom Chords		X				
Diagonals		X				
Connections		X			X	
Bracing						
Main Cables			X			
Suspenders			X			
Cable Saddle			X	X		
Cable Anchor			X	X		
Tower Legs			X	X		
Tower Struts			X	X		
Stay Cables				X		
Arch					X	
Tension-tie					X	

Williamson et. al (2005) proposed a brief sample list (see Figure 21) of possible threats at specific locations on or near a bridge component.

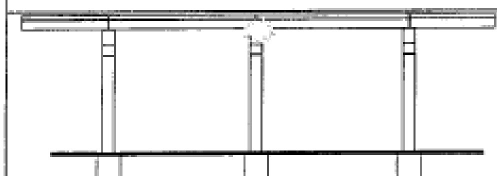
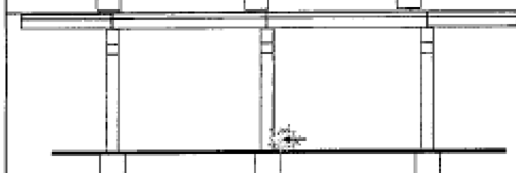
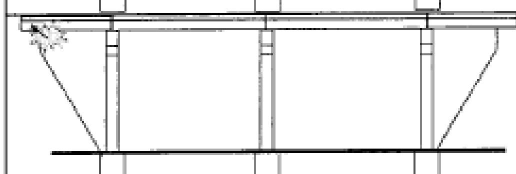
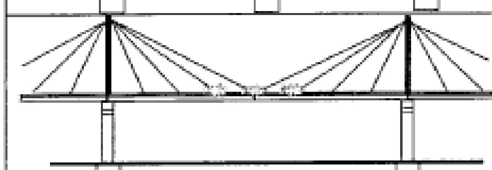
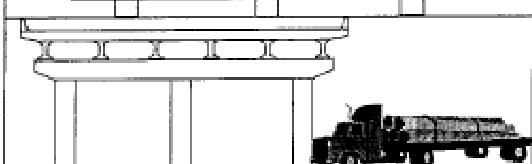
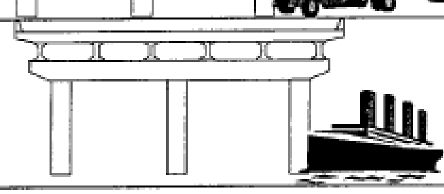
Diagram	Weapon	Location	Desired Effects
	Hand placed explosives	At girder supports	Destroy supports, collapse 2 spans
	Hand placed explosives	At column base directed towards column	Destroy column near base, damage footing, create crater, collapse 2 spans
	Hand placed explosives	On abutment seat	Destroy abutment and collapse 1 span
	Hand placed explosives	Cable anchorages	Destroy anchorages and collapse 1 or more spans
	Fuel tanker/truck bomb	On deck	Destroy deck, spall girders, subject bridge to sustained fire, collapse 1 or more spans
	Large truck	Into column	Destroy column, possible fire, collapse 2 spans
	Ship/barge	Into pier	Destroy pier, collapse 1 or more spans

Figure 21: List of possible terrorist threat actions (Williamson 2005)

For critical components, the following actions should be considered for security protection:

1. Provide enough standoff distances from these critical components.
2. Restrict access to travelers near these components.
3. Provide surveillance under and around the structure.
4. Upgrade these components using strengthening and confining techniques.

Tables 7 and 8 give approximate minimum and desired standoff distances for moving trucks near piers.

Table 7: Desired Barrier Standoff Distances from Piers (FHWA 2003)

Desired Barrier Standoffs* from Bridge Piers (Measured in ft from face of pier to front of barrier)					
Threat Type	Explosive Weight (lbs TNT)	Pier Thickness (ft)			
		~3’	~4’	~7’	> 8’
Sedan	Values	15	12	10	10
Passenger Van	have been	50	35	25	25
Box Truck	omitted	100	100	45	35
Moving Van/Water Truck	intentionally	200	150	100	100

*These are estimated values. A structure specific assessment should be done to determine actual standoff distances. FHWA Blue Ribbon Workshop (2003).

Table 8: Minimum Barrier Standoff Distances from Piers (FHWA 2003)

Minimum Barrier Standoffs* from Bridge Piers (Measured in ft from face of pier to front of barrier)					
Threat Type	Explosive Weight (lbs TNT)	Pier Thickness (ft)			
		~3’	~4’	~7’	> 8’
Sedan	Values	8	8	8	8
Passenger Van	have been	35	25	16	16
Box Truck	omitted	75	75	25	22
Moving Van/Water Truck	intentionally	150	100	75	75

*These are estimated values. A structure specific assessment should be done to determine actual standoff distances. FHWA Blue Ribbon Workshop (2003)

CHAPTER 5. RISK ASSESSMENT

Terrorism has surely existed since before the dawn of recorded history (Merrari and Friedland 1985). However, over the past 20 years the number of threats and man-made acts has increased. There are many types or threats that could be classified in the following different ways:

1. **Domestic –** in own country against own people.
2. **International –** in another country by non state actors.
3. **State sponsored –** by a government against their own people or in support of international terrorism. For example when a ruling regime provides funds, intelligence or material resources to terror groups, usually operating outside their borders.
4. **Political** – for ideological and political purposes. Groups that focus on gaining power or supremacy, removing government intrusion, or on changing beliefs.
5. **Non-political –** for private purposes or gain.
6. **Quasi-terrorism** – skyjacking and hostage taking.
7. **Limited political –** ideological but not revolutionary.
8. **Official or state –** used by nation against nation or people.
9. **Revolutionary** – aims to overthrow or replace an existing government.
10. **Nationalist –** promotes the interests of an ethnic or religious group that is seen as being persecuted by another.
11. **Cause based –** groups devoted to a social or religious cause using violence to address their grievances.

12. **Environmental** – groups dedicated to slowing down development they believe is harming animals.
13. **Genocide** – when a government seeks to wipe out a minority group in its territory.

Focusing on infrastructure and specifically bridges, malicious acts would take place for the following reasons:

1. Kill as many civilians as possible, so attacking a bridge during morning or afternoon rush hour would be considered.
2. Disrupt the commute of civilians by bombing a bridge span which could create a gap between two major cities where people would have to find different routes to commute to their jobs
3. Impact the economy resulting from the large cost and time it would take to repair or replace a bridge, weaken the government and set fear in peoples' lives.
4. Get the media's attention in order to become famous around the world of what have been caused.

From the above listed goals, we can begin the risk assessment by first identifying out of the 6000+ bridges we have in New Jersey, which ones are more critical or a target to an attack. One way of narrowing the important bridges down is to look at the map of New Jersey in relation to the 2006 population estimates in each county collected from the U.S. Census Bureau (see Figure 22).

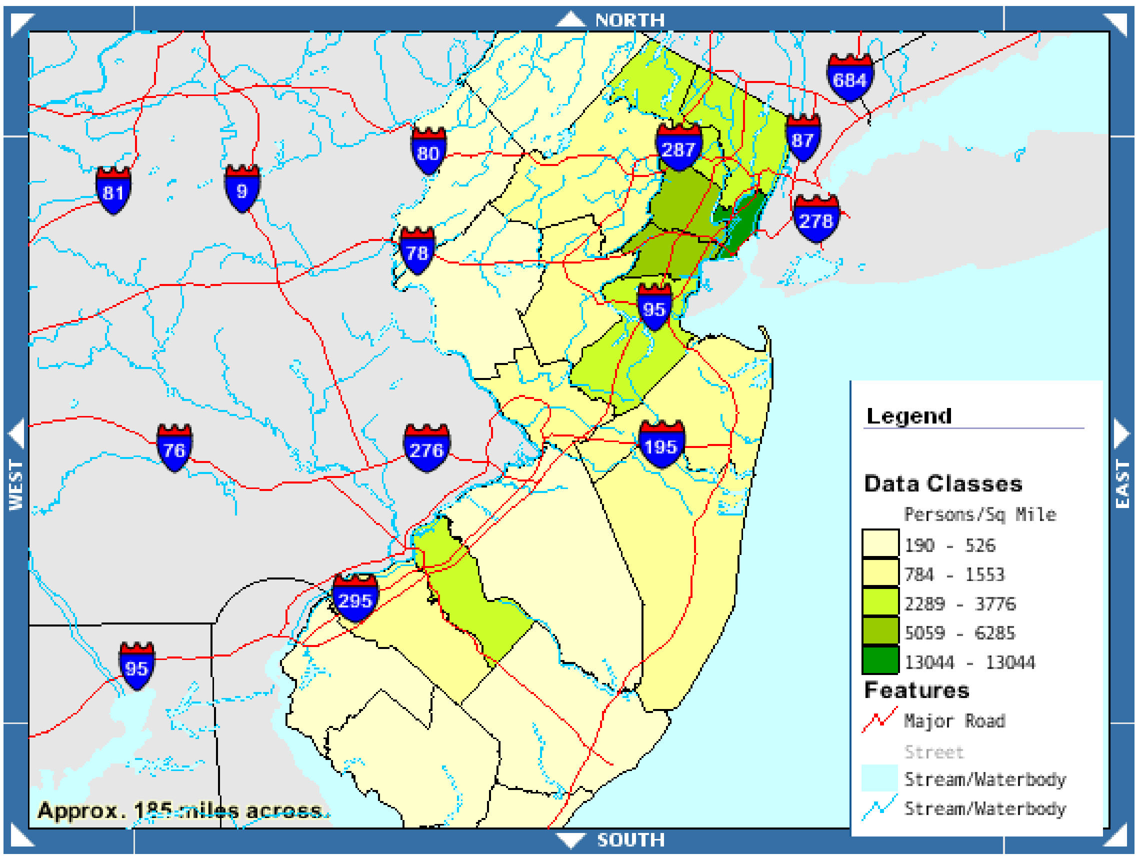


Figure 22: 2006 Population Estimates of New Jersey (U.S. Census Bureau) (http://factfinder.census.gov/servlet/ThematicMapFramesetServlet?_bm=y&-geo_id=04000US34&tm_name=DEC_2000_SF1_U_M00090&ds_name= DEC_2000_SF1_U&-_MapEvent=displayBy&-_dBy=050&-_lang=en&-_sse=on)

Figure 23: Map of New Jersey and its counties
(http://www.shotcredit.com/images/statemaps/New_Jersey_Counties.png)

As it's seen in the above map, the most populated county in the North connecting New Jersey to New York City (the most populated city in the state and in the entire United States) is Hudson with 13044 persons per square mile. Then come Essex and Union County with an average of around 6000 persons per square mile, and later Bergen, Passaic and Middlesex County with an average of around 3000 persons per square mile. Whereas in the Southwest connecting New Jersey to Philadelphia (the sixth most populous city in the United States) is Camden County with an average of about 3000 person per square mile. Not to forget Atlantic County and mainly Atlantic City with tourist attractions and casinos (even thought it's not a very populated county according to the U.S. census bureau).

Focusing on the northern counties of New Jersey, we find that the George Washington Bridge and Verrazano-Narrows Bridge are two important bridges because not only they connect two major cities together but also they are symbolic bridges that could be a target to attack and cause so much destruction.

From the above analysis, after understanding the behavior of bridge components under blast loads, a set of questions was developed to be part of the simple checklist that will mainly categorize all bridges in New Jersey according to the most risky and the likelihood that a certain bridge will get attacked. The questions were not included in this paper. For more information please contact NJDOT. The questions are categorized into three sections:

<u>Occurrence Factor (O)</u>

As mentioned previously, the occurrence factor measures the relative likelihood of a basic threat actually occurring against a given component on the bridge. The occurrence factor consists of multiple sub-factors:

- <u>Threat Likelihood</u>: the likelihood that a certain type of threat will be chosen instead of another one. From various lists of incidents collected for this study, it has shown the most preferred method of weapon is to use hand-emplaced explosive devices and vehicleborne explosive devices both landborne and waterborne such as truck bombs and boat bombs.

- The likelihood of a given threat against a given component: similar to the above sub-factor, however it narrows down the choice of a specific type of threat used at a certain component of the bridge. For example, a non-explosive cutting device is less likely chosen to attack a reinforced concrete pier.
- Visibility or attractiveness of a component: The likelihood that a bridge component will be recognized as critical to the structural stability.
- Access to a component: this deals with how easy it is to access a certain component such as bearings or a deck.

Vulnerability Factor (V)

The vulnerability factor is the likelihood that a bridge will be susceptible to destruction by a given threat. One important aspect is the resistance of a component to a type of threat such as vehicleborne explosive devices or hand-emplaced devices. This means how much destruction a component will face if subjected to a specific amount or size of explosives. Terrorists will try to get as close as possible to a component when using their threat. However, to make it easier and have more time efficient, they will not carry large explosives to place them in certain areas.

Importance Factor (I)

The importance factor measures the importance of an individual component to the bridge. The following sub-factors are considered:

- Structural importance of component: this deals with the importance of a component to the overall stability of the bridge. Looking for specific components that if attacked, will result in complete collapse and destruction of the bridge is something to consider. For this matter, this is the most important sub-factor and will be given a higher weight.
- Historical/symbolic importance of the component: this applies to components of the bridge being historic or well known after a famous engineer.
- Relative repair cost for the component if damaged: this relates to if a component was attacked and got damaged, however the bridge did not completely collapse. Nonetheless, it will cost a fortune to repair the component and get the bridge back to service.
- Relative time out of service for the bridge if component is damaged: similarly, this deal with the actual time the bridge will be out of service until the component is fully repaired.

According to Ray et. al (2007) the weight for each sub-factor (shown in table 9) were derived using the pairwise comparison procedure of the analytical hierarchy process (Ragsdale 2002). Knowledgeable sources were asked to assign numeric value to the relative importance of one sub-factor over another. There is still much room for improvement of these factors.

Table 9: Weight for sub-factors (Ray 2007)

Risk Factor	Sub-factors	Weight
Occurrence	Threat likelihood in general	0.11
	Threat likelihood against component	0.25
	Visibility and attractiveness of component	0.09
	Easy access to component	0.54
Vulnerability	Resistance of component to basic threat	1.00
Importance	Structural importance	0.56
	Historic/symbolic importance	0.06
	Repair cost if damaged	0.26
	Time out of service if damaged	0.12

Most of the questions are a Yes or No answer and are addressed in a simple matter to make it easier for bridge inspectors or engineers to answer them. Each question is assigned a weight based on its importance. Each answer is then evaluated and assigned a relative score depending on each question. The scores are then multiplied by the weight, and summed for each section to determine its overall score. Finally, the total scores of each section are multiplied together to determine the relative risk of that specific bridge.

Some answers could be retrieved from the National Bridge Inventory. For that matter, a link between the checklist and the NBI could be made to automatically answer those questions, specifically questions related to the bridge's average daily traffic, the length of the span, the location of the bridge, the sufficiency rating, and many more.

The risk assessment checklist was tested on actual bridge sites selected as a case study. Three bridges were selected: Bridge 1, Bridge 2, and Bridge 3.

The checklist was applied to each bridge and the scores were automatically calculated in excel format. The results conclude that the Bridge 1 has a risk factor of 0.63 whereas Bridge 2 has a risk factor of 0.12 and Bridge 3 has a risk factor of 0.19. This means that Bridge 1 has 63% chance of being targeted, Bridge 2 has a 12% chance and Bridge 3 has 19% chance of being attacked. The intent of this checklist is to evaluate all bridges in New Jersey and sort them by their likelihood of being targeted. The top 10 percent will be chosen to focus on protecting them against any malicious act. The checklist is not limited to New Jersey bridges only. Nevertheless, it could be used for any type of bridge anywhere in the world because the questions target the critical components of all bridges and also deals with security. Inspectors could use the checklist while doing their routine bridge inspection or start off by focusing on the most populated counties mentioned previously.

The checklist needs to be implemented for on-site assessment. There are many ways someone can think of doing that will facilitate the use of the checklist. One of them is to use a portable electronic device called a tablet notebook computer that will process the checklist. The Table PC (Figure 24) has all of the capabilities of a notebook computer plus the ability to fold the screen flat and interact using a digital stylus. A Table PC uses the Windows XP™ operating system. All of the user interfaces and file formats are the same as any typical desktop computer. The user can exchange files directly without additional conversion or adapters. Furthermore, the Table PC can store other necessary reference documents and multimedia for instant use in the field. Bridge plans, inspection manuals, previous inspection reports, photos and others are ready at the touch of a screen. In terms of security, Table PCs are available with the latest digital encryption with fingerprint or password protection. Table PCs feature high speed USB ports and BlueTooth™ connectivity. Peripherals such as digital cameras can be connected to upload field photos and add to the inspection files.

Table PCs are more versatile and less expensive than in the past. A fully charged internal lithium ion batter can power the tablet for up to four hours. Extra batteries can easily be swapped for extended inspections. Tablet PCs are also highly portable. A typical size is 10x12x1.5 inches weighing about 4 pounds. Ruggedized models are available at a higher cost, but will survive more abuse.

Since the Table PC is a full-featured notebook computer, there is no need for a separate desktop computer. The inspector can use the Tablet in the field to collect information and later use the same computer to prepare the final report. Additionally, the answers to the questions and the calculated risk could automatically be transferred and stored in a database file at the State DOT even while still at the field.

Future versions of the checklist can take advantage of the handwriting recognition. Extra notations can be made in writing instead of time consuming keyboard entry. Quick sketches of bridge details can be made. A built-in microphone could also record voice messages to be transcribed later. GPS receivers can be added to record geospatial information such as the location of structure features. The GPS data can be processed with common mapping software to provide maps of inspection information. The location data can also be synchronized with Geographic Information Systems (GIS).

Figure 24: Table PC (Wikipedia 2008)
http://en.wikipedia.org/wiki/Tablet_PC

CHAPTER 6. COUNTERMEASURES

After completion of the risk assessment and identifying the critical bridges in New Jersey, appropriate countermeasures need to be considered. There are a variety of countermeasures that can be used to reduce attractiveness and/or vulnerability of a bridge or to reduce consequences if an attack occurs. New technologies are available to deter attacks, deny access, detect presence of terrorists, defend the facility, or design structural hardening.

Capers et. al (2005) suggested the following countermeasures:

1. Restrict parking under a bridge structure.
2. Installation of surveillance cameras.
3. Restrict the placement of vegetation.
4. Restrict access to ventilation machinery in tunnels.
5. Detail installation of emergency shut-off mechanisms.
6. Restrict access to key details.
7. Restriction of access to movable bridge machinery and operator’s housing.
8. Detail the lighting to ensure surveillance.
9. Detail all components so that no component is concealed from view.
10. Prohibit the use of non-redundant members.
11. Protect all main load carrying members from direct impact.
12. Locate utilities as to minimize their potential use as weapons.

Michael Baker Jr. Inc. (Baker 2007), located in Princeton, NJ, conducted an evaluation on one of their bridges in New Jersey. For the Route 52 Causeway Replacement Project, located between Ocean City and Somers Point, the countermeasures listed below were found to be the most suitable and would provide the needed level of protection.

- Secure Superstructure box entrance; place at visible, high locations.
- Provide bollards around piers in land areas where access is prohibited, or provide bollards in areas that would deny vehicular access to pier locations.
- Under deck, parking will be totally prohibited by disallowing access to areas underneath the bridge to the general public.
- Only maintenance and emergency vehicles would have controlled access to areas underneath the bridge.
- Provide lighting inside boxes for inspection and security.
- Provide remote alarm signal to register if access openings to the boxes were opened by unauthorized personnel.
- For piers in the water, a consideration should be given for providing a fendering system to increase the standoff distance.
- Provide a closed circuit television (CCTV) camera system with night vision capabilities in select sensitive areas on land that could detect suspicious activity.

The Federal Highway Administration provided recommendations and countermeasures for bridge and tunnel security (Bride and Tunnel Security 2003). Some of those recommendations were divided into the following two categories:

1. Approaches to mitigate threats
    - Establish a secure perimeter using physical barriers.
    - Provide inspection surveillance, detection and enforcement, and closed circuit television (CCTV).
    - Provide visible security presence.
    - Minimize the time on target.

2. Approaches to mitigate consequences
    - Create standoff distance- incorporating sufficient standoff distances from primary structural components will help resistance from blasts.
    - Add design redundancy – this will help limit collapse in the event of severe structural damage from unpredictable terrorist acts.
    - Hardening/strengthening the elements of the structure – this will minimize damage and complete collapse of the structure.
    - Develop an accelerated response and recovery plan – alternative routes and evacuation plans should be established.

NIPP (2006) introduced an effective, efficient program over the long term. Five steps, described below, were used for this program.

1. Building national awareness – this could be done by organizing workshops about bridge security and bring in experts that could present new things.
2. Enabling education, training and exercise programs – bridge inspectors need to be trained to use the checklist. Community residents need to be educated by preparing them for any threat and be aware of any suspicious act.
3. Conducting research and development and using technology – for this research a checklist was developed and new technological devices were used.
4. Developing, protecting, and maintaining data systems and simulations – this means that for example the developed checklist will only be provided to certain agencies.
5. Continuously improving the checklist and associated plans and programs through ongoing management and revision, as required.

Furthermore, Winget et. al (2005) recommended that design and retrofit options for girders should include the use of fiber reinforced polymers (FRPs). Fiber-reinforced polymers are robust materials that are highly resistant to corrosive action, have a high strength to weight ratio and are well suited for assembly line production into modular components that can be rapidly erected. However, FRP material costs are significantly greater than traditional concrete and steel materials. Therefore, cost savings due to either reduced weight, increased speed of construction or lower maintenance and increased life expectancy must offset this higher cost to make sensible use of FRP materials. Additional steel reinforcement using blowout panels on the decks to help vent loads are also recommended. To prevent a span collapse, the girders and deck can be restrained at the supports with steel cables, or hinge restrainers can be used to hold the deck to the columns. Abutment seat sizes can be increased or hinge seat extensions can be used under expansions joints. For piers lateral bracing could be included and minimum pier diameters and reinforcement could be established.

CHAPTER 7. CONCLUSIONS

A risk-based methodology and bridge security checklist has been presented in this research to provide identification of critical bridges throughout New Jersey. After evaluating all bridges in New Jersey, security measures and hardening of the structure will take effect for the top 10 percent. Based upon the analysis of the three bridges evaluated in this case study, the methodology has proven very useful and provided consistent and reliable results. The use of the security checklist in a spreadsheet format makes it easy and timely efficient for engineers and inspectors to evaluate the bridges. The checklist is enhanced by links to help type functions that provide images or explanations to provide the bridge inspector with unambiguous directions. The tablet PC is a lightweight device where the answers to the questions and the calculated risk could automatically be transferred and stored in a database file at the State DOT even while still at the field.

The inspection for Bridge 3, using the checklist, was closely coordinated with the NJDOT Transportation Security Bureau and NJDOT Bridge Bureau as well as the State Law Enforcement Agencies. Various NJ bridge inspectors were selected. They visited bridge 3 and applied the checklist. The experienced inspectors provided some important feedback on the applicability of the checklist. They found no difficulty in answering the questions because the answers were provided in a drop down list format.

For future work, the inspectors will be trained in a classroom workshop on the use of the checklist and the tablet PC. They will learn where to look on the bridge and easily identify the critical components. Inspectors will be asked to provide detailed comments on the ease of use, applicability, and changes needed to improve the checklist or on the PC programming. The comments will be compiled and reported to the NJDOT Project Manager for further refinement and/or development.

Weapons and tactics against transportation systems will keep on being invented in an attempt to create public fear and panic while gaining publicity and attention. The events of September 11, 2001 have heightened the growing need to provide security to vital assets of our transportation infrastructure. According to the U.S. Transportation Secretary Norman Y. Mineta, “America is fundamentally different place from the one that awoke on September 11th. We have entered into a new era in transportation, an era in which one of our most cherished freedoms, the freedom of mobility, has been threatened. Overcoming that threat will require all of us to take a fresh and honest look at the business we are in. We must rethink the basic approach with which we provide for the safety and security of everyone traveling on America’s transportation systems” (Mineta 2001).

Bridges are not only public structures used to commute from and to cities, but they also carry symbolic references as well as serve utilitarian purposes. These great structures of humankind give us a real, physical reminder of who we are what we can achieve. It is very important to protect them from any kind of theat. The methodology presented in this research has much room for continued improvement. It is hoped that this checklist will help our nation in the fight against man-made threats.

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APPENDIX A

Bridge Data in New Jersey (Tobin 2007)

MATERIAL	DESIGN	# OF BRIDGES
STEEL	SLAB	3
	STRINGER/MULTIBEAM GIRDER	2740
	GIRDER AND FLOORBEAM SYSTEM	219
	BOXBEAM OR GIRDERS-MULTIPLE	4
	BOXBEAM OR GIRDERS-SINGLE OR SPREAD	2
	FRAME (EXCEPT FRAME CULVERTS)	1
	TRUSS-DECK	8
	TRUSS-THRU	159
	ARCH-DECK	11
	SUSPENSION	2
	MOVABLE-LIFT	11
	MOVABLE-BASCULE	35
	MOVABLE-SWING	11
	CULVERT(INCLUDES FRAME CULVERTS)	12
STEEL CONTINUOUS	STRINGER/MULTIBEAM GIRDER	319
	GIRDER AND FLOORBEAM SYSTEM	29
	BOXBEAM OR GIRDERS-SINGLE OR SPREAD	1
	FRAME (EXCEPT FRAME CULVERTS)	2
	TRUSS-THRU	3
CONCRETE	OTHER	1
	SLAB	206
	STRINGER/MULTIBEAM GIRDER	15
	TEE BEAM	58
	BOXBEAM OR GIRDERS-MULTIPLE	19
	FRAME (EXCEPT FRAME CULVERTS)	127
	ARCH-DECK	204
	ARCH-THRU	2
	TUNNEL	1
	CULVERT(INCLUDES FRAME CULVERTS)	382
CONCRETE CONTINUOUS	OTHER	1
	SLAB	57
	STRINGER/MULTIBEAM GIRDER	9
	TEE BEAM	13
	BOXBEAM OR GIRDERS-MULTIPLE	7
	FRAME (EXCEPT FRAME CULVERTS)	10
	CULVERT(INCLUDES FRAME CULVERTS)	26

MATERIAL	DESIGN	# OF BRIDGES
PRESTRESSED CONCRETE	SLAB	284
	STRINGER/MULTIBEAM GIRDER	452
	GIRDER AND FLOORBEAM SYSTEM	6
	TEE BEAM	4
	BOXBEAM OR GIRDERS-MULTIPLE	535
	BOXBEAM OR GIRDERS-SINGLE OR SPREAD	31
	FRAME (EXCEPT FRAME CULVERTS)	3
	CHANNEL BEAM	2
PRESTRESSED CONTINUOUS	SLAB	1
	STRINGER/MULTIBEAM GIRDER	18
	BOXBEAM OR GIRDERS-MULTIPLE	18
	BOXBEAM OR GIRDERS-SINGLE OR SPREAD	2
	SEGMENTAL BOX GIRDER	1
TIMBER	OTHER	10
	SLAB	101
	STRINGER/MULTIBEAM GIRDER	147
	TEE BEAM	2
	BOXBEAM OR GIRDERS-MULTIPLE	1
MASONRY	ARCH-DECK	70
ALUMINUM/WROUGHT IRON/CAST IRON	STRINGER/MULTIBEAM GIRDER	1
	GIRDER AND FLOORBEAM SYSTEM	1
	TRUSS-THRU	14
	ARCH-DECK	3
	CULVERT(INCLUDES FRAME CULVERTS)	8
OTHER	STRINGER/MULTIBEAM GIRDER	3
	BOXBEAM OR GIRDERS-MULTIPLE	1
	CULVERT(INCLUDES FRAME CULVERTS)	4

Count of Bridges by Structure Type (FHWA 2007)

	Slab	Stringer /Multi-Beam or Girder	Girder & Floorbeam System	Tee Beam	Box Beam or Girders (Multiple)	Box Beam or Girders (Single or Spread)	Frame (Except Culverts)
ALABAMA	755	5,676	274	1,881	137	6	157
ALASKA	20	687	15	290	52	7	0
ARIZONA	879	1,268	32	169	382	556	96
ARKANSAS	1,893	4,304	78	596	64	0	16
CALIFORNIA	5,601	3,854	84	3,093	7,332	199	35
COLORADO	342	3,851	87	1,477	331	287	137
CONNECTICUT	514	2,179	52	134	265	80	121
DELAWARE	71	368	10	3	110	12	16
DIST. OF COL.	4	130	31	5	17	4	23
FLORIDA	3,201	5,097	36	312	19	94	7
GEORGIA	1,152	5,311	44	2,168	196	106	10
HAWAII	202	276	39	255	113	0	20
IDAHO	235	2,003	57	913	97	28	518
ILLINOIS	2,352	7,691	197	618	8,373	55	130
INDIANA	3,429	6,233	148	202	4,466	520	42
IOWA	4,644	13,255	201	1,165	43	3	18
KANSAS	4,856	9,520	494	1,300	364	8	53
KENTUCKY	740	3,591	180	2,548	3,074	185	17
LOUISIANA	5,405	4,318	185	401	75	0	0
MAINE	366	1,186	57	253	10	4	62
MARYLAND	392	2,599	93	159	206	25	94
MASSACHUSETTS	562	2,870	143	249	210	76	113
MICHIGAN	598	5,098	129	818	2,331	145	29
MINNESOTA	1,813	5,463	268	10	79	0	32
MISSISSIPPI	668	7,258	127	162	44	304	66
MISSOURI	2,535	12,970	292	1,704	231	256	21
MONTANA	272	3,512	96	613	13	2	12
NEBRASKA	1,812	8,414	429	634	53	0	12
NEVADA	204	233	14	42	413	29	39
NEW HAMPSHIRE	203	1,357	41	78	33	1	252
NEW JERSEY	656	3,713	259	77	584	36	142
NEW MEXICO	344	1,470	6	75	108	16	20
NEW YORK	1,090	9,925	519	184	1,471	27	898
NORTH CAROLINA	1,949	9,327	233	704	28	18	33
NORTH DAKOTA	106	1,716	17	384	226	591	0
OHIO	4,342	11,611	498	864	6,496	0	526
OKLAHOMA	2,365	12,341	201	723	73	11	45
OREGON	2,454	3,069	106	123	545	38	225
PENNSYLVANIA	1,143	7,744	663	2,305	2,974	2,102	218
RHODE ISLAND	75	434	12	22	51	1	25
SOUTH CAROLINA	4,245	2,833	17	891	14	4	5
SOUTH DAKOTA	1,296	2,134	26	752	34	4	18
TENNESSEE	260	5,329	24	2,156	870	1,524	54
TEXAS	4,525	22,064	75	1,379	2,288	36	40
UTAH	122	1,511	20	316	39	0	249
VERMONT	414	1,547	57	296	17	1	17
VIRGINIA	1,578	6,871	105	979	301	16	157
WASHINGTON	1,323	3,078	130	1,186	418	325	135
WEST VIRGINIA	554	2,853	313	133	1,663	35	27
WISCONSIN	4,447	6,551	133	5	108	0	74
WYOMING	468	1,484	48	439	45	4	26
PUERTO RICO	403	1,061	37	199	57	6	28
TOTALS	79,879	249,238	7,432	36,444	47,543	7,787	5,110

	Orthotropic	Truss-Deck	Truss-Thru	Arch-Deck	Arch-Thru	Suspension	Stayed Girder
ALABAMA	0	3	113	26	7	0	1
ALASKA	9	7	52	5	0	0	2
ARIZONA	1	8	24	34	1	0	0
ARKANSAS	419	11	97	76	7	2	0
CALIFORNIA	4	60	235	305	12	11	0
COLORADO	0	6	90	45	14	1	0
CONNECTICUT	1	6	30	173	1	0	0
DELAWARE	0	2	6	22	1	2	1
DIST. OF COL.	1	0	0	16	0	0	0
FLORIDA	0	1	52	25	2	1	2
GEORGIA	0	2	31	49	0	0	2
HAWAII	0	4	7	26	5	0	0
IDAHO	0	4	100	15	2	2	0
ILLINOIS	3	7	345	70	14	3	10
INDIANA	0	10	481	771	6	0	2
IOWA	0	7	1,309	112	13	3	1
KANSAS	0	15	660	316	46	0	0
KENTUCKY	0	11	169	24	10	2	1
LOUISIANA	0	3	49	20	0	0	1
MAINE	0	6	63	39	4	3	0
MARYLAND	0	10	85	202	8	2	0
MASSACHUSETTS	0	19	88	300	9	1	3
MICHIGAN	2	14	100	103	18	1	0
MINNESOTA	0	6	159	76	5	1	0
MISSISSIPPI	0	4	69	24	0	0	0
MISSOURI	0	8	999	99	8	7	3
MONTANA	0	11	168	12	0	1	0
NEBRASKA	0	2	938	51	3	0	0
NEVADA	0	2	2	17	0	0	0
NEW HAMPSHIRE	0	3	63	59	4	0	0
NEW JERSEY	0	8	177	288	2	2	0
NEW MEXICO	0	7	38	7	1	0	0
NEW YORK	3	33	583	761	16	19	0
NORTH CAROLINA	0	2	46	45	0	0	0
NORTH DAKOTA	0	0	224	2	1	0	0
OHIO	0	187	1,081	366	20	3	0
OKLAHOMA	2	14	822	123	7	0	0
OREGON	0	38	153	48	16	3	0
PENNSYLVANIA	1	46	660	856	20	10	0
RHODE ISLAND	1	0	11	80	1	2	0
SOUTH CAROLINA	0	1	42	49	0	0	0
SOUTH DAKOTA	0	6	177	12	2	0	0
TENNESSEE	0	7	68	183	8	0	0
TEXAS	7	25	298	98	11	5	0
UTAH	0	2	17	14	3	0	0
VERMONT	0	8	135	25	11	0	0
VIRGINIA	0	13	157	157	12	0	1
WASHINGTON	1	33	174	170	30	5	5
WEST VIRGINIA	2	31	247	465	6	4	2
WISCONSIN	0	15	109	87	8	0	0
WYOMING	0	3	60	5	1	0	0
PUERTO RICO	1	5	9	19	1	0	0
TOTALS	458	736	11,872	6,972	377	96	37

	Movable-Lift	Movable-Bascule	Movable-Swing	Tunnel	Culvert	Mixed Types	Segmental Box Girder	Channel Beam	Other
ALABAMA	1	1	0	1	5,979	1	1	823	38
ALASKA	0	0	0	0	67	0	0	0	16
ARIZONA	0	0	0	0	3,921	0	1	11	4
ARKANSAS	0	0	0	0	2,920	0	0	2,048	3
CALIFORNIA	6	16	17	24	3,210	10	2	19	53
COLORADO	0	0	0	0	1,689	0	16	0	1
CONNECTICUT	2	8	4	0	593	0	2	9	1
DELAWARE	0	9	2	0	222	0	0	0	0
DIST. OF COL.	0	0	1	13	0	0	0	0	0
FLORIDA	4	137	10	1	2,220	1	66	343	15
GEORGIA	0	3	1	0	5,454	7	0	26	1
HAWAII	1	0	0	4	164	0	0	0	1
IDAHO	1	0	0	0	114	0	1	13	1
ILLINOIS	6	53	3	5	4,238	0	4	1,469	352
INDIANA	0	3	0	0	1,617	0	19	420	125
IOWA	0	0	1	0	3,746	0	1	224	30
KANSAS	0	0	0	0	7,747	0	0	2	83
KENTUCKY	0	1	0	0	2,855	0	3	209	19
LOUISIANA	46	12	94	3	2,445	0	0	269	6
MAINE	4	1	8	0	321	0	0	0	0
MARYLAND	0	21	3	0	1,157	1	1	2	68
MASSACHUSETTS	0	22	7	5	302	0	32	1	7
MICHIGAN	1	21	4	0	1,458	0	2	6	45
MINNESOTA	2	1	2	1	5,144	0	0	2	2
MISSISSIPPI	2	7	3	1	3,370	0	6	4,835	57
MISSOURI	0	0	0	0	4,748	0	2	171	17
MONTANA	0	0	0	0	205	3	0	49	11
NEBRASKA	0	0	0	0	3,073	0	1	47	3
NEVADA	0	0	0	0	704	0	4	0	2
NEW HAMPSHIRE	2	2	0	0	244	0	0	2	20
NEW JERSEY	11	35	11	1	430	0	1	2	12
NEW MEXICO	0	0	0	0	1,679	0	9	69	0
NEW YORK	24	33	12	2	1,678	2	3	12	66
NORTH CAROLINA	1	6	12	0	4,928	0	3	421	2
NORTH DAKOTA	0	0	0	0	874	0	1	313	3
OHIO	5	5	1	0	1,774	0	0	0	220
OKLAHOMA	0	0	0	0	6,738	0	2	36	25
OREGON	9	8	3	0	297	2	2	170	9
PENNSYLVANIA	1	3	0	1	1,672	1,768	0	35	98
RHODE ISLAND	0	0	1	0	28	0	1	1	2
SOUTH CAROLINA	0	3	4	3	1,082	0	2	12	14
SOUTH DAKOTA	0	0	0	0	1,210	0	0	251	2
TENNESSEE	0	1	0	0	8,474	0	0	878	2
TEXAS	2	1	7	0	18,337	0	0	0	1,074
UTAH	0	0	0	0	544	0	0	0	7
VERMONT	0	2	0	0	176	0	0	5	1
VIRGINIA	3	7	8	1	3,034	0	8	1	9
WASHINGTON	47	12	6	0	283	0	5	290	22
WEST VIRGINIA	0	0	0	0	514	0	10	129	19
WISCONSIN	7	35	0	1	1,973	0	0	229	16
WYOMING	0	0	0	0	432	0	0	9	3
PUERTO RICO	1	0	0	0	317	0	1	0	1
TOTALS	189	469	225	67	126,401	1,795	212	13,863	2,588