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Infrastructure Security and Emergency Preparedness: Selecting Asset Protection Strategies

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Disclaimer

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ABSTRACT

Transportation infrastructure is exposed to several kinds of unintentional (natural) and intentional (attacks) hazards. Keeping the transportation system working before and after a severe event is a vital task of transportation agencies. In the past decade, transportation agencies have used an asset management framework to support the improvement, maintenance and operation of transportation facilities. So, risk analysis and management is an essential part of any asset management framework. Choosing the appropriate countermeasures to prevent, mitigate and control the risk of severe events is an important activity in the risk management process. A recent National Cooperative Highway Research Program (NCHRP) report provides a guide for transportation agencies to select appropriate countermeasures to protect their critical assets. However the selection of countermeasures is completely qualitative and subjective.

This report develops a quantitative system to evaluate the effectiveness of countermeasures. Moreover, budget constraints are always a limitation for transportation agencies and this is not addressed in the NCHRP guide. The problem of choosing countermeasures is redefined as "selecting the most effective countermeasures considering the budget constraint". This problem is formulated as an optimization problem. The objective of the optimization problem is to maximize the effectiveness of the selected set of countermeasures. This objective is subject to a budget constraint. A conventional optimization solution method is applicable to this problem. A case study using bridges in the state of Delaware is developed and the results of the new method are compared with the result using NCHRP guide. The optimization method shows significant improvements over the qualitative method in terms of the effectiveness of protection of the bridges.

CHAPTER 1 INTRODUCTION

1.1 Problem Statement

Natural disasters are always major threats to civil infrastructure. The owners of transportation infrastructure (assets) have learned that to keep their system working during and after a disaster some countermeasures should be applied to prevent the infrastructure failure and to mitigate the impact of damage and failure. Several studies have been conducted to address this issue. Most studies focus on a specific kind of natural hazard that is particularly relevant to or important for local agencies, and these studies have tried to assess the risk related to the natural hazard and propose the appropriate countermeasures based on benefit/cost analysis. But the point is natural disasters are not the only source of hazards; errors and variability in design and operation and intentional attacks are the other kinds of hazards that agencies should deal with. Moreover, each transportation agency is responsible for many different types of assets such as pavements, bridges, and tunnels. Transportation agencies and authorities should decide how to allocate their budget to different types of assets recognizing the kinds of hazards to which these assets are exposed.

To help transportation agencies to allocate their budget an all hazard guide for transportation agencies for costing asset protection (CAPTA) was developed as part of a National Cooperative Highway Research Program project (Science Applications International Corp. and PB Consult, 2009a). In this guide, critical or high cost assets are identified first. Then, a list of appropriate countermeasures for those assets is proposed. The users of the guide choose the most appropriate countermeasure for their assets from the proposed countermeasures. Although the effectiveness of countermeasures for each asset is identified by choosing one of three levels: high, medium and low, it is still complicated for users to choose the best countermeasure for their assets for several reasons. First, the effectiveness of a countermeasure is defined based on the highest effectiveness of that countermeasure for different hazards. In this case there is no difference between a countermeasure which has a high effectiveness for several kinds of hazards and a countermeasure which is highly effective only for one kind of hazard. Second, choosing a set of countermeasures that is in the budget range and has the greatest total effectiveness is complicated and needs lots of iterations.

This research is developed to help agencies in choosing the most effective countermeasures while they are using CAPTA as their guide to protect their critical assets.

1.2 Motivation, Objective and Scope

The motivation for this research comes from real experiences. The Department of Homeland Security considers the protection of our national infrastructure systems to be one of its main missions as set forth in Homeland Security Presidential Directive 7 (HSPD-7), Critical Infrastructural Identification, Prioritization, and Protection. The primary goal of the National Infrastructural Protection Plan (Department of Homeland Security, 2006)—which defines the specific federal responsibilities and strategies for implementing HSPD-7—is to build a safer, more resilient America by enhancing the nation's civil infrastructural systems from terrorist attacks and natural or technological disasters through strengthening preparedness, improving response capabilities, and developing rapid recovery strategies. Of special relevance to this proposal is the joint responsibility of the Department of Transportation and DHS to collaborate on all matters pertaining to transportation security and transportation infrastructural protection (Department of Homeland Security, 2006).

Given the many pressing needs for transportation resources in Delaware, assessing the vulnerability and risk of Delaware's critical transportation infrastructure, identifying possible countermeasures, and estimating the capital and operating costs of these improvements is challenging.

CAPTA is a high level modeling system, which is intended to be used by managers in transportation agencies responsible for several modes (Science Applications International Corp. and PB Consult, 2009a). An appropriate use of CAPTA is at the state level. Working with CAPTA to identify the best countermeasures for assets in Delaware revealed that the most subjective part of CAPTA, which ends in different results for different users, is the step involving choosing the countermeasures. However, consistency in results was a major goal in the CAPTA model. Besides a more in-depth look at the results showed that countermeasures, which are defined as having the same level of effectiveness, may really have a different overall effectiveness based on the number of hazards they can mitigate.

Another real experience from transportation agencies managers who were working with CAPTA showed that it may be not that hard to choose all the highly effective countermeasures in the first iteration but choosing which countermeasures should be omitted because of budget constraints is a complicated process. CAPTA does not help users in this step other than showing three levels of effectiveness. So users are not confident that the results are an effective solution.

The objectives of this research are:

- To provide background and context for addressing risks and vulnerabilities as outlined above,
- To explore the applicability of one tool, CAPTA, for costing asset protection.
- To provide a basis to quantify the effectiveness of the countermeasures based on the three levels that are already defined by the CAPTA developer group, and

- To develop methodology for users to choose the most effective set of countermeasures meeting their budget constraint by solving an optimization problem.

This research work has the same scope as CAPTA; however it includes more detailed information about the effectiveness of each countermeasure.

1.3 Overview of Approach

The ultimate goal of this research is to maximize the effectiveness of the chosen set of appropriate countermeasures in a specific budget range. To reach this goal, a quantitative measure is needed to evaluate the effectiveness of an individual countermeasure and a set of countermeasures. So in the first step, a system to convert the qualitative effectiveness rank to a quantitative one is developed.

Now we have a quantitative objective to be maximized subjected to a constraint. The constraint in this problem is available budget. This is a classic optimization problem which can be solved by a conventional solution method. A branch and bound method is applied to solve the optimization problem since the formulation is based on integer variables.

A case study focusing on bridges in Delaware is conducted with the current CAPTA method and the new proposed CAPTA method and the effectiveness of the results are compared to show the advantages of newly proposed method.

1.4 Report Outline

This report provides background and documents the proposed methodology to address the objectives outlined above. This chapter introduces these concepts and provides background. The remainder of the report is organized as follows

A literature review is the second chapter of this report. Terminology used in the report is defined and previous work in the area of risk analysis and management is reviewed in this chapter.

Chapter three is dedicated to the detailed explanation of the CAPTA method with a complete explanation of each step in CAPTA procedure.

A risk analysis of Delaware's bridges using the CAPTA methodology is presented in chapter 4. In this chapter, 50 of the most critical bridges in Delaware are identified then the appropriate countermeasures are chosen based on the information provided by the CAPTA method. A brief report of economic impacts is included.

Chapter five describes the new mechanism for choosing effective countermeasures. The quantitative ranking system and the mathematical model of optimization problem are developed. The case study based on Delaware bridges is repeated using the new method and the differences between new method and CAPTA are discussed.

The final chapter includes the report conclusion and suggestions for future work. References are included at the end of the report. An appendix presents an implementation plan.

CHAPTER 2 LITERATURE REVIEW

Risk assessment and management is a process to ensure that organizations understand their risk exposure and critical assets, and have plans in place to manage risk to acceptable level (Association of Local Government Engineers of New Zealand, 2006). Therefore, to apply risk assessment and management first you should find the assets with the largest negative consequences of failure in the case of being exposed to a hazard. Then, finding the most cost effective method to mitigate and control the risk. So, the process of risk management for transportation assets has two major elements:

1- Finding the critical assets
2- Applying risk management methods

The literature on risk management for transportation assets is not very rich. But there are some studies that address the first element "finding critical assets" for a different purpose. In these studies critical assets are sought to assign routine maintenance projects to them. The prioritization criterion for maintaining these highway assets is their criticality. Since this area of research uses the same concept as assessing the negative consequences of asset disruption to find the critical assets, the process is compatible with the risk management procedure. This chapter reviews some of the research in this area. In this area of research, studies start with a single kind of asset, which is "bridges" in most cases, and later include all kinds of assets that transportation agencies have to consider. Before reviewing the literature, the following section summarizes the terminology used. The following sections review processes for identifying critical assets, risk assessment and management methods and recent research on critical asset protection.

2.1 Terminology

The following terminology is used throughout the report.

Asset: Persons, facilities, activities, or physical system that have value to the owner or society as a whole (Science Applications International Corp. and PB Consult, 2009a).

Consequence: The loss or degradation of an asset resulting from a threat or hazard [1].

Critical Assets (Key Assets): Individual targets whose destruction could cause large-scale injury, death, or destruction of property and/or profoundly damage our national prestige and confidence (Moteff and Parfomak, 2004).

Effectiveness: The capability of preventing damage caused by hazards (Science Applications International Corp. and PB Consult, 2009a).

Events:

Natural Events: Natural events include major weather or geological events that might cause significant loss of life, destruction of assets or long-term interruption of agency mission (Science Applications International Corp. and PB Consult, 2009b).

Intentional Events: Intentional events include terrorist attacks, crimes, and war (Science Applications International Corp. and PB Consult, 2009b).

Unintentional Events: Unintentional events are usually created by human-induced traffic accidents, due to insufficient skills or experience in design, operation, or enforcement of vehicles (Science Applications International Corp. and PB Consult, 2009b).

Likelihood: Probability of the occurrence of an event (Science Applications International Corp. and PB Consult, 2009b).

Hazard (Threat): The potential natural event, or intentional and unintentional act, capable of disrupting or negatively impacting an asset (Science Applications International Corp. and PB Consult, 2009a).

Reliability: The ability of a system or component to perform its required functions under stated conditions for a specified period of time (IEEE, 2008).

Risk: The quantitative or qualitative expression of possible loss (Science Applications International Corp. and PB Consult, 2009a).

Risk assessment: Risk assessment is a step in a risk management process. Risk assessment is the determination of quantitative or qualitative value of risk related to a concrete situation and a recognized threat (also called hazard).

Risk management: Risk management can be considered the identification, assessment, and prioritization of risks followed by coordinated and economical application of resources to minimize, monitor, and control the probability and/or impact of unfortunate events (Douglas, 2009).

Severity: A measure of the consequence of damage, destruction or other functional loss to an asset resulting from a hazard (Science Applications International Corp. and PB Consult, 2009a).

Threshold: The planning factor used to set the level of consequences at which the decision maker or agency assumes greater responsibility for managing the risk (Science Applications International Corp. and PB Consult, 2009a).

Vulnerability: A weakness in asset design or operations that is exposed to a hazard or can be exploited by a threat resulting in negative consequences (Science Applications International Corp. and PB Consult, 2009a).

2.2 Identifying Critical Assets

This section reviews three studies that identify critical assets using different criteria and methodologies. The studies then use different strategies to prioritize the assets for maintenance.

One of the earliest works in this area was done by Cesare, Santamarina, Turkstra, and Vanmarcke (1992). This paper outlines a methodology for bridge project selection, which could serve as part of bridge management system. In this paper risk is a function of the reliability of the bridge and the consequence of closure. The reliability is defined based on the probability of failure. The probability of failure is calculated applying a Markov model. The Markov model captures the natural deterioration of the pavement and also models the repairs. Consequence is evaluated as the product of the average daily traffic and the detour around the bridge (in units of time, distance or cost). The objective of the study is to minimize the risk for the whole network. A near optimum solution (genetic algorithm) is used to solve the optimization problem. In this research the criticality of an asset is defined based on its condition and its mission importance and extreme events are not considered. The projects which can control risk in this research are regular maintenance and rehabilitation measures.

A 2004 study by Flaig and Lark (2005) introduces a framework for a bridge management system. The framework is a risk based decision support system. The paper addresses two key issues in the bridge management process, the assessment of structural adequacy and the prioritization of competing maintenance, repair and rehabilitation projects. They have used a risk-based method to prioritize the projects.

Risk is defined as the probability of failure multiplied by the consequences. Consequences are divided into four main categories:

(a) Human; that is, personal injury or loss of life.

(b) Financial; that is, the direct costs of reconstruction or repair.

(c) Economic; that is, the indirect costs, such as traffic delay costs incurred due to the loss of service of the bridge.

(d) Legal, environmental and political; that is, those consequences associated with possible litigation, environmental damage and loss of public confidence.

Researchers recognize that estimating these costs is not easy. For example, the value of a life and the costs associated with environmental damage and loss of public confidence are particularly difficult to quantify and open to dispute. Indeed, one of the major drawbacks of this approach is that the relative values of cost assigned to each of these categories tend to be such that it is those costs that can be easily calculated that always dominate, and therefore the high-profile, highly trafficked route always appears to present the greatest risk.

To deal with this problem, the researchers have proposed a "Consequence Ratio" (CR) which is the ratio of anticipated consequences of the failure of the bridge under consideration and those that are deemed appropriate for the bridge stock to which it belongs. The probability of failure is identified by a ratio too. The "Relative Safety Ratio" (SR) is calculated from the safety/reliability assessment of bridges based on their structural condition. With these definitions risk is shown in equation (1).

$$\text{Risk} = S_R \times C_R \qquad (1)$$

It is important to mention that researchers believe that the proposed system offers a great degree of flexibility in which the bridge manager can decide whether to follow a standard method, for example where a given optimization algorithm is used, or the manager can choose prioritization criteria such as safety, risk or a cost–benefit ratio and rank all structures in terms of these criteria. So risk is just one of the criteria for prioritization offered in this framework.

In a project for Virginia Transportation Research Council, Dicdican, Haimes and Lambert (2004) proposed a risk-based asset management method for highway infrastructure system. This report targets all kinds of transportation assets in the proposed framework but just bridges are included in the case study.

Four essential steps in applying risk-based asset management methodology are:

Step 1- Identification of Risk:

Hierarchical Holographic Modeling is employed to identify sources, opportunities and effects of risk. In the HHM scheme, several models represent the various aspects of the system, with each model termed a holographic submodel. The HHM approach recognizes that no single vision or perspective of a system is adequate to represent a system and its component parts. Instead, the HHM approach identifies and coordinates multiple, complementary decompositions of a complex system. A decomposition is a hierarchy of the system's components, subcomponents, and subsubcomponents that captures the structure of a particular view of the system (Haimes, 1981). The hierarchical holographic model for the surface highway system is developed through interviews and meetings with highway agencies regarding maintenance efforts. In addition, literature on maintenance and highway issues is used to identify sources and effects of risks to highway infrastructure.

Step 2- Asset Classification (Finding Critical Assets) :

Three levels of criticality are defined:

- Reconstruction,
- Must (means assets that must be maintained) and
- Non-Must.

Reconstruction includes a group of assets for which there are reconstruction plans. These assets are allowed to deteriorate by the agency. Must assets have high priority for maintenance versus Non-Must assets that have low priority. The priority for maintenance for highways and bridges is defined based on highway classification, Annual Average Daily Traffic and current condition. An example of these criteria is shown in **Table 1**.

For those pavement sections which are not in the Must group a contingency filter has been applied. This is driven by abnormal or extreme events that may occur if maintenance activities are not performed. Contingencies are categorized in three groups: 1- man made hazards, 2- natural hazards, and 3- unusual wear and tear. Examples of each type of hazards are shown in Table 2. For each group a subjective assessment of risk severity and frequency is done. Assets exposed to frequently-occurring sources of risk and whose non-maintenance can lead to severe effects are given higher maintenance priority and are classified as Must.

Step 3- Asset Level Trade off :

In this paper three objectives are defined: minimizing short term cost, minimizing long term cost and maximizing the remaining life of the roads and highways. To choose the appropriate treatment for the assets a multi objective decision tree (MODT) (Haimes et al, 1990) is employed. The MDOT enables consideration of different maintenance options and their impacts on future action. In the case study presented in this paper the point of uncertainty in the decision tree is the weather condition. Consequences of different treatments in the case of normal and severe weather conditions are evaluated. Tradeoffs among short term cost, long term cost and remaining life as a result of different countermeasures should be done by agencies at the local level.

Table 1 An example of criticality criteria

Classification	Characteristic	Pavement Condition	Bridge Condition
Reconstruction		Critical Condition Index (CCI) = 30	General Condition Rating (GCR) = 2
Must	Part of Strategic Highway Network, Hazardous Material Network, or National Highway System	CCI = 60	GCR = 4
Must	Annual average daily traffic (AADT) ≥ 25000	CCI = 60	GCR = 4
Must	Truck traffic = 10% of AADT	CCI = 60	GCR = 4

Table 2 Categories of risk sources and examples for identifying most prevalent source of risk to the asset

Risk Source	Examples
Man-made hazards	Oil spill Hazardous material spill Terrorist threat
Natural hazards	Heavy rain Strong wind Heavy snow and ice
Unusual wear and tear	Unexpected heavy traffic Vehicular crashes

Step 4- Aggregation of Lower-level Options

To avoid sub-optimization, each local agency should promote the optimal maintenance strategy, which includes a list of assets needing maintenance and the options for each asset, the short- and long-term costs and their remaining life to upper level in the organization hierarchy (i.e. local, district, and state level) until it reaches to state level. At the level of the district, maintenance strategies for each of the district's localities are collected and aggregated. The district manager reviews the set of maintenance strategies and the needs of the localities, removes any unreasonable strategies, and performs tradeoff analysis. After this filter has been applied, the final set of district-level maintenance strategies is passed up to the level of the state. At the state level, decision makers consider the budget available and the resulting resource allocations are funneled down to the lower organizational levels. These levels may need to perform additional tradeoff analysis to meet new budget constraints.

The three papers described above focus on identifying critical assets and setting some priority for the routine maintenance of critical assets. In the next section papers with a focus on risk analysis and management methods are introduced.

2.3 Risk Assessment and Management Methods

While identifying critical assets is a key element of asset protection, risk assessment and management methods are needed to account for the consequences of hazards in the decision making process.

Most of the studies in this area are focused on one type of hazard. For example another research project for Virginia Transportation Department concentrates on the threat of terrorist attacks (Crowther et al, 2004). This study was conducted to assess and manage the risk of terrorism to Virginia's interdependent transportation infrastructure. The focus was to understand how the failure of one piece of infrastructure or any of its elements propagates. This information is then used to implement management policies that can mitigate the consequences. The research uses several risk assessment and management models:

- Hierarchical Holographic Model (HHM) for identifying risks. The HHM methodology is described in the previous section as a part of the paper by Dicidican et al (2004).
- Risk Filtering, Ranking, and Management (RFRM) for ranking risks. This method includes 8 Phases.
    - Phase I, Scenario Identification.
    - Phase II, Scenario Filtering-The risk scenarios identified in Phase I are filtered according to the responsibilities and interests of the current system user.
    - Phase III, Bi-Criteria Filtering and Ranking.
    - Phase IV, Multi-Criteria Evaluation.
    - Phase V, Quantitative Ranking- Filtering and ranking scenarios is continued based on quantitative and qualitative matrix scales of likelihood and consequence; and ordinal response to system resiliency, robustness, redundancy.
    - Phase VI, Risk Management- Identification of management options for dealing with the filtered scenarios, and estimating the cost, performance benefits, and risk reduction of each is performed.
    - Phase VII, Safeguarding Against Missing Critical Items- Performance of the options selected in Phase VI is examined against the scenarios previously filtered out during Phases II to V.
    - Phase VIII, Operational Feedback- The experience and information gained during application is used to refine the scenario filtering and decision processes in earlier phases (Haimes, Kaplan and Lambert, 2002).
- Inoperability Input-Output Model (IIM) for accounting for direct and indirect impacts/consequences. The IIM is an analytical framework to quantify and address the risks from the intra- and inter-connectedness of economic and infrastructure sectors in the United States. The IIM uses data from the U.S. Department of Commerce to assess the economic interdependencies of sectors and to estimate

sector disruptions as a result of direct and indirect effects (Institute for Information Infrastructure Protection, 2007).

- Partitioned Multi-Objective Risk Method (PMRM) for accounting for extreme events. PMRM generates a set of conditional expected value functions, termed risk function, which represents the risk given that the damage falls within specific ranges of probability of exceedance (Haimes, 1998).

At the statewide level, the direct and indirect economic impacts of transportation infrastructure disruptions (natural hazard, intentional attack, etc.) on various dependent industry sectors are assessed using the IIM. The industry impacts are measured in two metrics, economic losses and percentage of inoperability. Workforce impacts are also considered in the IIM in terms of income reduction and the number of workers affected. Data from the Bureau of Economic Analysis (BEA) Input-Output Table and the Regional I-O Multiplier System II (RIMS II) is used in IIM for ranking industry sector impacts. Census workforce data and commodity flow data are used to quantify the disruption to the transportation system produced by an act of terrorism.

Seismic risk associated with transportation assets is studied by Kermidjian, Moore, Fan, Yazlali, Basoz and Williams (2007). In this study, the risk from earthquakes to a transportation system is evaluated in terms of direct loss from damage to bridges and travel delays in the transportation network. The direct loss is estimated from repair costs due to damage to bridges and is dependent on the size of the bridge and the expected damage state of the bridge. The travel delays resulting from closure of damaged bridges are calculated using origin-destination (O-D) tables, coupled with network analysis of the pre-earthquake scenario with a base transportation network and the post-earthquake scenario with a modified transportation network. The consequence of earthquakes on the transportation network is evaluated for a magnitude 7.0 earthquake scenario in California. The information related to the bridge inventory and the highway transportation network was obtained from transportation agencies for this study. The study reports that liquefaction damage is the largest contributor to the repair cost, which is used as a measure of the losses from damage.

Other research conducted to analyze the seismic risk was done by Shiraki, Shinozuka, Moore, Chang, Kameda and Tanaka (2007). The authors develop methods for evaluating the performance of highway systems subjected to severe earthquake impacts. In this study, the total transportation network delay is estimated with user-equilibrium network analysis methods to evaluate the network system performance due to seismic induced damage. The bridge damage and highway network link damage is evaluated by means of a damage index with Monte Carlo simulation techniques and bridge fragility curves. The fragility curves for individual bridges are developed on the basis of empirical damage data and dynamic analysis performed on bridge structures. These curves are used to generate network damage states for various earthquake scenarios by means of Monte Carlo simulation. To test the approach, changes in system performance using different scenarios are measured in terms of additional total network delay for a set of sample scenarios. The final result of these efforts is a transportation system risk curve, which shows the annual probability of exceedance and the hazard-consistent probability for different levels of network delay.

"Modeling the Impact of Infrastructure Interdependencies on Virginia's Highway Transportation System" (Dryden et al, 2004) is a research project in which infrastructure elements are considered as a system. In this study, risk assessment and risk management techniques are used to identify system vulnerabilities and the risks associated with those vulnerabilities. HHM described above is used to identify risks and vulnerabilities. Information used in HHM includes jurisdictional, intermodal, economic and user perspectives. A case study is presented focusing on risk management and finding ways to unlock the interdependencies of the highway system to reduce the risks associated with those interdependencies. As part of the project findings, a sampling of risk management options is introduced in two categories:

- Response (form response teams, alternative routes, redundancy in the system, etc.)

- Unlock Interdependencies (alternate forms of transportation, overstocking critical facilities, staggering work schedules, etc.).

Of the four studies reviewed in this section three focuses on a single hazard- terrorist attack, and seismic events. The fourth study focuses on impacts. The techniques used build on the methods introduced in the previous section but in general emphasize the consequences of events.

2.4 Recent Research

Increasing interest in protecting assets against hazards- natural or man-made- has grown over the past decade. Improving infrastructure to reduce vulnerability and increase resilience is one element of asset management. This work builds on strategies to identify critical assets and risk management methods to understand the consequences of different hazards.

More recent research in this area proposes methods to analyze all kinds of hazards for all kinds of assets under the responsibility of transportation agencies. CAPTA (Science Applications International Corp. and PB Consult, 2009a) is documented in an NCHRP report with these features. The method used in CAPTA is completely explained in next chapter.

CHAPTER 3 CAPTA INTRODUCTION

3.1 What is CAPTA?

The National Highway Research Program (NCHRP) of the Transportation Research Board of the National Academies initiated a series of research projects in the area of risk management and assessment following the attacks of September 11. The final goal of this series of research is providing risk management guides for transportation agencies. “Costing Asset Protection: An All Hazards Guide for Transportation Agencies (CAPTA)” is a project in this series of research projects with unique features (Science Applications International Corp. and PB Consult, 2009a).

First, it is a multi modal risk analysis model. Reviewing the previous research published in the area of risk analysis for transportation assets reveals that most of these works have focused on a specific transportation mode or asset type. However, transportation agencies usually deal with several modes and different kinds of assets including bridges, tunnels, ferries and transit facilities. To allocate resources optimally, agencies need an equitable basis that could be applied consistently to all assets. CAPTA provides this basis.

Moreover, CAPTA is an all hazard tool. Some hazard-specific risk analysis has been conducted for transportation assets. This research generally focuses on a specific kind of hazard, mostly natural hazards, such as an earthquake, hurricane or flood. CAPTA provides a tool to assess the risk for all kinds of hazards that agencies consider applicable for their assets.

Additionally, CAPTA needs less data compared to other methods. This feature makes CAPTA a convenient tool for use by agencies and leads to more consistent results. All these features make CAPTA a key advance in surface transportation risk assessment, which provides users with a capital planning and budgeting tool, used as a strategic point of departure for resource allocation decisions (Science Applications International Corp. and PB Consult, 2009a).

The application of CAPTA should be followed by the use of an asset-specific risk analysis tool, as CAPTA is a high level tool and does not include details about specific assets. CAPTA is designed to be applied at the state level. The preferred users of CAPTA are senior managers whose responsibility includes different modes of transportation and asset types.

In this chapter after describing the CAPTA methodology, CAPTool, which is a computer-based Microsoft Excel spreadsheet model based on CAPTA is explained. The step-by-step explanation includes justification of the role of each step in the whole procedure.

3.2 CAPTA Methodology:

Threat, target, vulnerability and consequences are the four components of risk. In traditional scenario-based risk management methods threat is defined by severity and likelihood. Severity will be used to estimate negative consequences. From this point of view risk is a function of threat's likelihood and its respective consequences as depicted in **Figure** 1.

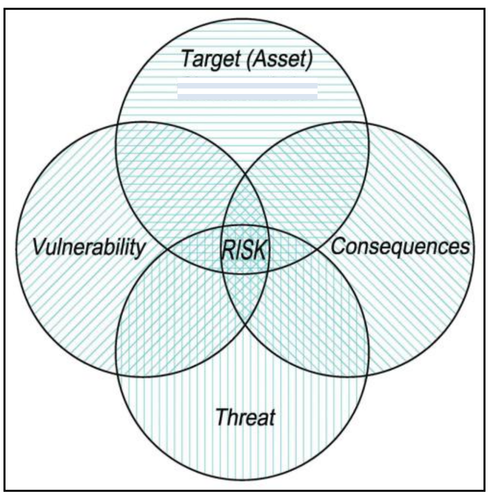


Figure 1 Risk components

In traditional risk assessment method, risk assessment accuracy is dependent on the accuracy of its components. Among relevant hazards for transportation agencies assets there are some for which the likelihood estimation is subjective. To elaborate, different types of hazards for a multimodal transportation system will be described. Below, three important types of hazards for transportation assets are described and some examples for each type are provided.

1. Natural Events: heavy rain, strong wind, heavy snow and ice, earthquake, hurricanes, flood, and mud and landslide.
2. Unintentional Events: fire, structural failure, and hazardous material spill
3. Intentional Attacks: terrorist attack, and war.

For natural events event frequency and likelihood is calculated based on historical data. For unintentional events, there are actuarial data regarding the frequency, nature and other characteristics of these events which are used in likelihood estimation based on experience. Intentional events is a special type of threat in which the likelihood of event changes actively in respond to situation and measures taken to mitigate the risk. Although there are difficulties to estimate the likelihood of the other two types of hazards, the intentional events type is the special type of hazard for which all the likelihood estimations are subjective. The CAPTA team found that the uncertainty associated with these estimations is so high that the results are not reliable. To deal with this problem a new method for risk assessment was developed which is consequence-based method.

A consequence-based approach diverges from traditional risk management strategies in that it does not attempt to assess the likelihood of an event explicitly. In essence, the consequence-based approach assumes that if a decision maker perceives an event to be possible, and if the consequences are sufficiently severe, the decision maker must consider alternatives for avoiding or minimizing consequences should the event take place. The consequence-based approach is strategic, beginning with how an asset has been adversely affected regardless of why or how it became disabled

(Science Applications International Corp. and PB Consult, 2009a). CAPTA applies a consequence-based method.

There are two terms in this definition that should be illustrated. The first one is “if the decision maker perceives an event to be possible”. Identifying the possible event, transportation agencies’ authority should keep this point in mind that CAPTA focuses on the threats with following characteristics:

- These threats and hazards can cause significant damage to transportation assets and mission or loss of life.
- Designed/engineered and operational measures to reduce the risk of these threats and hazards are not yet “mainstreamed” in conventional transportation agency practice.
- Reasonable and practical consequence-reducing countermeasures to these threats and hazards are available (Science Applications International Corp. and PB Consult, 2009a).

The second term which needs more explanation is “If the consequences are sufficiently severe” To find out which consequence is severe enough a threshold should be chosen by decision makers. A threshold is a point that goes beyond the effect of routine disruption and losses that current preparation and responses are designed to manage. Consequence thresholds do not need to be equal for all types of assets. A different threshold is a tool to reflect level of responsibility for different asset types or transportation modes. Assets or asset types for which the potential adverse consequence is more than threshold are considered as critical asset. Appropriate countermeasures will be assigned to these assets. Generally adverse consequences can be categorized in four groups:

1. Potentially exposed population
2. Property loss
3. Mission disruption

4. Social/cultural disruption

CAPTA does not include social/cultural disruption explicitly although there is an option for users to choose critical assets manually if they think the social/cultural disruption consequences is significant. For other three kinds of consequences some measures and some levels has been defined for each kind of assets to evaluate the criticality of the assets in that group. More details about these measures are provided in next section.

3.3 CAPTool Overview:

CAPTA comes with an electronic spreadsheet which helps users to apply the CAPTA methodology.

Figure 2 shows the Input data needed for this model the relation between input, methodology, data base and outputs. The heart of CAPTA methodology is a six step procedure. All parts of CAPTool procedure are explained in the section that elaborates on the methodology.

In the six steps related hazards or threats are introduced, assets and their characteristics are specified, consequences thresholds are identified, critical assets are determined, appropriate countermeasures are selected and the countermeasures configurations with the initial cost are reported. **Table 3** shows these six steps in the computer-based spreadsheet model CAPTool. As you see CAPTool comes in two formats, basic and expanded format. The expanded format is fundamentally used to modify the default values and assumptions based on the local data.

Step 1: Relevant Risk Selection

This step is concerned with the asset types which fall under the jurisdiction, influence or control of the relevant entities, and relevant risk is chosen by transportation authorities. There is a database that defines the relation between the type of asset and the type of consequences in terms of exposed population, property loss and mission disruption. This database is required to identify the appropriate countermeasures. A sample from the database illustrating the first step in the basic CAPTool is shown in **Figure 3.**

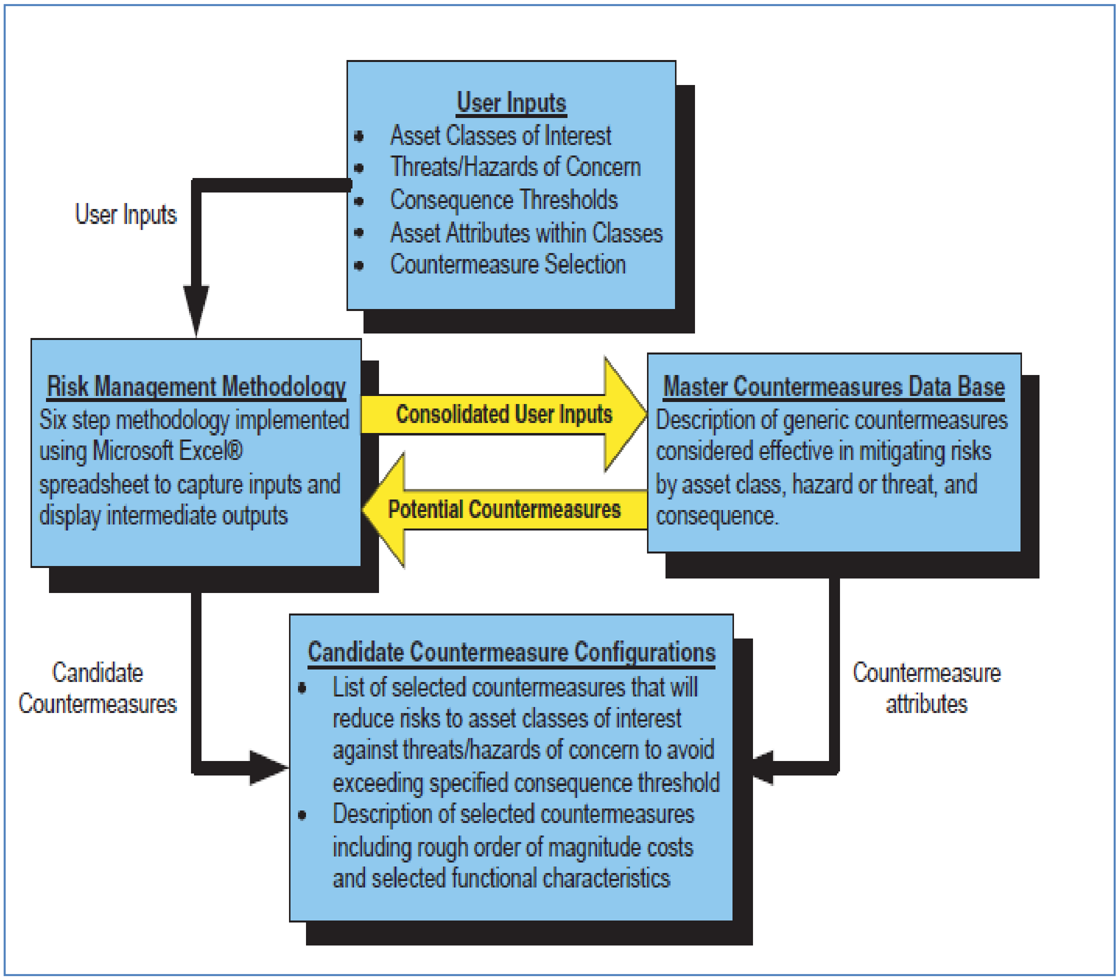


Figure 2 CAPTA procedure

There is an option in the expanded tool to modify this database if required. The asset types that can be selected are road bridges, road tunnels, transit/rail bridges, transit/rail tunnels, administrative and support facilities, ferry and fleets. Any other asset beyond this can be considered as a critical asset but the user should identify the asset criticality manually. **Figure 4** shows the expanded CAPTool Step 1a.

Table 3 Six-step CAPTool procedure

Basic Step	Basic CAPTool	Expanded CAPTool	Expanded Step
1	Relevant Risk Selection	Relevant Risk Selection	1
		Threat Hazard Vulnerability	1a
2	Thresholds	Thresholds	2
3	Asset /Asset Class Inventory	Asset /Asset Class Inventory	3
4	High-Consequence Assets Inventory	High-Consequence Assets Inventory	4
5	Countermeasure Opportunities (including asset-specific Opportunities)	Countermeasure Costs	5a
		Selection of Additional Countermeasures	5b
		Countermeasure Filter Selection	5c
		Countermeasure Opportunities (including asset-specific Opportunities)	5
6	Results Summary, including a break down by mode	Results Summary, including a break down by mode	6

Step 2: Thresholds

In step 2 users set the consequence thresholds. Having set these thresholds, critical assets for which the consequence of relevant hazards is beyond the threshold can be identified. These thresholds can be changed later in an iterative process based on the budget needed for countermeasures or other considerations like the importance of a special type of asset and its share in budget allocation.

As mentioned before, some measures are defined for each type of asset to show a measure of consequences in three categories: 1- exposed population, 2- property loss, and 3- mission disruption. A list of these measures is shown in **Table 4**. Users can use some default values or adjust them for their local case. **Figure 5** shows this step in CAPTool.

1—2-3-4—5-6 Basic CAPTool

1-1a-2-3-4-5a-5b-5c-5-6 Expanded CAPTool

Save Time-Stamped Copy to Default Folder | Previous

Reset Answers to "N" | Next

User-Entered On/Off

Identify Relevant Risks and Asset Classes
Instructions:
It is highly recommended that you save this as a new project. The "Save" button to the right will rename the file as a time and date-stamped copy to your default folder with the filename: "TransRiskManagementYYYY-MM-DD HH.MM.SS.xls"

For the asset classes of interest, please indicate the threats/hazards that you wish to include in your analysis by toggling the response from "N" to "Y" for each cell. Threat/hazard and asset combinations that are likely to result in serious loss will be considered in subsequent steps. When done, click "Next."

	Road Bridges	Road Tunnels	Transit/Rail Station	Transit/Rail Bridges	Transit/Rail Tunnels	Admin & Support Facilities	Ferry	Fleet
THREATS								
Small Explosives	Y	Y	Y	Y	Y	Y	Y	Y
Large Explosives	Y	Y	Y	Y	Y	Y	Y	Y
Chemical/Biological/Radiological	Y	Y	Y	Y	Y	Y	Y	Y
Criminal Acts	Y	Y	Y	Y	Y	Y	Y	Y
UNINTENTIONAL HAZARDS								
Fire	Y	Y	Y	Y	Y	Y	Y	Y
Struct. Failure	Y	Y	Y	Y	Y	Y	Y	Y
HAZMAT	Y	Y	Y	Y	Y	Y	Y	Y
NATURAL HAZARDS								
Flood	Y	Y	Y	Y	Y	Y	Y	Y
Earthquake	Y	Y	Y	Y	Y	Y	Y	Y
Extreme Weather	Y	Y	Y	Y	Y	Y	Y	Y
Mud/Landslide	Y	Y	Y	Y	Y	Y	Y	Y
ADDITIONAL								
Userentered threat/hazard 1	N	N	N	N	N	N	N	N
Userentered threat/hazard 2	N	N	N	N	N	N	N	N

Figure 3 Step1: threat/asset relevance

Previous

Next

Restore Defaults

①-(1a)-②-③-④-(5a)-(5b)-(5c)-⑤-⑥ Expanded CAPTool

Verify High Consequence Threats and Hazards
Instructions
For each asset class, indicate which threats or hazards could cause unacceptable consequences for exposed population, property damage, or loss of mission capabilities by placing an "X" in the appropriate square. Additionally, if you plan to manually mark certain assets as critical (manual override), indicate the threats or hazards of concern in the event of a manual override.

"Restore Defaults" gives default values for exposure, property, and mission, but leaves all fields blank for manual override.

When done, click "Next".

	Road Bridges				Road Tunnels				Transit/Rail Station			
	Potentially Exposed Population	Property Loss	Mission Importance	Manual Override	Potentially Exposed Population	Property Loss	Mission Importance	Manual Override	Potentially Exposed Population	Property Loss	Mission Importance	Manual Override
Small Explosives	X			X	X			X	X			X
Large Explosives	X	X	X	X	X	X	X	X	X	X	X	X
Fire	X	X	X	X	X	X	X	X	X	X	X	X
HAZMAT			X	X			X	X			X	X

Figure 4 Step1a: hazard/consequence relevance

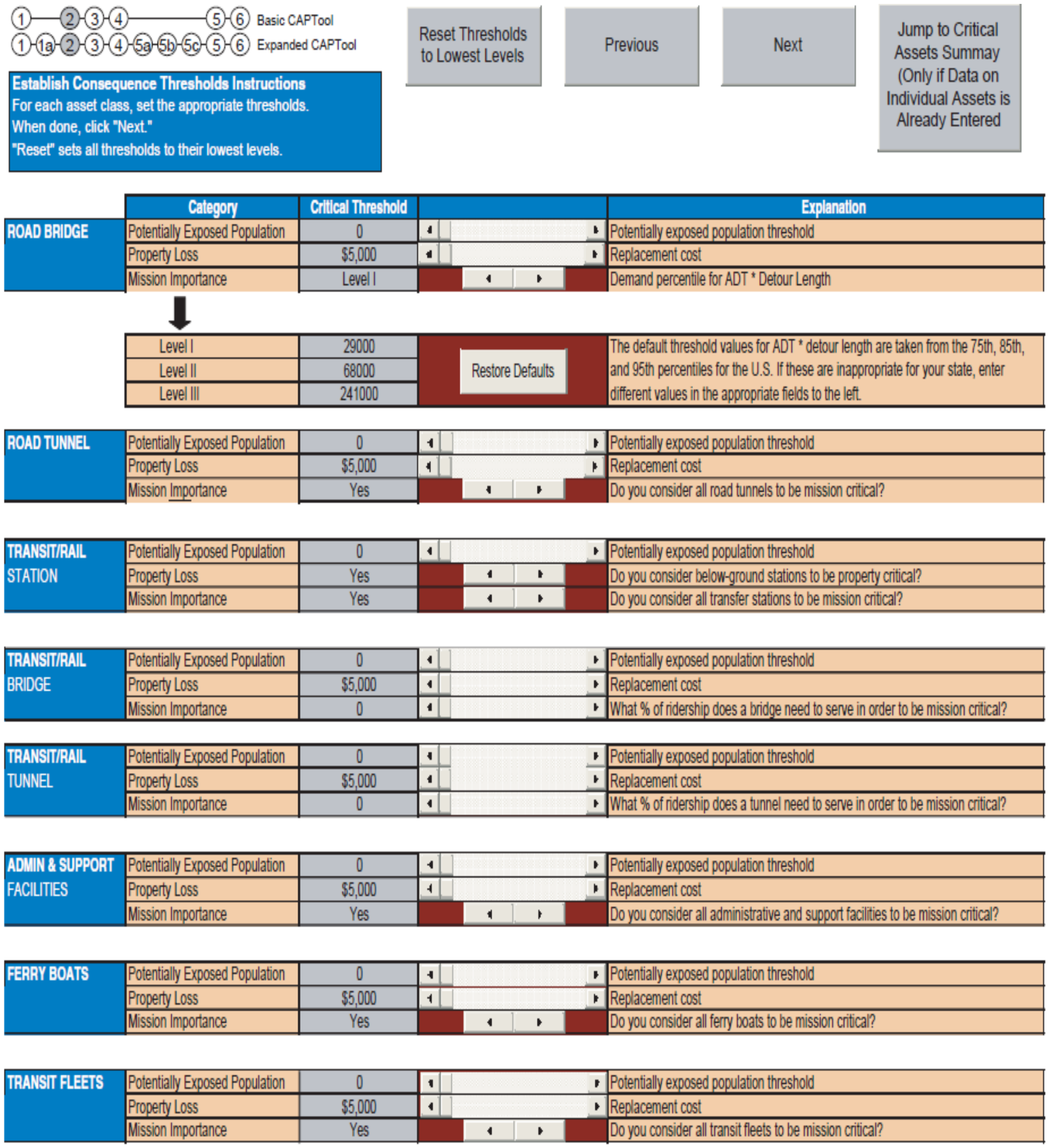


Figure 5 Step2: setting threshold

Table 4 Consequence measures

Asset Type	Consequence Category	Measures
Road Bridge	Exposed Population	Potentially Exposed Population
	Property Loss	Replacement Cost
	Mission Disruption	ADT*Detour Length
Road Tunnel	Exposed Population	Potentially Exposed Population
	Property Loss	Replacement Cost
	Mission Disruption	User Judgment
Transit/Rail Station	Exposed Population	Potentially Exposed Population
	Property Loss	Replacement Cost
	Mission Disruption	User Judgment
Transit/Rail Bridge	Exposed Population	Potentially Exposed Population
	Property Loss	Replacement Cost
	Mission Disruption	Percentage of Ridership
Transit/Rail Tunnel	Exposed Population	Potentially Exposed Population
	Property Loss	Replacement Cost
	Mission Disruption	Percentage of Ridership
Admin & Support Facilities	Exposed Population	Potentially Exposed Population
	Property Loss	Replacement Cost
	Mission Disruption	User Judgment
Ferry Boats	Exposed Population	Potentially Exposed Population
	Property Loss	Replacement Cost
	Mission Disruption	User Judgment
Transit Fleet	Exposed Population	Potentially Exposed Population
	Property Loss	Replacement Cost
	Mission Disruption	User Judgment

Step 3: Asset and Asset Class Inventory

In step 3 all the assets' characteristics which are needed to investigate their criticality should be entered by the user. Critical assets are those with potential consequences beyond the set threshold. This data can be entered for each asset individually or a class of assets with similar characteristics. If the class of assets is preferred users should be concerned that the data should represent the whole class. The list of data needed for each asset type is as below:

- Road Bridges/Tunnels
  - Annual average daily traffic (AADT)
  - Length
  - Lanes
  - Detour
  - Replacement cost per asset (optional)
- Transit/Rail Bridges/Tunnels
  - Maximum car occupancy
  - Replacement cost per asset (optional)
  - Length
  - Percentage of ridership using the bridge
- Transit/Rail Stations
  - Unique identification
  - Maximum occupancy
  - Above- or below-grade indicator
  - Transfer point indicator (User should indicate if the asset is critical in terms of mission disruption)
- Administration and Support Facilities
  - Square footage
  - Replacement cost
  - Maximum occupancy
- Ferries
  - Maximum occupancy
  - Replacement cost per asset
  - Manually mark as critical in terms of mission disruption
- Fleets
  - Number of vehicles
  - Maximum occupancy of vehicles

- Replacement cost of individual vehicles

CAPTool uses this data to compare the potential consequences with consequences threshold in terms of potentially exposed population (PEP), property damage and impact on mission. **Table 5** shows how the data entered can be used to find the exact measures used to define the thresholds. For example for a 1000 ft long, 2 lanes (2 directions) road bridge with 3500 AADT and 2 miles detour length, the primary direction AADT is 0.6*3500= 2100 and the secondary direction AADT is .4*3500=1400 (based on Highway Capacity Manual suggestion). Both of them is less than 2400 so the potentially exposed population for both is 7.5*1000(ft)/1000(ft) = 7.5 the total potentially exposed population is 7.5*2=15. The property loss for this bridge is $20,000/1ft*1000ft=$20,000,000. And the mission disruption measure is 3500*2=7000 vehicle mile.

Table 5 Criteria used to compare potential consequences with threshold

Asset Type	PEP Equation	Property Equation	Mission Equation
Road Bridges	Separated into primary direction and secondary direction -- for each, if vehicles/lane > 2400, assume 40 vehicles/ 1000ft. Otherwise assume 7.5 veh./1000 ft[1]	$20,000/lf	(ADT)* (detour length) 75th, 85th, 95th percentile as thresholds relative to typical bridge inventory (Example is based on the National Bridge Inventory)
Road Tunnels	Separated into primary direction and secondary direction—for each, if vehicles/lane > 2400, assume 40 vehicles/ 1000 ft. Otherwise assume 7.5 vehicles/1000 ft	$100,000/lf	User Input for criticality
Transit/Rail Station	4 (maximum capacity of rail cars)[2]	Below ground = critical	User input if transfer station is critical
Transit/Rail Bridge	2 (maximum capacity of rail cars)[2]	$15,600/lf	User input percentage of ridership that regularly use this transit/rail transportation asset
Transit/Rail Tunnel	2 (maximum capacity of rail cars)[2]	$40,000/lf	User input percentage of ridership that regularly use this transit/rail transportation asset
Administrative & Support Facilities	1 person/175 sq ft	$210/sq ft	Never critical unless so designated by user
Ferries	Maximum capacity of ferry	User input	Never critical unless so designated by user
Fleets	Maximum occupancy of one fleet Vehicle	Av. cost per veh. ×max. number of veh	Never critical unless so designated by user

[1] Derived from the Highway Capacity Manual (Transportation Research Board, 2000)
[2] Derived from NFPA 130 (National Fire Protection Association, 2007)

Step 4: High Consequence (Critical) Assets

Step 4 identifies critical assets based on previous steps. In this step the assets for which the potential consequences (based on step 3) are beyond the thresholds (based on step 2) is shown. Besides, the type of criticality in terms of potentially exposed population, property loss and mission importance will be shown. An important point to mention here is that for all assets user can manually choose the asset as a critical asset. This option is useful when there is some special concerns beyond the criticality types defined exist for a special asset. In this step these critical asset will be shown too and they will go under the title of “manual override” referring to criticality type.

Moreover, the hazard types for each critical asset are determined too. As mentioned in step 1 CAPTool has a predefined table for relevant hazards for each type of assets. This table can be changed by user. The relative hazards for each critical asset are shown in this step is borrowed from that default table.

. **Step 5: Countermeasures Opportunities**

Step 5 is the most important step in CAPTool procedure. In this step users should choose countermeasures and the quantity of them for each critical asset to help the user to decide which countermeasures are more appropriate for an asset, a table is included in step 5 which shows the effectiveness of countermeasures by a color coded scale. Users can see the level of effectiveness as “medium” or “high”. Based on this information provided, users can choose the effective countermeasures for each asset. For each countermeasure a unit is defined. The number of countermeasures’ unit that should be applied for an asset is supposed to be identified by the user. To identify the level of effectiveness of countermeasures for each asset CAPTool uses several databases. The first database is a list of countermeasures that is applicable to manage risk. This database is shown in **Table 6**. Besides, a table of the effectiveness of each countermeasure for each hazard and for each type of assets is provided. The effectiveness of countermeasures is defined based on engineering judgment and previous experience. There is a three level scale to explain the effectiveness of a countermeasure for a special threat/hazard. It may have low effectiveness shown by "L", medium effectiveness shown by "M" and high effectiveness shown by "H" in effectiveness table. **Figure 6** shows a sample of this database.

To help users to choose the appropriate amount of countermeasures and have an estimation of the countermeasures' cost a database is provided by CAPTool developers in which a unit is defined for each countermeasure and the cost of each unit is estimated. **Error! Reference source not found.** shows a sample of countermeasures' unit definition and their cost.

The last database called countermeasures' attributes provides some more detailed information about the countermeasures. The most important attribute of a countermeasure is its function. The Countermeasures' function is defined in 5 categories: prediction, deterrence deflection, detection, interdiction, response preparedness, and design/ engineering. A sample of countermeasures attribute is shown in **Figure 7.**

An expanded version is useful to localize the CAPTool default values and assumptions. Users can change the unit cost for the countermeasures in Step 5a of expanded version of CAPTool if they have more accurate information. New countermeasures can be added by the user also. The cost, effectiveness and other attributes of new countermeasures should be added in step 5b of expanded CAPTool. In Step 5c users can set some filters on countermeasures' attributes for example they can choose the countermeasures for prediction only.

Table 6 Countermeasures database

1	Lighting	17	Explosive Detection
2	Barriers and Beams	18	Establish Clear Zones
3	Fences	19	Visible Signs
4	CCTV	20	Seismic Retrofitting
5	Intrusion Detection Devices	21	Fire Detection & Suppression
6	Physical Inspection of Assets	22	Encasement, Wrapping, Jacketing
7	ID cards	23	Patrols
8	Biometrics	24	Weather/Seismic Information
9	Background Checks	25	Intelligence Networking
10	Metal Detectors	26	HAZMAT Mitigation
11	Restricted Parking	27	Security Awareness Training
12	Random Inspections	28	Emergency Response Training
13	Visible Badges	29	Emergency Evacuation Planning
14	Limited Access Points	30	Planned Redundancy
15	Visitor Control and Escort	31	Public Information and Dissemination
16	Locks		

Table 7 A sample of countermeasures' units and their cost

Measure	Estimated Per-Unit Cost (x1000)	Description	Unit of Measure
Lighting	$11.30	One per 100 ft of road or perimeter. Assumes nearby power connection, no demolition or excavating.	One installation
Barriers and Beams	$3.30	10 jersey barriers and two end planters to cover 100 ft of space.	One installation
Fences	$21.00	12 ft high security fence, in concrete with four gates (6 ft high, 3 ft wide). Infrared detection system. Power install, relay to central monitor. Excludes central monitoring station operation	100 linear feet (lf)
CCTV	$17.50	Four remote PTZ cameras, one control panel.	One
Intrusion Detection Devices	$0.90	One burglar alarm with remote signal installed.	One

	Countermeasure	1 Lighting	2 Barriers & Berms	3 Fences	4 CCTV	5 Intrusion Detection Devices	6 Physical Inspection of asset
		Physical Security Countermeasures					
Ferries	Small Explosives	M	L	L	M	M	H
Ferries	Large Explosives	M	M	M	M	M	M
Ferries	Chemical/Biological/Radiological	M	L	L	L	M	H
Ferries	Criminal Acts	M	L	L	M	M	M
Ferries	Fire	L	L	L	L	L	L
Ferries	Struct. Failure	L	L	L	L	L	H
Ferries	HAZMAT	L	L	L	L	L	M
Ferries	Flood	L	M	L	L	L	H
Ferries	Earthquake	L	L	L	L	L	L
Ferries	Extreme Weather	L	M	L	L	L	L
Ferries	Mud/Landslide	L	M	L	L	L	L
Fleets	Small Explosives	M	L	L	M	M	H
Fleets	Large Explosives	M	M	M	M	M	M
Fleets	Chemical/Biological/Radiological	M	L	L	L	M	H
Fleets	Criminal Acts	M	L	L	M	M	M
Fleets	Fire	L	L	L	L	L	L
Fleets	Struct. Failure	L	L	L	L	L	H
Fleets	HAZMAT	L	L	L	L	L	M
Fleets	Flood	L	M	L	L	L	H
Fleets	Earthquake	L	L	L	L	L	L
Fleets	Extreme Weather	L	M	L	L	L	L
Fleets	Mud/Landslide	L	M	L	L	L	L
Other	Small Explosives	M	M	M	M	M	M
Other	Large Explosives	M	M	M	M	M	M
Other	Chemical/Biological/Radiological	M	M	M	M	M	M
Other	Criminal Acts	M	M	M	M	M	M
Other	Fire	M	M	M	M	M	M
Other	Struct. Failure	M	M	M	M	M	M
Other	HAZMAT	M	M	M	M	M	M
Other	Flood	M	M	M	M	M	M
Other	Earthquake	M	M	M	M	M	M
Other	Extreme Weather	M	M	M	M	M	M
Other	Mud/Landslide	M	M	M	M	M	M

Figure 6 A sample of countermeasures' effectiveness

		Physical Security Countermeasures					
		1	2	3	4	5	6
Countermeasure		Lighting	Barriers & Berms	Fences	CCTV	Intrusion Detection Devices	Physical Inspection of asset
Functions	PREDICT						X
	DETER	X	X	X	X	X	
	DETECT	X	X	X	X	X	
	INTERDICT						
	RESPONSE PREP.						
	DESIGN/ENGINEERING						
Cost	Investment $ (x1000)	$11.3	$3.3	$21	$17.5	$0.9	$30
Implementation	Area-Wide						
	Asset Specific	X	X	X	X	X	X
	Temporary/Redeployable						X
	Multipurpose Potential	X	X	X	X	X	X
Package	Basic	X	X	X	X	X	X
	Enhanced						
	Threat Responsive						X

Figure 7 A sample of countermeasures' attributes

Step 6- Result Summary

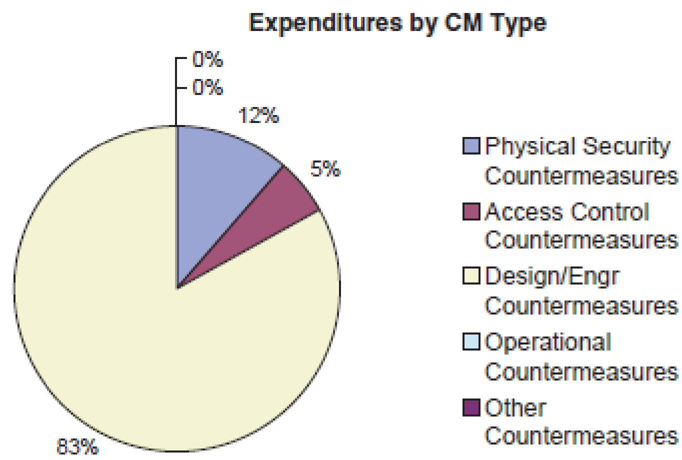
In this step users can see a summary of "inputs" including relative risk and threshold and "results" including the number of critical assets and countermeasures besides countermeasures' expenditure for each type of assets. The expenditure for countermeasures is presented for all countermeasures' functional classes. Additionally, the total expenditure for each functional class of countermeasures for all asset types is shown in the result summary table. **Figure 8** is an example of tabular result summary. Moreover, two pie charts showing each countermeasure's functional class expenditure share from the whole expenditure and each asset types' expenditure share from the whole expenditure is provided in result summary. An example of these two charts is shown in **Figure 9**.

The primary use of this result summary is comparing the result for different set of input specially the thresholds. As it mentioned before, setting threshold is an iterative procedure based on the budget (expenditure) and the importance of each asset type. This kind of result summary in which the user can see the calculated expenditure and asset type share from the whole expenditure is very helpful to set a threshold based on the users' constraints and preferences. The ultimate use of the result summary is obviously using in reports.

		Road Bridges	Road Tunnels	Transit/Rail Stations	Transit/Rai Bridges	Transit/Rail Tunnels	Admin & Supp Facilities	Ferries	Fleets	Other
Relevant Risks	Small Explosives	X								
	Large Explosives	X								
	Chemical/Biologic	X								
	Criminal Acts	X								
	Fire	X								
	Struct. Failure	X								
	HAZMAT	X								
	Flood	X								
	Extreme Weather	X								
Thresholds	Potentially Exposed Population	Persons	Persons	Persons	Persons	Persons	Persons	Persons	Persons	--
		200	0	0	0	0	0	0	0	--
	Property Loss	Damage	Damage	Below Ground Stations Critical?	Damage	Damage	Damage	Damage	Damage	--
		$135,597,881	$5,000	Yes	$5,000	$5,000	$5,000	$5,000	$5,000	--
	Mission Importance	ADT * Detour Length	Road tunnels critical?	Transfer Stations Critical?	% of ridership that causes mission	% of ridership that causes mission	Facilities critical?	Ferries critical?	Fleets critical?	--
		Demand Percentile	Yes	Yes	0	0	Yes	Yes	Yes	--
Counts	# of Unique Critical Assets	52	0	0	0	0	0	0	0	0
	# of Unique	28	0	0	0	0	0	0	0	0
	Total # of	835	0	0	0	0	0	0	0	0
Expenditures	Physical	$2,337.6	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
	Access Control	$14,929.2	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
	Asset	$543,950.8	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
	Operational	$108,839.2	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
	Other	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
	Total	**$670,056.7**	**$0.0**	**$0.0**	**$0.0**	**$0.0**	**$0.0**	**$0.0**	**$0.0**	**$0.0**

Totals	Physical Security	$2,337,600
	Access Control Countermeasure	$14,929,200
	Design/Engr Countermeasure	$543,950,784
	Operational Countermeasure	$108,839,200
	Other	$0
	Overall Total	**$670,056,732**

Figure 8 An example of tabulated results



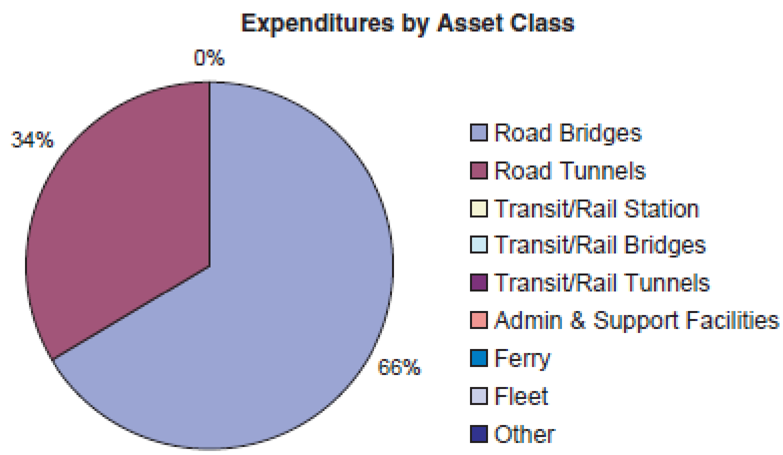


Figure 9 An example of results displayed as pie charts

CHAPTER 4 DELAWARE CASE STUDY

To understanding CAPTA better, a case study using transportation assets in the state of Delaware is developed. This study identifies the critical assets and effective countermeasures as well as provides cost data for the countermeasures. This chapter begins by reviewing the necessary input data. The chapter then reviews the process of setting thresholds using a sensitivity analysis, and concludes by describing the countermeasures and results.

4.1 Input Data

The first step in this study is preparing a list of transportation assets in Delaware. The asset types included in CAPTA are: road bridge/tunnels, transit bridge tunnels, ferries, administration facilities and fleets. This study is focused on road bridges/ tunnels. There are no tunnels in Delaware so bridges are used for this research. First, we need a list of all bridges and their attributes. The specific information needed for bridges is their name (ID), length, number of lanes and average daily traffic. All these data is available in Nation Bridge Inventory (NBI) Database. NBI (2009) for the state of Delaware is selected to be used as input data. There are 1158 bridges in Delaware recorded in NBI database. To be more accurate the bridges are not classified in this study and all the assets, one-by-one, are used to assess their criticality and effective countermeasures. The next step is to choose the relevant hazards for road bridges. Based on previous experience and natural hazards statistics, earthquakes and mud/landslides are removed from the list of hazards. Other threats including intentional, unintentional and other natural hazards are considered as relative hazards.

4.2 Setting Thresholds

The objective of this case study is identifying the most critical assets and the effective countermeasures for these assets. A sensitivity analysis has been conducted to see how changing the threshold affects the number of critical assets.

This sensitivity analysis is done for each type of consequences separately. It means that there is a separate sensitivity analysis for potentially exposed population, property loss and the level of mission disruption, which is the product of detour length multiplied by average daily traffic. In this study the final threshold is set in a way that the 50 most critical assets will be identified. But more information can be excavated from sensitivity analysis diagrams.

The process begins by selecting a threshold for exposed population, property loss, and mission disruption. These thresholds are adjusted until the final outcome is achieved. The following chapter summarizes the relationship between the number of critical assets and the critical assets as well as identifying the threshold selected. **Figure 10** shows the sensitivity analysis for exposed population. As the figure shows for more than 400 persons the number of critical assets are relatively constant. The largest possible number to choose as a threshold is 1000 and still 13 assets are critical for this number. So these 13 assets are critical regardless of the level of threshold. The threshold criterion for exposed population is set at 200 people.

The least possible property loss threshold in CAPTA is $5000. For this amount all the assets are critical. The largest possible threshold is $2,000,000,000 and two bridges are valued at more than this amount. **Table 8** shows the number critical assets versus the property loss threshold. The last three values have been deleted in **Figure 11** to see smaller amount clearly besides they are not useful in this study since we are seeking the 50 most critical assets. $136,000,000 is chosen as the property loss threshold for the study goal.

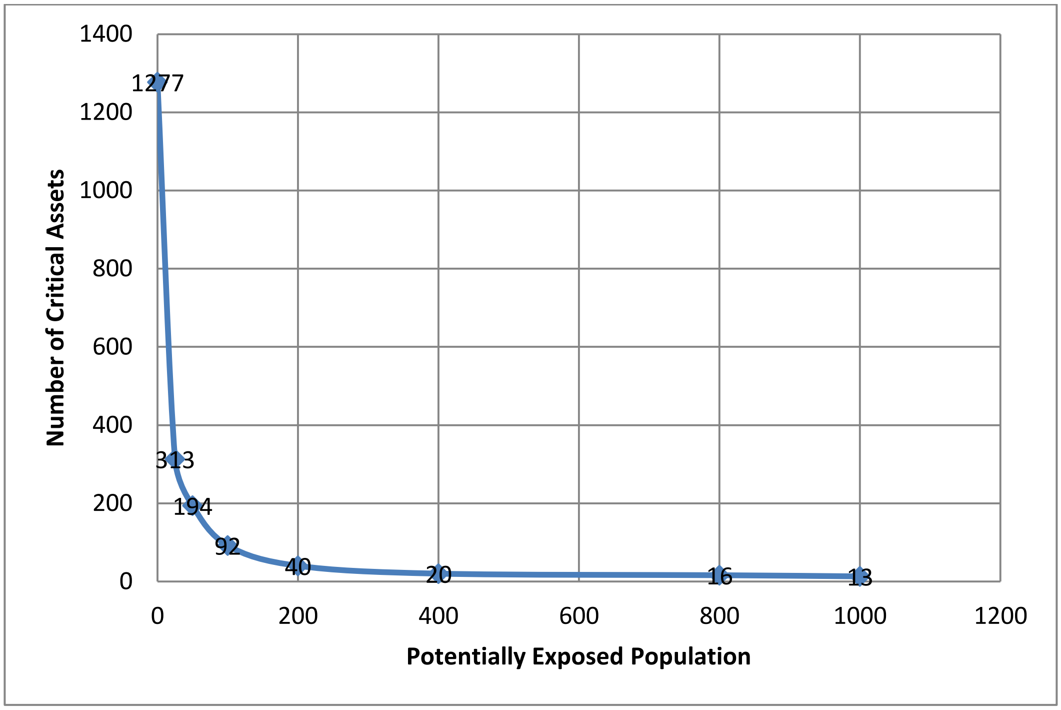


Figure 10 Sensitivity analysis for potentially exposed population

Table 8 Sensitivity for property loss

Property Loss ($1000)	Number of Critical Assets
5	1277
17,000	351
34,000	231
68,000	81
136,000	34
271,000	17
542,000	9
1081,000	4
2,000,000	2

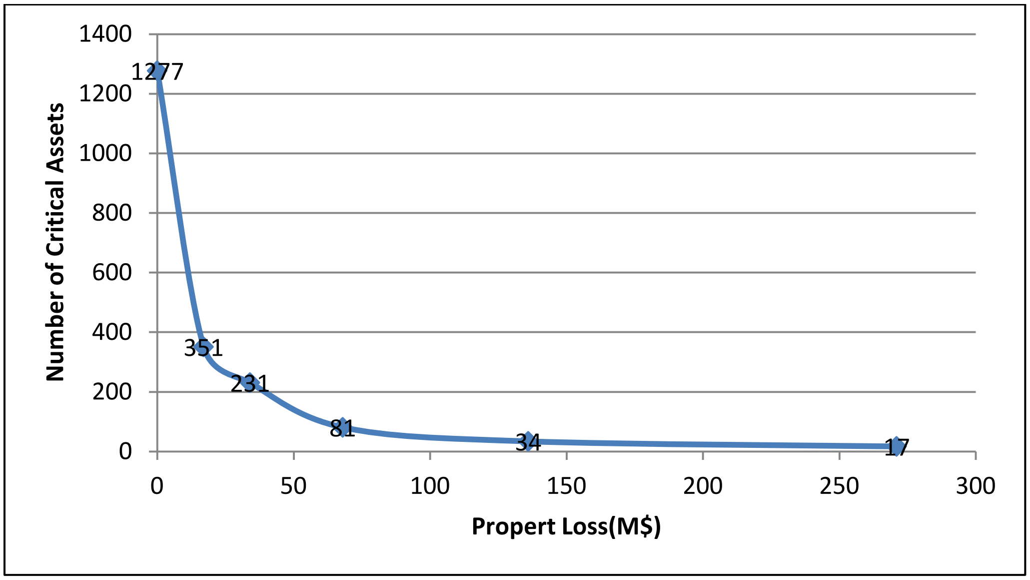


Figure 11 Sensitivity analysis for property loss

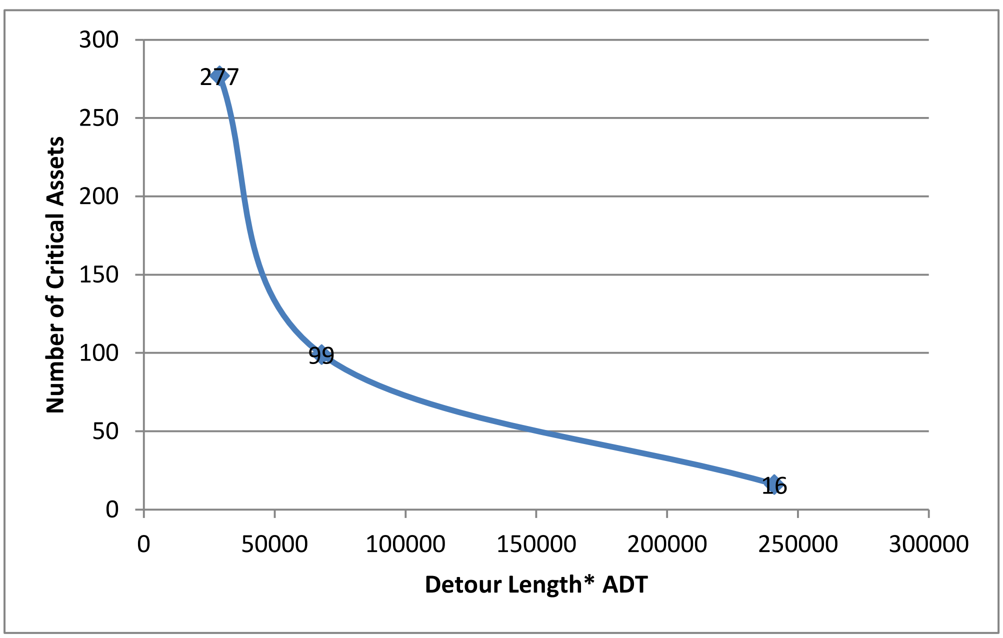


Figure 12 Sensitivity analysis for mission disruption

The Sensitivity Analysis is a little different for mission disruption consequences. The measure defined to evaluate mission disruption for bridges is the detour length (Mile) multiplied by the average daily traffic (given in units of vehicle mile). Three levels are set as default thresholds. Level I (75^{th} percentile), level II (85^{th} percentile), and Level III (95^{th} percentiles) of the national inventory for this measure are considered as default thresholds. Users can use these default values or change them. In this study default values are used. There was a problem in that the CAPTool that could not calculate the criticality properly. This part has been done manually. The sensitivity analysis for mission disruption is shown in **Figure 12**. Demand percentile (detour length* ADT) level III is chosen to find 50 most critical assets.

Table 9 shows the critical assets based on selected thresholds. In the table assets' IDs are the same IDs used in NBI database. "Y" shows that the asset is critical besides it shows the source of its criticality. "X" shows the relevant hazards for each asset. The three selected criteria identify 52 assets as critical assets. Exploring the results shows the property loss and potential exposed population have a good correlation. Forty (40) assets are identified as critical asset based on potential exposed population criteria and 34 assets are critical based on property loss criteria. Thirty one (31) assets are common for both criteria. So we have total 43 critical assets based on the first and second criteria and 73% of them are critical with both criteria. But the story is different for mission disruption, 16 assets are identified as critical assets; among them 9 assets are new assets which are not critical based on the other two criteria. Six (6) assets are critical based on all three criteria which can be called most critical assets.

Table 9   Critical assets

	Asset ID	1025 004	1229B011	1329N067	1329S067	1394S022	1494 016	1495 034	1496 002	1501 006	1576 043	1585 049	1587 267	1629 027	1632 011	1635 011	1664 033	1680 006	1684 028	1686 029	1687 029	1693 050	1713 056	1715 018	1719 056	1720 056	1721 056
CRITICALITY	Potentially Exposed Population		**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**			**Y**	**Y**	**Y**		**Y**	**Y**	**Y**	**Y**	**Y**		**Y**			
	Property Loss			Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y				Y							
	Mission Importance	Y						Y									Y						Y		Y	Y	Y
RELEVANT THREATS/ HAZARDS	Small Explosives		X											X	X	X		X	X	X	X	X		X			
	Large Explosives	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Chemical/ Biological/ Radiological	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Criminal Acts																										
	Fire	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Struct. Failure	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	HAZMAT	X						X									X						X		X	X	X
	Flood	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Earthquake																										
	Extreme Weather	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X			X			X		X	X	X

Table 9 Critical assets (Continued)

	Asset ID	1727 056	1729 056	1737A056	1737B056	1744 059	1745 059	1748 059	1748N059	1748S059	1758G6149	1759 059	1765 059	1770 059	1793 059	1813 060	1831 060	1902 067	2007B007	2008H008	2008I008	2915N150	2915S150	3156 050	1494016	1495034	1496002
CRITICALITY	Potentially Exposed Population		Y	Y	Y	Y	Y	Y	Y	Y	Y			Y	Y	Y		Y	Y	Y	Y	Y		Y			
	Property Loss			Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y				Y							
	Mission Importance	Y						Y									Y						Y		Y	Y	Y
RELEVANT THREATS/ HAZARDS	Small Explosives		X											X	X	X		X	X	X	X	X		X			
	Large Explosives	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Chemical/ Biological/ Radiological	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Criminal Acts																										
	Fire	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Struct. Failure	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	HAZMAT	X						X									X						X		X	X	X
	Flood	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Earthquake																										
	Extreme Weather	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X			X			X		X	X	X

4.3 Countermeasures and Results

The next step in CAPTool is choosing the countermeasures and the quantity of them. As discussed before, this part is the most controversial part. In this study since we do not have a budget constraint, all the countermeasures with high effectiveness are chosen and the quantity of "1" is assigned to all of them. The overall goal of this study is making this step more efficient. A procedure is proposed to find the most effective countermeasures considering a budget constraint. **Table 10** shows a sample of current strategy to choose the countermeasures for critical assets.

The summary results for Delaware's critical bridges are shown in **Table 11**. This study was designed to find the 50 most critical assets so the number of critical assets is very close to this number. The total number of critical assets is 52. The number of unique countermeasures is 28. It means that 28 different countermeasures have been proposed for all critical assets. The whole budget needed for the countermeasures is almost $670 million. A pie chart illustrates the expenditure share for each type of Countermeasures is shown in **Figure 13**. The biggest share is for asset designing and engineering countermeasures which includes seismic retrofitting, fire detection and suppression and encasement wrapping and jacketing.

Table 10 A sample of critical assets' countermeasures

Color Key	Medium Effectiveness	High Effectiveness

ASSET ID	1025 004	1229B011	1329N067	1329S067	1394S022	1494 016	1495 034	1496 002	1501 006	1576 043
Lighting										
Barriers & Beams		1								
Fences		1								
CCTV										
Intrusion Detection Devices										
Physical Inspection of asset	1	1	1	1	1	1	1	1	1	1
ID Cards										
Biometrics										
Background Checks										
Metal Detectors										
Restricted Parking										
Random Inspections	1	1	1	1	1	1	1	1	1	1
Visible Badges										
Limited Access Points										
Visitor Control & Escort										
Locks										
Explosive Detection	1	1	1	1	1	1	1	1	1	1
Establish Clear Zones	1	1	1	1	1	1	1	1	1	1
Visible Signs										
Seismic Retrofitting	1	1	1	1	1	1	1	1	1	1
Fire Detection & Suppression	1	1	1	1	1	1	1	1	1	1
Encasement, Wrapping, Jacketing	1	1	1	1	1	1	1	1	1	1
Patrols	1	1	1	1	1	1	1	1	1	1
WX/Seismic Information	1	1	1	1	1	1	1	1	1	1
Intelligence Networking	1									
HAZMAT Mitigation	1	1	1	1	1	1	1	1	1	1
Security Awareness Training	1	1								
Emergency Response Training	1	1	1	1	1	1	1	1	1	1
Emergency Evacuation Planning	1	1	1	1	1	1	1	1	1	1
Planned Redundancy (e.g., detours)	1	1	1	1	1	1	1	1	1	1

Table 11 Summary results for Delaware bridges

Relevant Risks	Small Explosives	X
	Large Explosives	X
	Chemical/Biological/Radiological	X
	Criminal Acts	X
	Fire	X
	Structural Failure	X
	HAZMAT	X
	Flood	X
	Earthquake	
	Extreme Weather	X
	Mud/Landslide	
	User entered threat/hazard 1	
	User entered threat/hazard 2	
Thresholds	Potentially Exposed Population	Persons
		200
	Property Loss	Damage
		$135,597,881
	Mission Importance	ADT * Detour Length
		Demand Percentile III
Counts	# of Unique Critical Assets	52
	# of Unique Countermeasures	28
	Total # of Countermeasures	835
Expenditures	Physical Security Countermeasures (x1000)	$2,337.6
	Access Control Countermeasures (x1000)	$14,929.2
	Asset Design/Engr Countermeasures (x1000)	$543,950.8
	Operational Countermeasures (x1000)	$108,839.2
	Other Countermeasures (x1000)	$0.0
	Total Countermeasure Expenditures (x1000)	$670,056.7

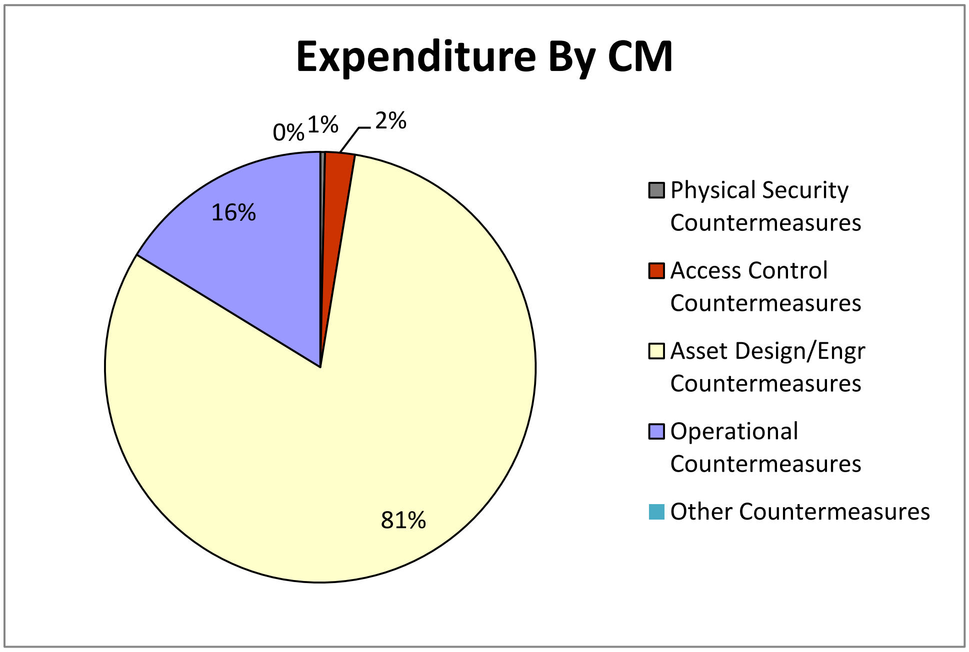


Figure 13 Countermeasures share from the total budget

CHAPTER 5 A NEW MECHANISM TO CHOOSE COUNTERMEASURES

5.1 Problems with the Current Method

In chapters 3 and 4 the procedure to choose appropriate countermeasures is described. After ranking the countermeasures by their effectiveness using CAPTA, it is up to the user to choose the most appropriate countermeasures based on three degree of effectiveness: high, medium and low.

The strategy used to pick the appropriate countermeasures in the Delaware case study involves selecting all the countermeasures with “high” effectiveness. Although it might not be the smartest strategy, CAPTA does not provide us with a better one. Even if we solve this problem by choosing a strategy like this a bigger problem will arise when a budget constraint is added to the problem.

Selecting the most appropriate countermeasures based on the available budget in CAPTA is based completely on a trial and error procedure. It means that you first pick a bundle of countermeasures and watch the required budget for that in the result page. Then remove some countermeasures and repeat the steps till the budget constraint is met. This may be a very time consuming and frustrating procedure when you are working with different asset types and different hazards. Besides, the biggest weakness of this procedure is that there is no criterion to choose one countermeasure over another one. Different users may omit different countermeasures to match the required budget with the available budget.

One of the goals defined for this tool (CAPTA) is producing consistent results for different users but the current procedure will not lead us to this goal and makes using this software hard. Justifying the results and the proposed countermeasures is not easy and it is dependent on the user and evaluator opinion.

5.2 Rationale for a New Method

The two key functions of CAPTA are identifying critical assets and assigning appropriate countermeasures to them. For the first function (identifying critical assets) CAPTA is consistent with literature review (chapter2). It uses some of previously developed measures to identify critical assets.

However, second function (selecting appropriate countermeasures) is not rigorous and is time consuming besides the literature does not provide a solution. Therefore, the proposed method uses the CAPTA method to select critical assets and develops a new method having optimization to select appropriate countermeasures for the application to critical assets.

5.3 The Proposed Optimization Problem

To solve problems with the current countermeasure selection procedure, first we need a criterion to choose the countermeasure. We know that the goal of the whole procedure is selecting the most appropriate countermeasures. So we should define "the most appropriate" in a way that we can measure it. CAPTA provides us with three level of effectiveness for each countermeasure. We can consider the "effectiveness" as appropriation criteria. So from now on the goal is finding the most effective set of countermeasures which is limited by a specific budget constraint.

Now we have the three essential elements of an optimization problem: an objective (maximizing effectiveness), a set of variables (to choose or not to choose a countermeasure) and constraint (budget constraints). Each of these three elements should be quantified and converted to a mathematical formula to be usable in an optimization problem.

5.3.1 Objective

The effectiveness in CAPTA is defined by three qualitative levels. To quantify the objective we need to assign a number to each level. As a first attempt "1" is assigned to "low effectiveness", "2" is assigned to "medium effectiveness" and "3" is assigned to "high effectiveness". This scale is referred as scale I. Later in this chapter another scale will be discuss in which the weights assigned to the three levels of effectiveness is different from the above numbers. The proposed measure calculates the aggregate effectiveness of a set of countermeasures by summing the effectiveness of individual countermeasures. No weight is considered for any countermeasure. However, if an agency wants to set some priority for a particular hazard they can assign a larger weight to the countermeasures suitable for that specific hazard. For example, if earthquakes are the most important hazard in a region, a larger weight can be assigned to "Seismic Retrofitting" and other countermeasures with high effectiveness for earthquake hazards. The objective of the problem is to maximize the total effectiveness of countermeasures chosen.

5.3.2 Variables

In CAPTool, Users should answer two questions to complete selection countermeasures step:

1. Which countermeasures should be chosen?
2. How many units of it should be applied?

In this problem we are just answering the first question. For the second question we assume that the appropriate number of units is chosen by the authority. So we want to solve the problem of implementing a countermeasure with a given appropriate number of units or not. The variable in this problem is designated by X_{ij}. X_{ij} is a binary variable which is one if a countermeasure (i) is selected for an asset or asset group (j) and it is zero if it is not selected.

5.3.3 Constraints

The only constraint considered in this problem is the budget constraint. The unit cost of each countermeasure is provided in CAPTA. The total required budget for the countermeasures selected to implement should be less than or equal to the budget available for the risk management.

5.3.4 The Mathematical Model

$$\textbf{Maximize } \sum_{i=1}^{n}\sum_{j=1}^{m} E_i X_{ij} \qquad \textbf{(2)}$$

Subject to

$$\sum_{i=1}^{n}\sum_{j=1}^{m} c_i X_{ij} \leq C \qquad \textbf{(3)}$$

$$X_{ij} = 0 \text{ or } 1 \quad \forall\, i, j \qquad \textbf{(4)}$$

Where

X_{ij}=1 if countermeasure i is selected for asset j, otherwise 0.

c_i = cost of countermeasure i

E_i= effectiveness of countermeasure i

C = available budget

m= number of assets

n= number of countermeasures

5.4 Delaware Case Study

The new methodology is applied to Delaware bridges, which are analyzed in chapter 4 with CAPTool. There are 52 critical assets (bridges). These 52 assets can be categorized in 3 groups based on the effectiveness of countermeasures. The effectiveness (H, M, and L) of each countermeasure for all the assets in a group is the same. For simplification it is assumed that "1" unit of countermeasure is enough for each asset. Weights "1","2" and "3" is assigned to "Low", "Medium" and "High" effectiveness respectively in this scale. This scale is referred as scale I in this chapter. Another scale for assigning weights to the levels of effectiveness is discussed later to analyze the sensitivity of results to the assigned weights. Finally the cost and total effectiveness results are compared for 4 Scenarios:

1- Selecting only highly effective countermeasures (Initial)
2- Selecting optimized effectiveness countermeasures with the same budget of scenario 1 (Opt)
3- Selecting optimized effectiveness countermeasures with the 80% of budget of scenario 1 (Opt 80%)
4- Selecting optimized effectiveness countermeasures with the 50% of budget of scenario 1 (Opt 50%)

The optimization problem is solved by Excel Solver. Excel solver uses a branch and bound method to solve problems with binary variables. A branch and bound algorithm is an organized and highly structured search of all possible solutions to a problem. It is a general form of backtracking methods (Daintith, 2004). It consists of a systematic enumeration of all candidate solutions, where large subsets of fruitless candidates are discarded, by using upper and lower estimated bounds of the quantity being optimized. The result of the analysis is shown in

Figure 14 where "Opt" refers to the assets selected using the optimization procedure, and "Initial" refers to the assets selected using CAPTool.

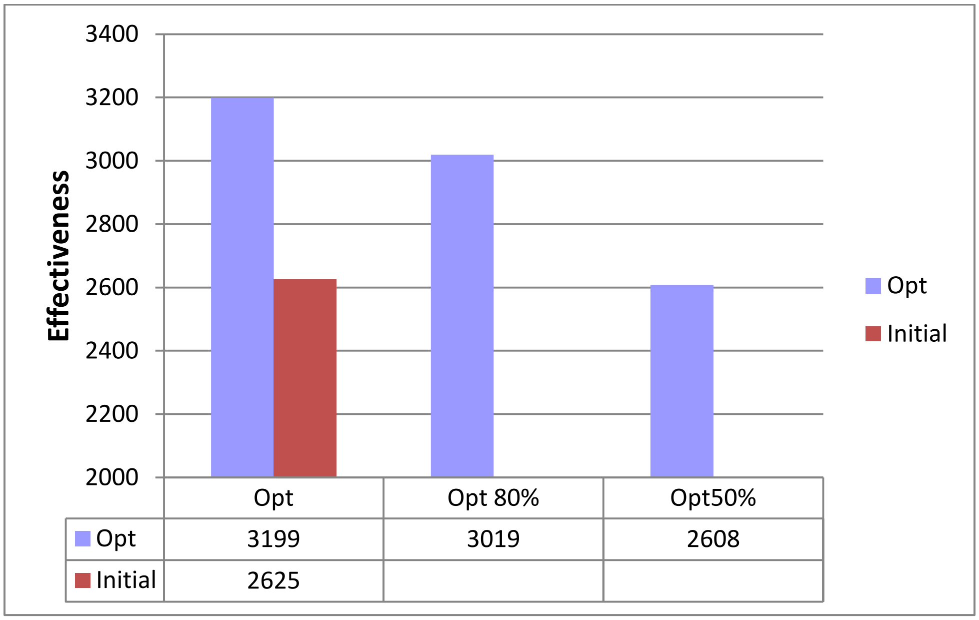


Figure 14 shows that using optimization to help us in selecting countermeasures leads to a set of countermeasures with the same effectiveness of initial selection with approximately half the budget (cost). Even 80% of budget with new method results in larger effectiveness compared with the initial set of countermeasures.

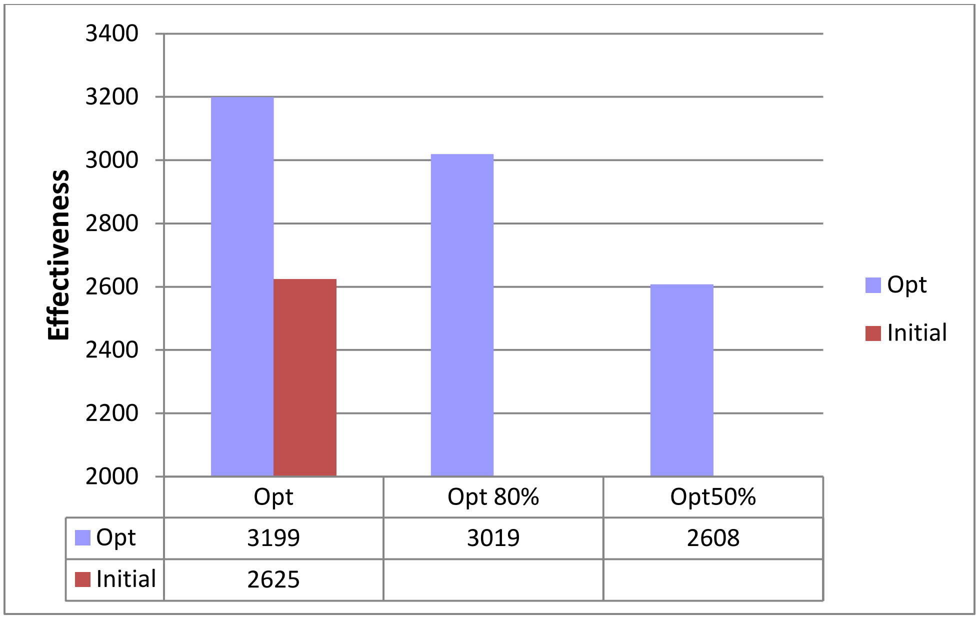


Figure 14 Budget-effectiveness relation for two methods (scale I)

To analyze the sensitivity of results to the weights we considered for “low”, “medium” and “high” effectiveness a new scale (II) is applied. In scale II “low” effectiveness has the weight of “1”, “medium” effectiveness has the weight of “5” and the “high” effectiveness weight is “10”. The result for the four scenarios above is shown in Figure 15**.**

Since the weight considered for high effectiveness is relatively high in scale II is the gap between optimization method and initial strategy in which only the countermeasures with high effectiveness were selected is smaller. However, the optimization method clearly results in a better selection based on budget and effectiveness relation.

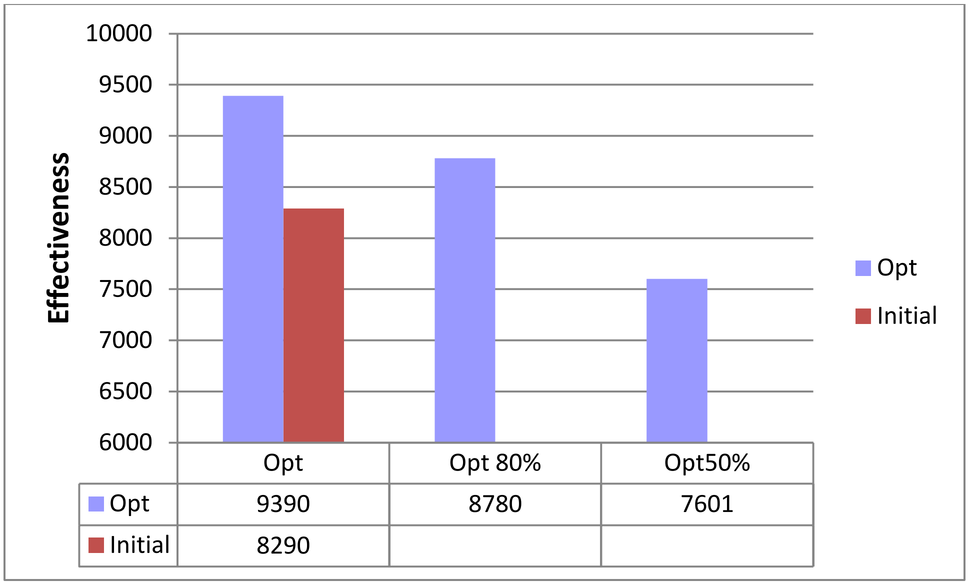


Figure 15 Budget-effectiveness relation for two methods (scale II)

To sum up, the advantages of optimization method is: first, provides a standard method to select the most effective countermeasures which ensure consistent results and, second improve the effectiveness of results for a specific budget.

CHAPTER 6 CONCLUSIONS AND FUTURE WORK

The research presented in previous chapters is aimed at improving risk analysis for costing asset protection for transportation agencies (CAPTA). CAPTA developers intended to keep CAPTA as a high level all hazard guide. A consequence based method is applied in CAPTA to find the most critical hazards and the developers intended to use the least detailed data possible to maintain consistent results. This procedure gives pretty consistent results in identifying critical assets. However in the next step when appropriate countermeasures should be selected for the critical assets, the method applied by CAPTA is a subjective one. This method uses three levels of ranking to show the effectiveness of a countermeasure for a specific asset. Users are supposed to choose the countermeasures based on their judgment.

CAPTA is applied for the bridges in Delaware. Data required for this tool is extracted from National Bridge Inventory database. The capability of CAPTA for identifying the most critical bridges based on very few fields of NBI database makes it desirable as a quick, cheap, high level analysis method. The required data for other types of assets is also available in Departments of Transportation databases and no new data is required. CAPTA includes several databases that help the decision makers to keep all kinds of hazards and the appropriate countermeasures in mind.

In this report a quantitative system to evaluate the effectiveness of results is developed first. Then, the optimization method is used to find the most effective sets of countermeasures considering the budget constraint.

The advantages of the new method are, first it produces consistent results for different users. Second, the optimization solution identifies the best solution for the problem; when the problem is defined appropriately users are confident about the result. Third, the budget constraint is implied in the problem. The frustrating iteration method is not necessary to keep the expenses in the range of budget. The comparison between CAPTA and the quantitative method showed that for bridges in Delaware, the quantitative method selects a set of countermeasures with the same effectiveness as the CAPTA selected set with half the budget. Generally, the method proposed in this report makes the NCHRP method more efficient and consistent.

Current effectiveness ranking system of the countermeasures is based on three levels for which the difference between 2 levels is not clear. For more accurate results from the quantitative method, a survey can be conducted to ask the expert to rank the countermeasures based on a given scale, for example 5 levels with equivalent differences between the levels. This method still keeps the idea of not using too much detailed data and in the other hand provides a good basis for the quantitative method. To make this procedure more effective, a comprehensive analysis of different quantitative ranking methods should be done to find the most applicable one. Besides, the idea of weighting assets or hazards can be applied to find the most appropriate sets of countermeasures. The weights assigned to assets or hazards may be chosen by the user. But there should be a systematic method to show the effect of the weighting on the results to help users to come up with a practical weighting system. Choosing “1” unit of a countermeasure, which was an assumption in the report, should be eliminated. Expanding the database to show the user how many units of countermeasures are needed for an asset based on the size of the asset is recommended.

Since the Excel solver is applied to solve the optimization problem in the quantitative method there is a good potential for integration of the new method with CAPTA. Step 5 of CAPTA, which is dedicated to providing “countermeasure opportunity”, may be changed to also include the most effective set of countermeasures. The option of choosing a different set of countermeasures is still useful if agencies want to use the quantitative solution as an initial solution and apply their own desirable changes in the selected set to see the consequences.

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APPENDIX – IMPLEMENTATION PLAN

In the course of this project, several activities have been undertaken to disseminate this work. In November 2009, along with the researchers, the Project Manager participated in a webinar "Costing Asset Protection: An All Hazards Guide for Transportation Agencies" offered by the Transportation Research Board. In May 2010, the researchers participated in the DCT Showcase.

A research needs statement prepared for the Transportation Research Board by Committee ABE40, Critical Transportation Infrastructure Protection dated October 2010 is titled "Costing Asset Protection: An All Hazards Guide for Transportation Agencies (CAPTA) - Update and Implementation" (http://rns.trb.org/dproject.asp?n=27252). The statement says:

> *While the methodology has been widely endorsed by NCHRP Project Panel members who directed its development and the transportation agencies where it has been demonstrated, it has yet to be fully embraced and implemented due, in part, to the relatively "fragile" state of the spreadsheet model used to implement the methodology. Moreover, the prototype implementation of the methodology has embedded in code some of the parameters used in assessing asset criticality, thus making it difficult for users to either see or modify these parameters in response to either local conditions or changes over time. Finally, because the tool was developed as a prototype, it has not been "hardened" • to the point where user errors are trapped and reported to the users and other user-oriented features provided so that state DOTs and other users can apply the methodology with greater confidence.*

The statement presents the following objective:

> *The objective of the proposed research effort is to update, enhance, and "hardened" the CAPTA methodology and promote its use by state DOTs and other transportation agencies so that it can become part of a "mainstreamed" process for including security and related considerations in the transportation planning process and resource allocation decisions so that, to the extent possible, investments in transportation infrastructure represent "system level" decisions that consider security as an important factor comparable to safety, reliability, and other aspects of transportation capital investment decision making. Simplifying and packaging the approach is essential to*

encourage broader interest and adoption and overcoming the sources of resistance to embodiment of security into resource allocation decisions including

- *Lack of institutionalized statewide planning that addresses resource allocation*
- *Perceived reduced urgency of security issues*
- *Reduction in funding for emergency and security related planning*
- *Overcomplicated processes and methods for incorporating threat-related factors into planning and programming*

Overcoming these barriers requires that the methodology be framed with respect to the typical state and metropolitan planning and programming activities and easily integrated into those processes. In addition an "educational" • (marketing) element may need to be added to promote awareness and use of the methodology.

While this proposed research project has not been funded, it is feasible for DelDOT to consider implementation. CAPTA is intended to be a high level budgeting/ programming tool to help state DOTs "mainstream" security, like safety, into their planning processes. To implement this strategy, significant coordination is required between planning and operations. Given Delaware's size, some of the issues addressed in the research needs statement are not as a critical. Nevertheless, significant data development is required to integrate these process.

As proposed in the research needs statement, an implementation effort could proceed as follows:

- CAPTA is presented to potential users, users provide feedback regarding strengths and weakness
- A strategy is developed for enhancing CAPTA to address DelDOT's needs, and integrating CAPTA with the planning process.
- The enhancements are made and the processes modified to accommodate consideration of security, as well as assemble the necessary data.
- A series of workshops are conducted to demonstrate the role of CAPTA
- An evaluation is conducted after the implementation.

The benefits of this effort would be to include consideration of critical transportation infrastructure protection in planning and capital investment decision making to determine investment needs or to allocate available resources among competing needs.

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