Framework for Estimating Cost of Infrastructure Adaptation to Climate Change

H. Lee, T. Park, H. Jeong and *H. Kim
Yonsei University
134 Shinchon-dong, Seodaemun, Seoul, Korea
*(*Corresponding author: hyoungkwan@yonsei.ac.kr)*

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ABSTRACT

Recently, the effects of global climate changes have become top concerns for governments' decision making regarding infrastructure investments. Extreme weather events that exceed the capacity of existing systems have considerably increased in frequency, and the potential effects of changing trends in temperature and rainfall on infrastructure are difficult to ignore. It is essential for governments to estimate the costs and benefits of adaptation to climate change to properly assess the financial feasibility of infrastructure adaptation strategies. This paper proposes a framework for estimating the economic aspects of infrastructure adaptation to climate change. The framework is composed of three steps of implementation: establishment of alternatives for infrastructure adaptation, performance prediction of infrastructure using future climate scenarios, and asset valuation based on costs and benefits. The first step specifies target assets, their adaptability to climate change, and applicable adaptation technologies. The second step evaluates the effects of climate change on the performance of infrastructure. The last step determines the optimal adaptation strategies among various alternatives based on their net benefits. The framework reasonably incorporates future climate scenarios into the estimation processes for climate change effects and provides a basis for budget allocation for governmental infrastructure investments. The framework is expected to assist government decision makers in establishing adaptation strategies in a rational manner under uncertain future climate change.

KEYWORDS

Adaptation, climate change, infrastructure, future climate scenario

INTRODUCTION

As many studies have indicated, the effects of climate change have already been observed in social, economic and ecological systems. Using climate models, previous studies have shown that climate change will continue and accelerate in the future (Solomon et al. 2007). In the beginning, researchers studied how to reduce greenhouse gas emissions – mitigation (Ford and Berrang-Ford 2011). Although, mitigation could alleviate climate change effects, it would not be enough to prevent inevitable climate change effects such as global warming and sea level rise. Obviously, it's time to tackle how to cope with these risks in practical manner – adaptation.

Adaptation represents a broad range of adjustment actions in ecological, social or economic systems to properly cope with potential climate effects (Smit and Pilifosova 2001). In this study, infrastructure adaptation means to prepare civil engineering infrastructure such that they can perform their intended functions under the unusual weather or climate events caused by global warming. From a governmental perspective, the implementation of adaptation should meet the following three considerations. First, adaptation should reflect future climate scenarios. Second, adaptation should account for the performance of infrastructures. Third, adaptation benefits should be estimated in monetary units, thereby making the net benefits (benefits – costs) the basis for determining optimal adaptation strategies. Thus, this paper proposes a framework that reflects the aforementioned considerations by incorporating a deterioration model and future climate scenarios into the framework. Overall, this study could provide a guideline for governmental decision making regarding adaptation strategies under uncertain future climate change.

LITERATURE REVIEWS

Over the last two decades, extensive studies on adaptation have been performed to address global climate change effects in various areas. Studies performed over the last ten years have mostly been dedicated to the estimation of adaptation costs (Stern Review 2006; Larsen et al. 2008; Robert 2008; Richards and Nicholls 2009; UNFCC 2009). Now, many researchers claim that it is time to shift from theory to practices that policy makers and the general public could adopt to adapt to climate change (Schiermeier 2007).

The process of adaptation to climate change is mainly composed of three steps: vulnerability assessment, impact assessment, and adaptation policy assessment (Fussel and Klein 2006; IPCC 2007). Vulnerability assessment estimates how much a target asset is susceptible to climate change with the existing adaptive capacity. Impact assessment is the process by which potential damage reductions achieved by adaptation technologies against climate change effects are evaluated. Adaptation strategies should provide information about how the asset of improvement would be selected and how the asset of choice would be improved.

Although the aforementioned studies have provided a basic platform for the valuation of adaptation strategies, they do not properly reflect the probabilistic performance of infrastructures under uncertain future climate change. To successfully adapt to future climate change, the impact of adaptation technologies on infrastructure performance under different climate scenarios should be investigated to estimate potential damage reductions accurately. In addition, most studies on the estimation of adaptation costs have been conducted using the top-down approach on a macro scale. However, considering how the adaptation of infrastructure could be accomplished, the analysis should be conducted on a project-level or technology-level basis. Thus, this study proposes a model that assesses the effectiveness of adaptation technologies at the project level.

IMPACT OF ADAPTATION TECHNOLOGY ON THE PERFORMANCE OF INFRASTRUCTURE

Framework for infrastructure adaptation to climate change

It is clear that adaptation is essential to coping with climate change effects. Adaptation would increase the existing adaptive capacity of infrastructures and thus reduce the risks of climate change effects. Thus, technologies for infrastructure adaptation are defined as the type of technologies used to maintain or improve the performance of infrastructure under the new weather and climate events. For example, new pavement method is to be considered as an adaptation technology if it maintains or improves the existing performance of road pavement under the new temperature, rain, or snow conditions affected by the climate change.

This study proposes a decision framework for infrastructure adaptation. The framework consists of three steps: establishment of alternatives for adaptation, performance prediction using future climate scenarios, and asset valuation based on costs and benefits. First, governments should establish alternatives for improving infrastructure and gather the required information for the next level of analysis. Second, influential climate factors should be identified according to the type of target asset being considered, and their potential impacts on the performance of the asset should be assessed. Finally, based on the net benefits of adaptation, the government should prioritize investment alternatives and establish further adaptation strategies. Because adaptation costs for infrastructures are extensive, it is important that governments adequately estimate potential reductions in climate change effects by implementing adaptation strategies. These procedures are illustrated in Figure 1.

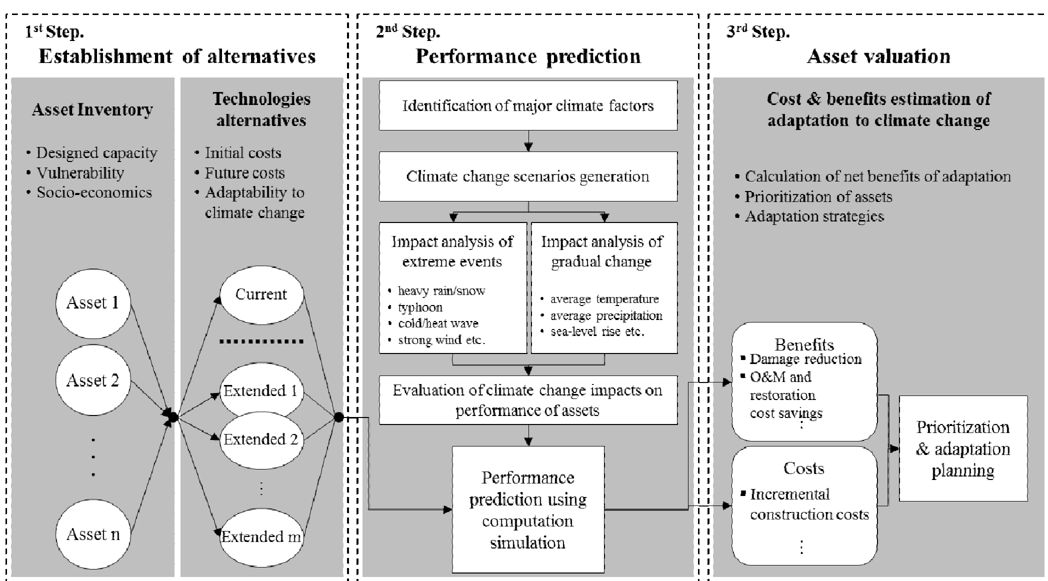

Figure 1– Framework for infrastructure adaptation to climate change

Climate change impacts on the performance of infrastructure

In this study, climate change impacts were categorized into two groups depending on how they affect the performance of infrastructures: extreme weather events and gradual change. Extreme weather events represent climate impacts that cause the immediate failure of partial or complete functions of an infrastructure, such as heavy rain and snow, typhoons, and strong winds (Lee and Kim 2012). These types of impacts incur the costs of new constructions as well as rehabilitations or restorations. On the other hand, gradual change impacts refer to climate changes that generate maintenance and rehabilitation (M&R) costs. Although these types of impacts do not demand immediate investments, the impacts create additional M&R costs for infrastructures in the long term. Changes in temperature, precipitation and sea level could be grouped into this category. The concepts underlying the estimations made for these impacts are described in the following sections.

1) Extreme climate change

The estimations for the impact of extreme climate change was predicated on the assumptions that the damages or costs of infrastructure due to certain weather events are proportional to the intensity of the weather events, where high-intensity weather events are less likely to occur than low-intensity weather events. Applying adaptation to target assets would decrease the probability of extreme weather events occurring but increase the total asset value. These concepts are illustrated in Figure 2.

In Figure 2, the x-axis and y-axis represent damage and probability of occurrence for a target asset, respectively. The expected damage for a target asset could be determined by multiplying the damage and occurrence probabilities. In this sense, the total expected damage before adaptation would be the area of A and B. If adaptation technologies were adopted for the infrastructure, the total expected damage would change from that represented by the area of A and B to that represented by the area of B and C. Thus, the net benefit of adaptation would be the difference between areas A and C.

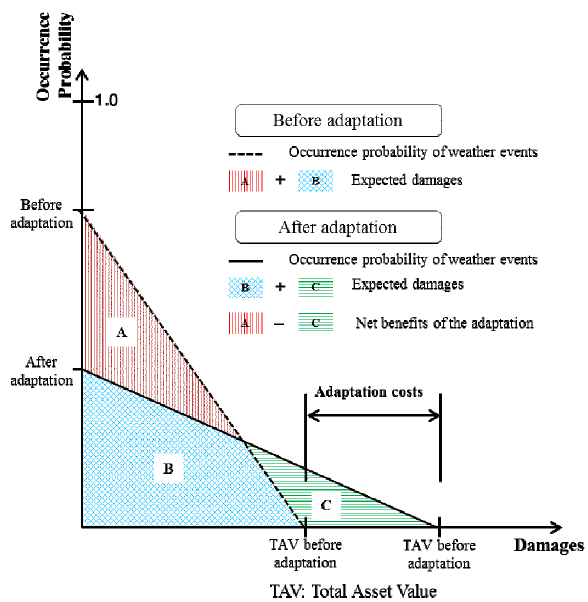

Figure 2– Estimation of the net benefits of adaptation to extreme weather events

2) Gradual climate change

In most cases, gradual climate changes do not require immediate investments in infrastructure improvements but do affect the deterioration of infrastructure and subsequently M&R costs. In this sense, investments for M&R heavily rely on the future performance of infrastructures (deterioration model). The expected benefits of adaptation for the M&R of infrastructure are presented in Figure 3.

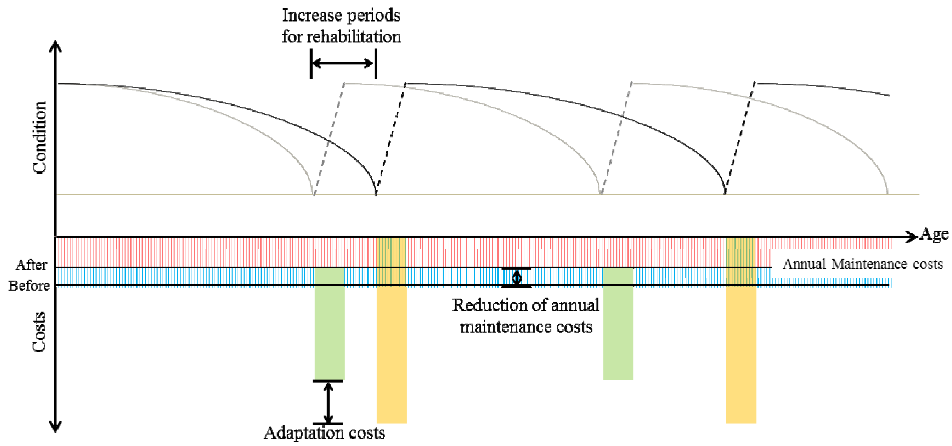

Figure 3–The impacts of adaptation on the M&R of infrastructure

As shown in Figure 3, when adaptation technologies are applied to infrastructure, additional costs associated with the technologies are incurred. However, adaptation reduces annual maintenance costs and increases the periods for rehabilitation as well. Using life cycle analysis for the target asset, the net benefit of adaptation can be estimated, and the financial feasibility of adaptation can be determined.

Application of future climate scenarios to the proposed models

The previous section described how adaptation could affect the performance of infrastructure. This section will explain how climate change impacts could be incorporated into the proposed framework. Typically, climate change increases the intensity and frequency of extreme weather events. Although climate change does not affect the inherent capability of the adaptation technology used, it would increase the potential damage of infrastructure without adaptation. These concepts are illustrated in Figure 4.

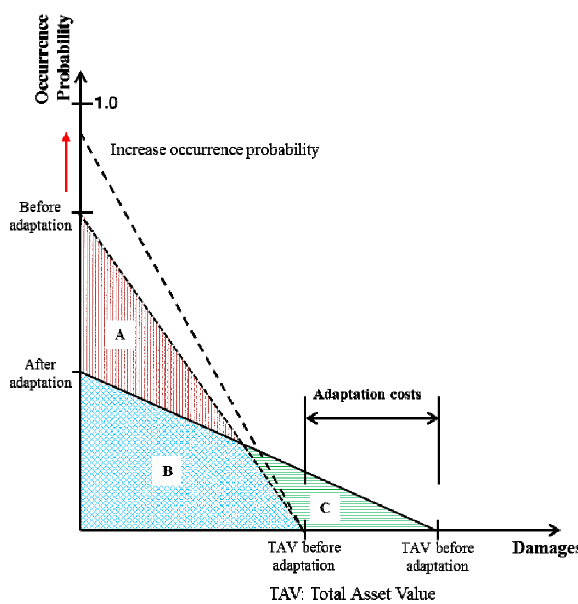

Figure 4– The impact of climate scenarios on the net benefits of adaptation to extreme weather events

Thus, it is inferred that adaptation is more beneficial when climate change impacts are more severe.

Climate change impacts also affect the deterioration of infrastructure, which represents the future performance of a system. Previous studies have shown that the future performance of an infrastructure typically follows the curve $y = e^{ax+b}$, as shown in Figure 5 (Butt et al. 1994; Morcous et al. 2002; FHWA 2002; Wirahadikusumah and Abraham 2003).

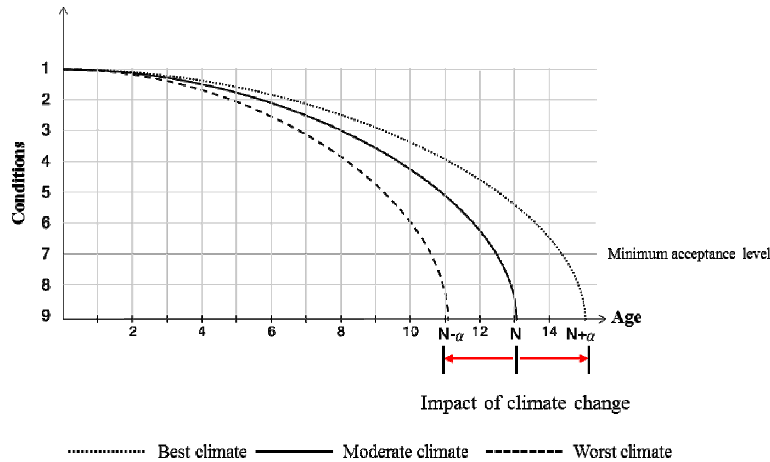

Figure 5– The impacts of climate scenarios on deterioration model

Figure 5 implies that a given system shows different service lives under different climate conditions. Using this concept, the proposed framework provides a more realistic deterioration model that reflects future climate scenarios. A case study, examining how expansion of drainage system (adaptation technology) could affect the adaptability of road infrastructure to climate change, will be conducted to check the validity and applicability of the proposed framework. The potential damages of future extreme weather events will also be estimated using statistical techniques such as multiple regression analysis.

CONCLUSIONS

This paper proposed a framework for estimating the costs of infrastructure adaptation to climate change. The contributions of the study to the body of knowledge are threefold. First, climate change effects on infrastructure were carefully investigated by grouping the effects into extreme weather events and gradual change. Second, this study provided a methodology for developing a more realistic deterioration model that reflects future climate change. Third, this study estimated the net benefits of adaptation at the project level. Consequently, this study provided a basis for establishing adaptation strategies for government decision makers. However, future study is required to identify the major climate factors affecting the deterioration of infrastructures to properly define the worst, moderate, and best climate conditions based on asset type.

ACKNOWLEDGMENT

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