Algorithm for Economic Assessment of Infrastructure Adaptation to Climate Change

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Abstract

Climate change, along with the increase of severe weathers and natural disasters, is becoming an important factor to consider for infrastructure investments. To adapt infrastructure to the effects of climate change, new design, construction, or rehabilitation methods – so-called adaptation methods – can be deployed. However, it is crucial to understand the impact of adaptation methods on infrastructure before they are actually implemented. When the economic benefit and cost are clear, asset managers can confidently make informed decisions about the priority of investment alternatives. This paper proposes an integrated algorithm to assess the benefit and cost of adaptation methods. The "integrated" aspect of the algorithm is derived from the fact that climate change effects on infrastructure can be divided into two categories. One is sudden extreme weather events caused by climate change; this sudden event leads to swift and disruptive damages to infrastructure. The other is a gradual climate change of which effects are shown over a long period of time. The algorithm combines the two different aspects of climate change to estimate the net benefit of adaption methods in an integrated manner. Future climate scenarios are first assumed and their input variables are determined for further procedures. With extreme events such as super-typhoon, the procedure for sudden failure of infrastructure is used to estimate the cost and benefit of the rehabilitation effort. Maintenance cost under gradual climate change is also estimated with the climate change adjusted deterioration curve for the infrastructure of interest. Finally, the above three steps are repeated for each year to estimate the life cycle cost infrastructure adaptation to climate change for the comparison of the costs with and without adopting the adaptation method.

Keywords: Adaptation, climate change, infrastructure, future climate scenario

1 Introduction

Previous studies have indicated that climate change increases the frequency and strength of the severe natural disasters and its effect is global (Easterling et al. 2000). Climate change would continue and intensify in the future (Solomon et al. 2007). There are two strategies to minimize influences of climate change; one is adaptation and the other is mitigation. Mitigation is an effort to reduce or eliminate causes of climate change. Greenhouse gas (GHG) is pointed out as a main source of climate change, so mitigation efforts, such as certified emission reduction (CER) policy by IPCC, are executed to minimize GHG emission.

Even though GHG emission can stay at the 1990s level, climate change's effect would last for next generations by its inertia (UNFCCC 2009). Thus, as a practical way of responding to climate change, adaptation is a viable choice to take. Adaptation recognizes climate change to overcome or adjust and it helps to reduce adverse impact and vulnerability regardless of the scale of mitigation efforts undertaken (IPCC 2007).

Adaptation appears on different spatial and societal scales (Adger et al. 2005) including coastal, agriculture, energy and infrastructure fields. In this research, adaptation is focused on management of infrastructure for its economic assessment. Cost is one of key factors - with others such as social acceptability, ease of implementation, and long term viability - to consider when infrastructure's adaptation methods are implemented (Agrawala and Fankhauser 2008). So this paper proposes a methodology to evaluate adaptation methods' net benefit and damages from climate change during life-cycle of infrastructure. Due to the infrastructure's characteristics, this study divides climate change into two categories to properly reflect its effect on a life of infrastructure: extreme weather events and gradual climate change. For the two types of climate change, damage and benefit calculation methods are separated. At the end, net benefit (benefits - costs) of adaptation is computed through the integrating simulation algorithm. With this result, this study can offer a guide for decision making processes in monetary units.

2 Literature Reviews

Global climate change has accelerated natural disasters for the last 35 years according to the Emergency Events Database (EM-DAT)'s statistics. This statistics reported that natural disaster frequency has been increased to 400 cases in 2010 from 120 cases of 1975. Population who were affected by these disasters in 2010 is grown up 2.5 times compared with 1975 and damage cost in 2010 has become 8 times more than that of 1975. This comparison supports that it is high time to make efforts about climate change issues.

In previous studies, an assessment of adaptation to climate change is identified in three steps (IPCC 2007, Fussel and Klein 2006, 2007). They are climate impact assessment, vulnerability assessment, and adaptation policy assessment. Climate impact assessment analyzes potential damages or harms from climate change. Vulnerability assessment estimates the level of climate change risk that a region is exposed to, considering its adaptive capacity. Adaptation policy assessment evaluates adaptation method's capacity to reduce impacts from climate change. In the view of this adaptation steps, this study is in line with the adaptation policy assessment and impact assessment in the infrastructure field.

Studies about adaptation cost assessment have been conducted on the global, regional and sectoral level (Stern Review 2006; Agrawala and Fankhauser 2008; UNFCC 2009; Richards and Nicholls 2009; Huge et al. 2010; Hinkel et al. 2010). These studies expanded the boundary of knowledge about estimation of adaptation costs considering climate change. However, their methods were mainly top-down approach showing a picture of large scale; there was a limit in producing economic results on a smaller scale such as individual construction project or infrastructure. In this study, a bottom-up analysis is proposed to assess the cost of infrastructure adaptation to climate change.

3 Methodology

3.1 Classification of the climate change

As previously mentioned, climate change is divided into two categories in a view of infrastructure damage patterns: hard strike (sudden damage) resulting in instant rehabilitation of infrastructure and acceleration of infrastructure's deterioration affecting maintenance parts. When damage is occurred by climate change, climate factors produce damage on infrastructure either in short term or long term. Summing up, infrastructure gets stressed by sudden extreme climate change, it leads to swift and disruptive damages, whereas gradual climate change that occurs over a long period of time causes increase on maintenance costs.

3.2 Adaptation method evaluation under extreme climate change

Adaptation cost, adaptation benefit and damages from climate change are calculated in the context of asset value. Adaptation cost is to increase capacity to climate change when infrastructure is vulnerable to the new climate. Adaptation benefit means potential cost savings from expected damage that can be caused by climate change. Damages are defined as reduction of infrastructure performance due to climate change. Adaptation cost reduces a probability of infrastructure performance failure; decrease of the probability is linked to mitigation of damages and rehabilitation costs.

3.3 Adaptation method evaluation under gradual climate change

Since gradual climate change affects performance decline of infrastructure in a long term, it is related with investments for maintenance. In other words, it has strong relations with infrastructure deterioration. With the introduction of adaptation methods, the rehabilitation cycle becomes longer and annual maintenance costs decrease. However, the adaptation method incurs a cost increase. With this trade-off concept, the net benefit of adaptation to gradual climate change can be determined.

In the first body of this simulation algorithm, information about target infrastructure and adaptation method alternatives should be summoned to set-up variables for simulation. At the following section, called climate factor simulation I, extreme climate change occurrence frequency is determined and its strength is predicted. If infrastructure is damaged by extreme climate change, the algorithm leads to adaptation decision making part under extreme weather events. In this part, the procedure for sudden failure of infrastructure is used to estimate rehabilitation costs with or without the adaptation method. It is assumed that infrastructure condition is restored to its initial status by the rehabilitation.

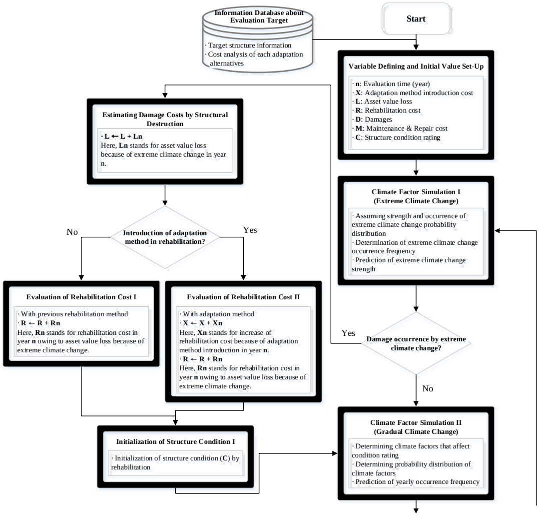

Figure 1. A simulation algorithm for estimating net benefits of climate change adaptations

If extreme climate events do not happen or the decision making procedure of adaptation method for extreme climate events is finished, future climate scenarios are created again for gradual climate change part. The infrastructure requires maintenance when its condition reaches the minimum acceptance level. Then, the decision making (Yes or No) on adaptation method introduction is executed and its effect is reflected in the following calculation. Through this procedure, it is assumed that the condition of infrastructure returns to the initial (newest) status once rehabilitated.

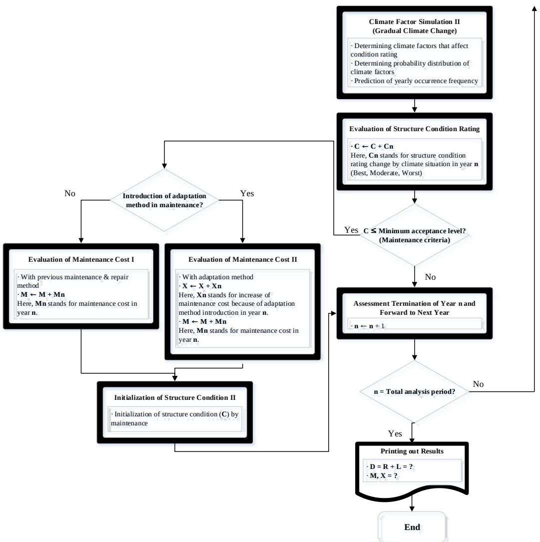

Figure 2. A simulation algorithm for estimating net benefits of climate change adaptations (continued)

After performing the above parts, the year-n's simulation is terminated and the yearly simulation is repeated for every year in the analysis period. If n meets the total analysis period, the yearly simulation stops and the aggregated damages, rehabilitation and maintenance cost are calculated. Finally this simulation algorithm allows estimating the life cycle cost of infrastructure adaptation to climate change for the comparison of the costs with and without adopting the adaptation method.

4 Conclusions

This paper proposed dividing the climate change effect into two categories by infrastructure's characteristics; one is extreme weather events that cause sudden damage to infrastructure and the other is gradual climate changes that bring long term effects on infrastructure. For each climate case, a methodology for assessing damage and adaptation benefit of infrastructure was suggested. The simulation algorithm was used to assess the integrated net benefit of infrastructure adaptation to climate change. The benefit figures from the algorithm can provide a basis for asset managers to make informed decisions about infrastructure adaptation. Future study is still required to research relationships between climate change factors and infrastructure performance. It is also important to evaluate adaptation methods' effects on adaptive capacity of infrastructure.

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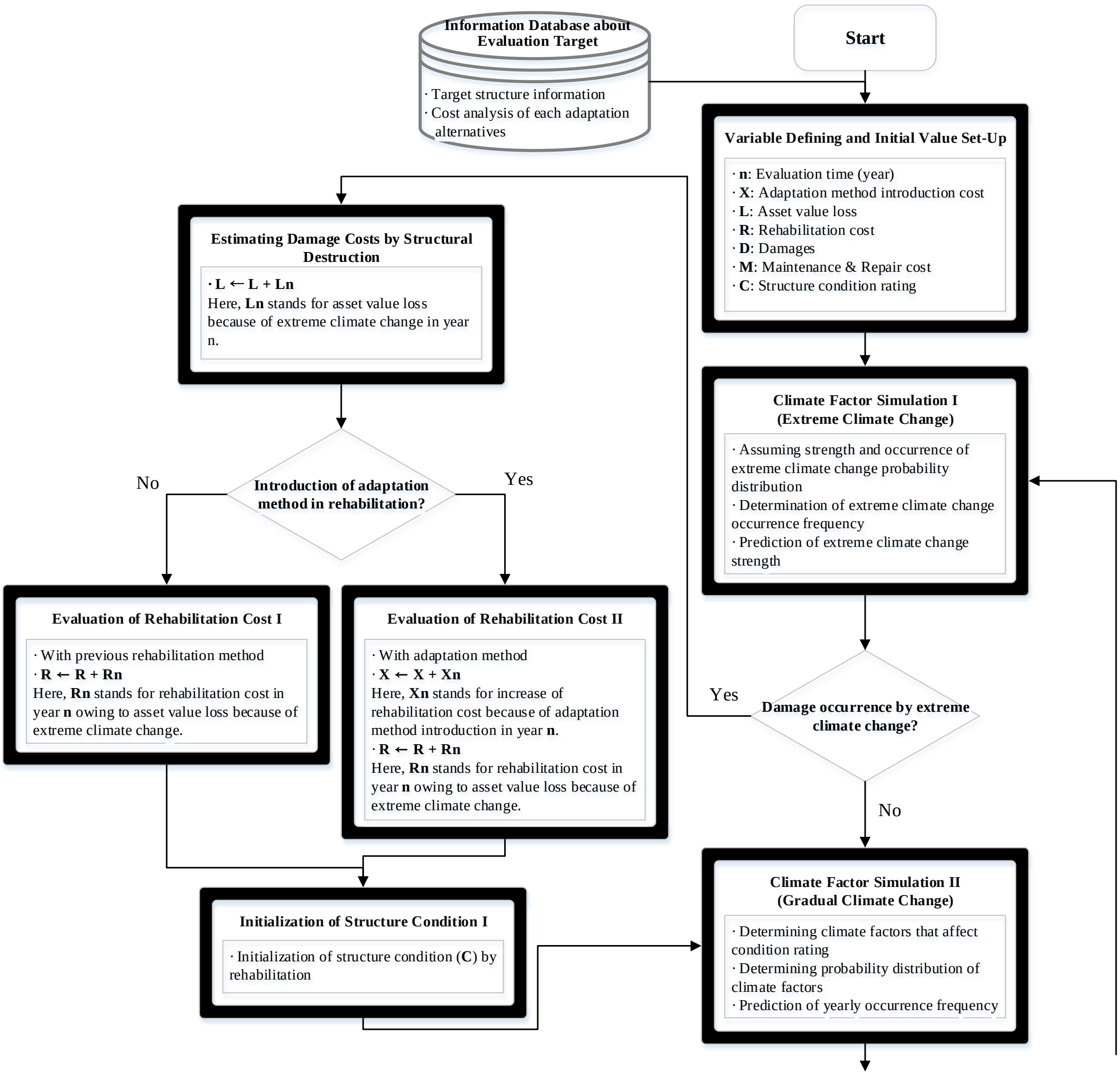

Figure 1. A simulation algorithm for estimating net benefits of climate change adaptations

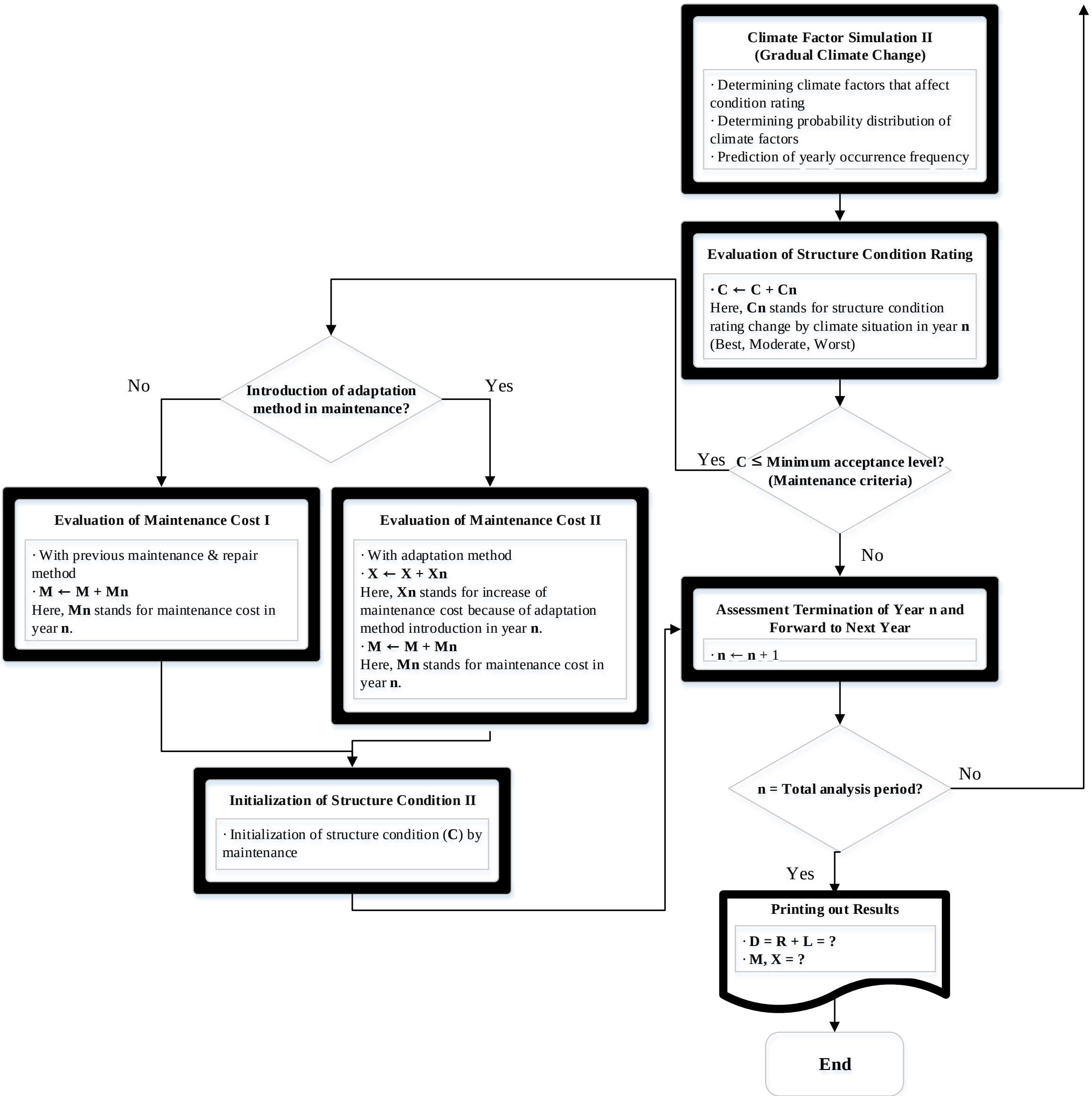

Figure 2. A simulation algorithm for estimating net benefits of climate change adaptations (continued)