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Adaptation strategies of transport infrastructures to global climate change

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ABSTRACT

Scientific records provide clear evidence of rising atmospheric greenhouse gases (GHG) concentrations. Global warming and rising extreme weather events are believed to be a result. Besides proactively combating global climate change, transport agencies may need to develop strategies for better preparedness of the impacts of climate change. This is particularly important for certain regions that are more vulnerable to the potential damages caused by climate change. A methodological framework for developing such strategies is presented in the paper. The framework is illustrated through two examples: the management of rural roads in Thailand where the vast road network is being threatened by increasing floods and rising sea levels and the improvement of pavement design strategies for expressways along the coast of Hong Kong. Adaption measures are proposed for the highway agencies to address the challenges caused by climate change.

1. Introduction

It is widely agreed that the current trend of global warming and other climate change phenomena are related to anthropogenic activities, in particular the buildup of greenhouse gases (GHG) by burning fossil fuels (IPCC, 2007a; Royer et al., 2007). Since the transport sector is a major contributor to fossil fuel consumption, it has been highly expected to play an active role in reducing GHG emissions (e.g., Kwon, 2005). Strategies to reduce GHG emissions in the transport sector have received wide discussions from the perspective of transport policies, especially in regulatory policies (e.g., Niederberger, 2005; Hickman et al., 2010; Hans et al., 2012). For instance, a study conducted in Brazil suggests that three measures are effective in reducing GHG emissions, including: the provision of incentives to public transport users, charging carbon fees to petrol car users, and encouraging the use of alcohol fuel (Ribeiro and Balassiano, 1997). Experience in Singapore indicates that the promotion of public transport is the best strategy to achieve various dimensions of sustainability, including the reduction of GHG emissions (Haque and Chin, 2013). A scenario analysis of emission trends from car travel in the United Kingdom (UK) shows that short-term reduction on emission is very difficult; however, a long-term GHG control target may be achieved by a combination of new cars, reduction of trip rates, and reduction of distance per trip (Kwon, 2005). It is also believed that behavioral and lifestyle change and technology development (Tight et al., 2005) are the main directions for the transport sector to achieve the GHG emission reduction goals. Therefore, policies may be directed to facilitate such change and promote technology development. Example policies reported in literature include taxes on GHG emissions and/or inefficient vehicles (Haque and Chin, 2013; Gallo, 2011), surcharge of fuel (Niederberger, 2005; Gallo, 2011), subsidies to the usage of efficient vehicles (Shepherd et al., 2012), establishment of more stringent emission rules for automobile industry and investment on the development of new technologies (Lutsey, 2012).

In spite of the various efforts made to cut down GHG emissions, a significant change is difficult to be achieved soon (Crozet and Lopez-Ruiz, 2013). GHG generated in the transport sector is affected by the lack of mature and widely accepted alternative technologies to power vehicles and the uncontrollable travel behaviors of many individuals. Studies suggest that, in order to achieve the climate stabilization goals for 2050, the electric-driven vehicles should dominate the vehicle fleet (Lutsey, 2012; Yang et al., 2009; Melaina and Webster, 2011; International Energy Agency (IEA), 2009). Without economically viable alternatives, the reduction of GHG emissions may likely curb economic activities and mobility, a move that is usually unwelcomed by governments,

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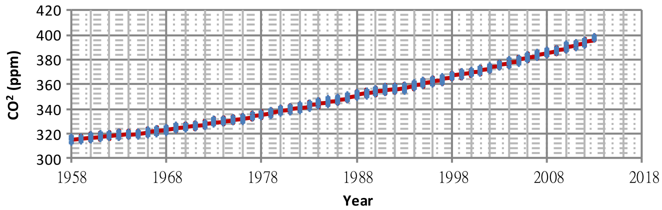

Fig. 1. Recorded CO_2 concentrations in Hawaii, US.
(Date source: NOAA, 2013.)

private sectors and individuals. Therefore, the switch of travel behaviors and the development and promotion of low-emission vehicles are not an easy task to be accomplished. Moreover, as the car ownership continues to rise in developing economies, the overall GHG emissions generated in the transport sector may further climb up. A paradigm shift in other industry sectors that would significantly cut down GHG emissions also appears to be missing.

Fig. 1 shows the long-term trend of the concentration of atmospheric CO_2, the primary component of anthropogenic GHG, recorded at the benchmark Mauna Loa Observatory in Hawaii station. An increase by 27% in CO_2 concentration has been recorded since 1958. In May of 2013, the concentration surpassed 400 ppm (ppm), a figure that was projected to be reached in 2015–2016 (United Nations Environment Programme, 2013). Figure one implies that the upward trend of CO_2 GHG concentration in the Earth's atmosphere is difficult to be stabilized in the near future, not to mention to be reversed.

It is generally believed that the rising GHG levels induce both chronic and acute climate changes. According to data from NASA's Goddard Institute for Space Studies (GISS), the average global temperature has increased by about 0.8 °C since 1880, and the two-thirds of the temperature rise has occurred since 1975 (NASA, 2010). This seemingly small shift in temperature per se may not have significant impacts on transport infrastructures such as roads or bridges. However, it has created profound impacts on the overall climate pattern on the Earth, manifested in rising extreme weather events such as intense precipitation (Easterling et al., 2000) and sea level rises. For instance, data on one-day precipitation in the contiguous United States over the last century shows that precipitation becomes more concentrated in precipitation extremes (NOAA, 2012) (Fig. 2). In Hong Kong (HK), weather data indicate that the fraction of total annual precipitation due to rainfall events exceeding “the daily 95th percentile of the climatological normal” have increased by 22 mm per decade (Wong et al., 2011). Conversely, dry spells in the summer months have also increased. Rainfalls apparently become more concentrated and hence increase flooding risk. Moreover, sea levels in the coastal regions around the global are rising. Fig. 3 shows the recorded annual average sea levels in several cities in Southeast Asia, measured against the Revised Local Reference (RLR) datum at each station (PSMSL, 2014). Although the sea levels at all the sites show an upward trend especially in recent years, certain locations appear to be more severely affected.

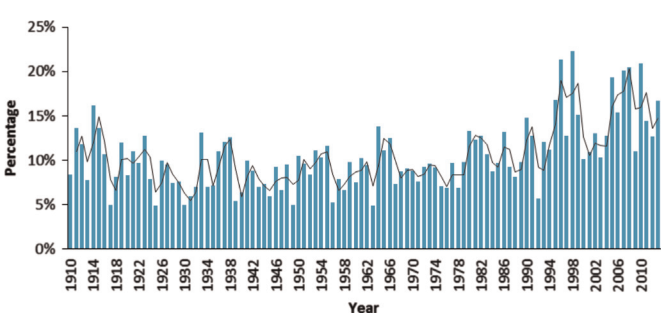

Fig. 2. Percent of extreme 1-day precipitation in contiguous U.S. in the past 100 years.
(Source: NOAA, 2012.)

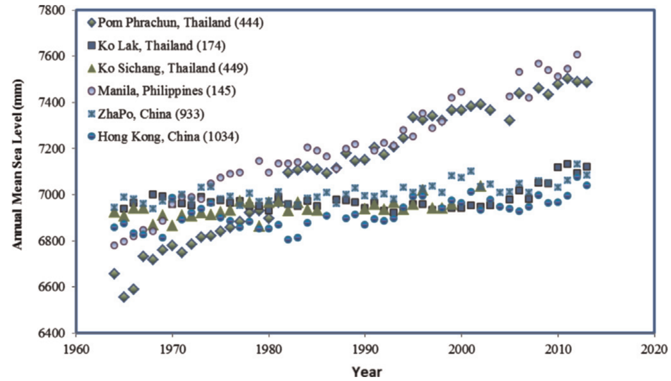

Fig. 3. Annual mean sea levels at monitoring stations in several Southeast Asian cities.
(Source: PSMSL, 2014.)

The rising precipitation intensity and sea level cause more frequent flooding in many lowland areas in the world, posing a real threat to the transport infrastructures. For instance, flooding in Thailand has become a common phenomenon in the middle part of the country. The flood in 2011 made 65 out of the 77 provinces become flood disaster zones (Aon Benfield, 2012). In the U.K., 10% of the road network is estimated by the Highway Agency to be susceptible to flood risk (Jacobs Engineering U.K. Limited, 2011). The Environment Agency (EA) in the U.K. recommends the current designs for the 1 in 100 years return period of precipitation levels to be increased by 30% (Jacobs Engineering U.K. Limited, 2011). In addition to flood risks, cold regions are experiencing more freeze–thaw cycles associated with climate change. The frequent freeze–thaws are the main culprit for accelerated highway pavement deterioration.

Although scientific data clearly highlights the urgency for the international communities to take immediate actions to reduce GHG emissions, many small developing countries such as Thailand have limited power to influence the global GHG level. Yet, transport infrastructures in these countries are disproportionally more vulnerable to the consequences of climate change, in particular the sea level rise and disastrous weather events. Therefore, besides proactively combating climate change, the transport agencies in these countries also need to develop strategies for better preparedness of the impacts of climate change. This paper develops a methodological framework for the development of adaptation strategies in response to climate change. The model and its major components are presented, followed by the applications of the model to the management of roads in Thailand and Hong Kong, respectively.

2. Development of adaption strategies

Climate change leads to rising sea level, warmer winters in cold regions, and more frequent occurrences of extreme weathers. These events create a challenge on the routine practices in transport infrastructure planning, design, construction and operation. Therefore, the implications of such events on the transport infrastructures need to be reviewed, and adaptation strategies need to be developed accordingly. The objectives of the strategies are to make the transportation infrastructures more resilient to climate change, remain affordable, and ideally also contribute to the