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A socio-economic analysis of Smart Infrastructure sensor technology

Risako Morimoto *

SOAS, University of London, Thornhaugh Street, Russell Square, London WC1H 0XG, UK

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ABSTRACT

Smart Infrastructure wireless sensor technology is designed to provide a new way of managing infrastructure. These wireless sensors are able to share information on infrastructure conditions across a range of agencies without human intervention. Thus, false readings can be corrected automatically and further incidents should be avoided. The advantages of using these wireless sensors are their reliability, low-cost, low power and fast deployment characteristics. In this paper, we conduct a socio-economic analysis on the application of Smart Infrastructure sensor technology to the British rail tunnel industry using Monte Carlo simulation. The study would offer insights on the feasibility of the technology. Furthermore, the simulation forecast would bring the deeper understanding of the wider socio-economic implications, which is important for decision makers. Our study shows that the mean value of the cumulative net present value for the application of the Smart Infrastructure sensor to the British tunnel market in the year 2056 is estimated to be US$40 million. According to the sensitivity analysis, the key parameters, which have significant impacts on the net present value, are the maximum target market penetration rate, base year disruption cost due to tunnel closure, total tunnel length, and annual number of tunnel collapses.

1. Introduction

Good quality infrastructure is a key ingredient for sustainable development and human well-being. Adequate supply of infrastructure facilitates both economic growth and social welfare (Aschauer, 1990). Numerous challenges that tunnel infrastructure operators, especially undergrounds, are facing range from impacts of ground water to flooding. Congestion and disruptions caused by delays or cancellations of transport service due to infrastructure failures are serious concerns that could lead to significant economic and social costs. According to Oxford Economic Forecasting (2005), the economic cost of transport delays to employees and businesses in central London is estimated to be US$1870 million a year. There are numerous studies that examine the value of travel time variability (e.g., Jenelius et al., 2011; Fosgerau and Karlstrom, 2010; Fosgerau and Engelson, 2011; Bowman and Ban-Akiba, 2001; Borjesson and Eliasson, 2011; Asensio and Matas, 2008; Carrion-Madera and Levinson, 2011).

Deteriorating ageing infrastructure is a major concern. Houlihan (1994) claims that Europe is facing a difficulty in managing ageing infrastructure. For example, the tunnels of the London Underground are 75–100 years old, with various problems ranging from deterioration of lining to risks from 3rd party construction. London Underground tunnels currently require repairs of approximately 100 locations every year after visual inspection. Thus, accurate monitoring meeting specific needs of repair is urgently required. In the United States, numerous advocates address the necessity of new policies to deal

* Tel.: +44 2078984730.
E-mail address: Rm36@soas.ac.uk

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with ageing infrastructure (e.g., Connery, 2008). Evidently, the fast growth of Asian countries could also be hampered by ageing infrastructure (Ford, 2008).

Infrastructure is generally under-invested and its operation is often not cost effective (Lortie, 2008). Recent trends on emphasising maintenance rather than new construction is seen in the government (e.g., the United States) favouring in spending more on maintenance (Durango-Cohen and Madanat, 2008). Different studies propose various maintenance approaches for better infrastructure management. These approaches include: risk-based tools for reducing potential risks of equipment failures (e.g., Seyedshohadaie et al., 2010; Ng et al., 2003); an adaptive control approach for optimum infrastructure management under uncertainty (Durango and Madanat, 2002); time series models to estimate infrastructure performance (Chu and Durango-Cohen, 2007); a programming framework to support transport infrastructure maintenance optimisation policies (e.g., Durango-Cohen and Sarytipand, 2010; Kuhn and Madanat, 2005; Madanat, 1993). Advanced inspection technologies such as sensors are identified as increasingly important for collecting infrastructure condition data and their causal factors especially with their capability of simultaneously evaluating and measuring multiple factors and distresses (Chu and Durango-Cohen, 2007). For example, Garcia et al. (2010) have presented an intelligent sensory system for obstacle detection on railways, while Oukhellou et al. (2008) have proposed the combined use of sensor data for a railway infrastructure diagnosis.

At the present time, infrastructure management policy appears to follow reactive rather than proactive monitoring (e.g., McCollum, 2008; Haffejee and Brent, 2008). The tendency of adopting a reactive approach to managing their assets is well explained by limited financial and human resources (McCollum, 2008). Moreover, Haffejee and Brent (2008) claim that a reactive approach to infrastructure management is due to the fact that the exact location and condition of the infrastructure is often not fully known.

Technologies have gained a significant amount of attention recently in the transport sector (Greelings et al., 2009). More specifically, interest in using wireless sensing networks for structural health monitoring to protect infrastructure has increased dramatically (Cheung et al., 2008). The Smart Infrastructure sensor technology enables us to effectively conduct real time monitoring and control of infrastructure. Wireless sensor networks have the potential to be cost-effective tools that can be deployed on all types of civil infrastructure and provide managers with critical real-time data on performance (Hoult et al., 2009). Various infrastructure-related potential applications of Smart Infrastructure sensors exist, ranging from water pipes to bridges. Competitors will be highly likely to develop systems to monitor bridges and buildings, but there is less chance of this happening for tunnels and pipelines (Stajano et al., 2010). There is even less chance that anyone else will develop system with the capability to share across agencies (Stajano et al., 2010).

The contribution of this study can be categorised in three aspects. First, this study demonstrates that a simple probabilistic cost benefit analysis (CBA) can provide a relatively clear picture of the situation to explain 'what if' we introduce a new innovative technology to a market. In addition, the benefit of this emerging technology is presented as a quantified figure, which will be useful for policy makers and managers. The advantage of the model is its flexibility, in which replacing data or modification of parameter specifications can be carried out in a fairly short period. Such easy-to-run feature using a probabilistic analysis is suited to an assessment like this, which includes huge uncertainties. For those parameters having great uncertainties, we will use a large range for their input data to take into account the possible variability. Another great feature of this type of the model is its versatility. We can use multiplier concepts to further expand the model, which is a simple extension from the previous model (Morimoto, 2010). Some data that are difficult to obtain will be estimated by using multipliers to the already existing data in Morimoto (2010) so that date scaling (up/down) can be performed.

Secondly, the study provides justification of developing the Smart Infrastructure wireless sensor technology in response to growing interests in this technology by quantifying its benefit with uncertainty consideration. Thirdly, the application of the proposed approach to the United Kingdom (UK) rail tunnel industry is a timely and useful attempt. The tunnel infrastructure is deteriorating rapidly that requires effective assessments to examine the role of innovative technologies for strategic future infrastructure management policy. This case study will demonstrate the importance of enhancing a strategic and proactive approach towards transport infrastructure management.

In this paper we will examine the socio-economic contributions of Smart Infrastructure sensors if applied to the rail tunnel industry in the UK. With limited financial resources available for infrastructure management, socio-economic justification of implementing emerging technologies would be a useful exercise. Moreover, we could quantitatively demonstrate the role of technology in improving infrastructure management. In order to deal with huge technological and market uncertainties, a probabilistic cost benefit analysis using Monte Carlo simulation technique is applied as the impact assessment tool. The rest of the paper is organised as follows. The next section provides the description of the Smart Infrastructure wireless sensor technology, followed by Section 3 that explains the methodology used in this paper. Section 4 summarises the findings and Section 5 concludes the paper as well as proposes future research directions.

2. Smart Infrastructure sensors

Smart Infrastructure wireless sensor is small in size that communicates over short distances (Fig. 1). The network of wireless sensors is placed along a 100-m stretch of tunnels, measuring small changes in pressure that would indicate movement. As Fig. 2 depicts, the sensors transmit information to receivers located in the access shafts, followed by the receivers sending the information (e.g., cracks), via the mobile phone network, to an online database archive, where the data processing is car-