Chapter 12
Roadmap to Sustainable Road Construction in Hong Kong

Dan Chong and Yuhong Wang

Abstract Road construction and maintenance is one of the largest government administered construction programs in Hong Kong. The large scale of the road construction and maintenance work has significant implication on economic, environment and society. A research question that should be emphasized by the administrators in Hong Kong is: what policy should be framed road construction and maintenance can achieve the most beneficial. This study aims to lay out a roadmap to the sustainable road construction and maintenance in urban environment based on Hong Kong case study. Four basic components were identified such as criteria, data, models and optimization. According to each component, several methods were explained to address the research questions. It is hoped that the present research has made a contribution to assist policy making for the road administers.

Keywords Sustainable • Road construction and maintenance • Urban environment

12.1 Introduction

About 1,900 km of roads and streets in Hong Kong (HK) are built with bituminous (asphalt) pavements. As the pavements become old, they will develop distresses such cracking, rutting, raveling, etc. These distresses affect ride quality and structural integrity of the pavements. Therefore, the bituminous pavements need to be maintained and rehabilitated periodically by resurfacing technique in HK.

With an annual resurfaced area of 1.2 million m^2, road resurfacing is one of the largest government administered construction programs in HK. However, there is still lack of a systematic policy on when, where, and how to resurface the 1,900 km

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of bituminous road and street pavements, which are currently divided into thousands of sections. Pavement resurfacing in a busy and crowded city such as HK involves multiple stakeholders and has great impacts on economy, environment, and society.

A question that has been interested by the administrators in HK is: What resurfacing policy should be made so that the road maintenance and rehabilitation are the most beneficial for the society?

In order to satisfy the sustainable development principles, this study plans to draw a roadmap to the sustainable road construction and maintenance in urban environment regarding Hong Kong as a case study. The aim of this study is to identify and develop four basic components to assist managing the pavement resurfacing program in HK under the principles of sustainability. The research results will provide valuable information and tools to aid the decision makers to further improve pavement management and promote sustainable development in HK.

12.2 Sustainability Considerations for Road Construction and Maintenance

To develop sustainability indicators for road in Hong Kong, one needs to identify the general requirements of sustainability, which can then be refined and adapted for road practices. According to UN's commission on sustainable development (CSD) – theme indicator framework, sustainability is categorized into four dimensions: social, environmental, economic, and institutional. Under these dimensions, there are 15 themes, 38 sub-themes, and 58 indicators, which are based on voluntary national testing and expert group consultations [1]. According to World Bank, sustainable transportation must satisfy three main requirements: economic and financial, environmental and ecological, and social [2]. The VTPI also divided sustainability considerations into three groups: economic, social, and environmental, which is agreed by a lot of other literature [3].

From the life-cycle view, there are great variations on what constitutes sustainability under these dimensions. The indicators developed in the previous section represent a wide spectrum of possible sustainability considerations for road facilities. In order to encourage or enforce their applications, additional steps are required, which include identifying a subset of indicators, developing measurable objectives, evaluating actual practices, and synthesizing the evaluation results.

12.3 Four Basic Components for Sustainable Road Construction and Maintenance

It is expected that a right combination of when, where, how to perform maintenance will maximize the sustainability contributions in road resurfacing and rehabilitation. To find answers to these questions, four major components need to be

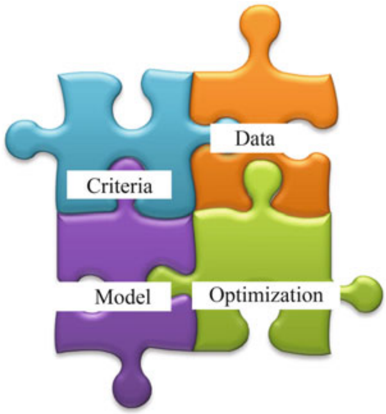

Fig. 12.1 Major research components

identified (Fig. 12.1), including criteria, data, model, and optimization, which consist of the whole roadmap for the urban road construction and maintenance. An important goal of this study is to develop these four major components and their sub-components and systematically integrate them to assist decision making in pavement resurfacing. The four components will be proposed in line with an incremental approach. The first part of the criteria will derive and prioritize optimization criteria for the road construction and maintenance program based on the sustainability considerations in HK. Secondly, in the roadmap, it is inevitable to collect and integrate data related to road performance and data related to sustainability in the construction and maintenance program. In the third step for laying out the roadmap, several mathematical models should be developed and evaluated to assists the multiple decisions for the HK government. Finally, following the above three components, it is necessary to optimize the road construction and maintenance decisions based on the chosen criteria, data and models. The whole roadmap for the decision-maker will be then demonstrated.

12.3.1 Criteria

As HK is embracing sustainability as its future development strategy, the implications of this large-scale work for HK's sustainability goals need to be carefully reviewed. Several criteria should be considered when optimizing the pavement resurfacing program. One of the important criteria is pavement condition, an indicator of its performance. HK starts collecting pavement condition data in 2011 by using a comprehensive pavement condition index (PCI). Besides PCI, multiple criteria need to be brought into consideration to cover many aspects of sustainability, including mobility, energy and resource, waste and pollution, life-cycle costs, etc. Variations in different functional areas in HK also need to be considered.

According to the Sustainable Development for the 21st Century in HK (SUSDEV 21), sustainability is defined by eight guiding principles and 39 indicators [4]. The guiding principles include economy, health and hygiene, natural resources, society and social infrastructure, biodiversity, leisure and cultural vibrancy, environmental quality, and mobility. The unique characteristics of the road resurfacing program in HK and its relationship to the guiding principles are discussed as follows.

12.3.2 Data

Complete and accurate data is another basic component for making valid decisions. The Highways Department currently has a pavement management system (PMS) on the platform of Geographic Information System (GIS). The system provides information on PCI (currently limited to HK Island but will be expanded), division of pavement sections, materials, structures, resurfacing history, traffic, etc. However, other important information such as construction cost, waste and pollutant generation, impacts of construction on traffic need to be found in other sources.

12.3.3 Model

Estimation and prediction models are the core component in Fig. 12.1. The models capture the systematic patterns from the data and link the data to decision variables. Four groups of models need to be developed and evaluated in the literature review, including economic models, performance prediction models, environmental impact models and social impact models etc.

The economic models are used to evaluate the life-cycle costs (LCC) of different resurfacing options. As mentioned, the LCC can be divided into user costs and agency costs (Walls and Smith [5]), and a detailed cost breakdown. The user costs can be further divided into vehicle operating costs (VOC) during normal operation and work zone road user costs (RUC). The VOC in normal operation refers to costs such as fuel and lubricant consumption, tire wear, etc. to the travelers when the road is free of construction and maintenance activities [5, 6]. VOC in normal operation is affected by many factors, but regarding pavement conditions, it is mainly affected by roughness (e.g., [6, 7]). The relationship between the VOC in normal operation and road conditions in HK has not been studied. The RUC is the increased VOC, delay, and crash costs caused by road work [5]. The estimate of RUC ranges from finding values from tables (e.g., [8]) to using computer programs, such as QuickZone [9], MicroBENCOST [10], and Construction Congestion Cost System (CO3) [11]. There is also lack of study on work zone RUC in HK.

The agency costs, including indirect and direct costs, are the costs incurred by the government. The indirect costs are caused by engineering designs, quality assurance (QA), inspection, etc. Most of these costs are absorbed within the agency, although sometimes they are paid to consultants. Recently, Hollar [12] developed models to estimate the agency's indirect costs, but such models cannot be readily used in HK because the data for building the models are from the U.S. For pavement resurfacing, direct costs refer to those paid to contractors. Although HK has historical resurfacing cost data, costs of resurfacing projects are affected by many factors, particularly by market bitumen and fuel prices [13, 14]. There is no model to predict the long-term prospect of resurfacing project costs in HK. In summary, the economic models for optimizing resurfacing decisions are currently unavailable in HK.

Besides indirect and direct costs, the LCC of a pavement section also depends on the performance period of each resurfaced layer. From the historical data, resurfacing cycles on the majority of roads can be obtained. However, the resurfacing frequencies in the past not necessarily mean that the same ones will be followed in the future. Therefore, performance models are needed to predict the lifespan of a resurfaced layer in different pavement condition levels and under various influencing factors. Many techniques have been used to develop performance models for the resurfaced layers, a.k.a. overlays. For example, in the Mechanistic-Empirical Design Guide for New and Rehabilitated Pavement Structures (MEPDG) in the U.S., mechanistic-empirical models are used to predict the overlay performance [15]. A set of staged survival models are developed by Wang and Allen [16] to predict overlay conditions based on pavement management data in Kentucky. Dynamic panel data models are also developed by Wang et al. [17] to dynamically predict the overlay performance.

The environmental impacts of bituminous pavement resurfacing mainly fall into four areas: waste materials generation, energy consumption, greenhouse gas (GHG) emission, and construction noise. The waste generation model is straightforward: The amount of waste generated is equal to the total amount of milled materials subtracting the recycled ones. The energy consumption in extraction, production, and placement of bituminous pavement materials is roughly estimated to be 3.783×10^6 MJ per ton [18], in which raw materials extraction and mixture placement account for 8.46 % of the total energy consumption and mixture production accounts for 91.54 %. However, the data on which the estimate is based show great discrepancy in different parts of the world, and the energy consumption in material transportation is not included. Various studies have also been conducted to estimate emissions in bituminous pavement construction (e.g., [19, 20]), but the results vary greatly, too. Therefore, both the energy consumption and GHG estimation models for resurfacing projects need to be developed. Noise of the resurfacing operation perceived by residents may depend on many factors, such as tasks and timing of the operation, construction location, background noise, etc. At the moment, there are no basic data and models for environmental assessment of the resurfacing operation in HK.

The social impacts may include delays, inconvenience, and loss of business caused by temporary road closures. Some of the impacts are related to the economic impacts. These impacts highly depend on the location of the project. The social impacts of conducting road resurfacing on a busy street will be different than those on a rural road. Because the transportation characteristics and urban layouts are unique in HK, specific models are needed to assess the social impacts.

12.3.4 Optimization

Many different approaches can be used to optimize multi-criteria pavement resurfacing decisions. One approach is to consolidate the different criteria into one criterion, which is often a monetary value. For example, in LCCA, the effects of user delay and work-zone safety are represented by the user costs [5]). It may be possible to assign monetary values to the other environmental and social factors assessed in this study. However, to avoid awkward conversion of everything into money, this study prefers to directly use different criteria.

Multi-criteria decision making (MCDM) involves choosing the best candidate(s) from aset ofoptions. There are numerous MCDM methods [21] and many are used in managing highway assets. Wu [22], in his Ph.D. dissertation, provides a summary of the most popular MCDM methods in highway asset management, including the weighted sum method (e.g., [23]), multi-attribute utility theory (MAUT) (e.g., [24]), generic algorithm (GA) (e.g., [25]), etc. Wu [22] also developed hybrid multi-criteria optimization models for pavement preservation in Virginia, U.S. [22].

The existing literature indicates that the use of MCDM models in managing pavement assets is promising. These models differ in concepts and complexity. It is unknown which models are appropriate for the particular application in this study and if different models will yield similar or quite different results. This part of the study is to identify the MCDM models to make resurfacing optimization decisions.

12.4 Research Methodology

It is essential to combine different methods to accomplish the roadmap to the sustainable road construction under the urban environment. According to the Sect. 2, there are four methods regarding to each components.

12.4.1 Identification and Prioritization of the Criteria

The chosen criteria for this study are based on the 8 guiding principles and 39 indicators for sustainable development in HK [26]. We will analyze these principles and indicators and use the ‘mapping’ technique [13, 14] to translate the general sustainability principles into concrete criteria related to the pavement resurfacing program. For example, one of the general principles is mobility. We will analyze how and to what extent the resurfacing projects will affect mobility.

12.4.2 Data Fusion

Data related to this study will be obtained from different sources and then be integrated by a data fusion process. A significant portion of the research data have already been secured, including traffic counts and percent commercial vehicles on the road network, pavement structures, types of materials, part of the pavement condition index (PCI), and resurfacing histories, etc. Other types of data can be obtained with moderate efforts, such as resurfacing costs, waste generation, energy consumption and GHG emission generated in resurfacing, and construction noises. For example, we plan to contact the four bituminous mixture plants and different road contractors in HK to find fuel consumption data, which can be further used to estimate GHG emission. The output of the data fusion process is an integrated research database, which not only benefits this study, but also provides a reference for the government.

12.4.3 Model Building and Assessment

The models developed in this study include deterministic models and stochastic models, both of which will be based on the collected research data. Relationships between certain types of data are subject to less variation; hence, deterministic models may be adequate to capture the interdependence of the data. For example, waste generated in the process of milling should be a percentage of the total milled materials, which can be calculated by the road geometry, thickness, and material density. This may be well modeled by a deterministic model. Similarly, energy consumption, GHG emissions, and noise may be modeled by deterministic models. On the other hand, performance of resurfaced pavements is influenced by many factors and their interactions; therefore, a deterministic model cannot reflect the random variations. Besides the models developed in this study, existing models will also be assessed and used. The particular group of the existing models that will be evaluated in this study is the impact of road closure to road users.

12.4.4 Optimization Based on Different Techniques

Different optimization techniques will be compared and used in this study. The selection of the optimization techniques will follow a four-step process. First, trial optimizations will be performed based on different techniques and software (e.g., The GMAS, AIMMS). Secondly, the optimization results obtained from different methods will be compared. Thirdly, the results from step 2 will be discussed with the Highways Department and industry practitioners; their feedback will be used to improve the optimization. At last, the chosen optimization technique(s) will be used to conduct the final optimization.

12.5 Conclusions

The purpose of this study is to draw a roadmap for sustainable road construction in urban environment. Several conclusions can be drawn from this study that deserves consideration. There are four basic components for optimizing road construction decisions including criteria, data, models and optimization. According to each component, several methods are suggested to achieve the roadmap with the principles of sustainability. These findings will hopefully influence the highway administrators in HK on making a pavement resurfacing policy in line with the principles of sustainability. Despite much effort, it remains that this study has focused only on the guideline for the sustainable road construction in urban environment regarding HK as a case study. More studies are recommended to quantify the optimization of sustainable road construction.

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