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Environmental burden evaluation of hot in-place recycling of asphalt pavement based on discrete event simulation

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ABSTRACT

Hot in-place recycling (HIR) is deemed as an environmental-friendly maintenance measure of asphalt pavement due to its complete recycling of aged asphalt mixture. However, the environmental burden of HIR process itself is remarkable but has been conventionally ignored. This study presented a discrete event simulation (DES) method to estimate and compare the environmental burdens of two HIR methods, the remixing method (A) and the repaving method (B). The simulation results indicated: (1) with the same paving mass, the emissions of A were greater than those of B by 19–21%; (2) with the same paving length, the emissions of A were less than those of B by 23–26%. Optimizations of the construction process were further conducted considering air emission, fuel consumption and construction time. Optimal truck number subject to transportation distance was recommended. And the impact of increasing truck capacity and altering truck dumping process calculated, with the former decreasing environmental burdens and the latter bringing trivial benefit. The developed DES model provides quantitative estimations of environmental burdens and allows for optimization of HIR construction process subject to field conditions.

1. Introduction

Hot in-place recycling (HIR) has been widely applied owing to its sustainable nature and sound construction quality. Many researches have been conducted on the performance evaluation of HIR asphalt mixture and the recycling technology (Imran et al., 2014; Huang et al., 2016; Yu et al., 2016). However, seldom efforts have been devoted to the evaluation of the environmental burdens of HIR process. One important objective of HIR implementation is to take full advantage of aged asphalt mixture so as to reduce the air emissions and energy consumption. However, the construction process of HIR itself also produces massive air emissions and consumes a large amount of fossil fuel. In order to reduce the environmental burdens and optimize the construction plan for HIR projects, it is necessary to quantify the environmental burdens of the construction process.

Field measurement is one of the common methods to collect the data of air emissions and energy consumption, but it is not efficient and costly. Hence several empirical models have been developed to facilitate the calculation of environmental burdens of construction activities. NONROAD model (EPA, 2010), MOVES model (EPA, 2015) and CalEEMod model (CAPCOA, 2017) are the typical ones and NONROAD model has witnessed most prevalent application in road construction. These models provide the calculation formula or window for estimating air emissions and fuel consumptions, and offer the emission rates for different ignition engines. Phil et al. (2009) evaluated the impact of engine idling on fuel consumption and CO_2 emissions based on NONROAD model. William et al (2012) used NONROAD model to evaluate the on-site fuel use and air emissions of a commercial building project.

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Elizabeth and Phil (2014) quantified the fuel use and air emissions for a bridge replacement project based on NONROAD model.

NONROAD model was developed based on the average data. For instance, the operation time in the model is the average time while the operation time of a project or equipment varies with respect to the filed construction condition and the properties of equipment. There are more uncertainties and complexities in the construction activity process. In order to deal with the uncertainty that are inherent in the construction process, some researchers applied discrete event simulation (DES) method to calculate the air emissions and energy consumption in the infrastructure construction (Tarek and Daniel, 2001; Lu, 2003; Zhang et al., 2014). Vicente and Tomas (2012) developed a dynamic environmental model based on DES to model the sustainability performance of construction in terms of the exhaustive emissions. Zhang (2015) integrated NONROAD model with DES simulation to assess the fuel consumption and air emissions of asphalt paving operations. Farshid et al., (2016) created a framework, which integrated building information modeling (BIM), DES and life cycle assessment (LCA), to evaluate the energy use and CO_2 emissions for a construction site.

The environmental burden of HIR construction process is a critical component in improving the effect of HIR practice but is still lack of quantitative results. Therefore in this study, DES model was integrated with NONROAD model to calculate and analyze the air emissions and fuel consumption of HIR construction process. Optimization of HIR construction process was then conducted to reduce the environmental burden.

2. Description of hot in-place recycling

HIR is a method to maintain and rehabilitate the aged asphalt pavement on-site. The vital step is to heat asphalt pavement and remix aged asphalt mixture. In order to renew the mechanical properties of aged asphalt mixtures, virgin asphalt mixtures and additives such as latex are added and remixed before paving. According to the construction process, HIR technique includes three types, surfacing recycling (the eldest one), remixing and repaving. In this study, the two most frequently used methods (the remixing method [A] and the repaving method [B]) were investigated.

The construction processes of the two HIR methods are depicted in Fig. 1. Aged asphalt mixture course is first heated and then virgin asphalt mixtures and additives are applied to the loose mixtures and paved, following by the compaction to form new asphalt mixture course. The difference between method A and method B lies on the overlay paving. Compared to method A, an additional process of overlay paving is conducted simultaneously to improve the skid resistance besides the “remixing” process of aged mixture for method B.

3. Parameters of HIR equipment

The HIR construction equipment considered in this study was the Wittgen4500, which is widely used in China and can support both HIR methods. The Wittgen4500 unit includes two heaters (HM4500) and one paver (RX4500). Their physical and mechanical parameters were obtained in the company website (Wittgen, 2018). Other equipment, such as dump truck and roller, referred to the database of NONROAD model. The NONROAD model computes emission inventories for nonroad engines. The calculations rely on emission factors: estimates of the amount of pollution emitted by a particular type of equipment during a unit of use. The NONROAD model documents exhaust emission factors, crankcase estimates, and brake specific fuel consumption (BSFC) estimates. The pollutants covered include exhaust total hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NOx), total particulate matter (PM), carbon dioxide (CO_2), and sulfur dioxide (SO_2)

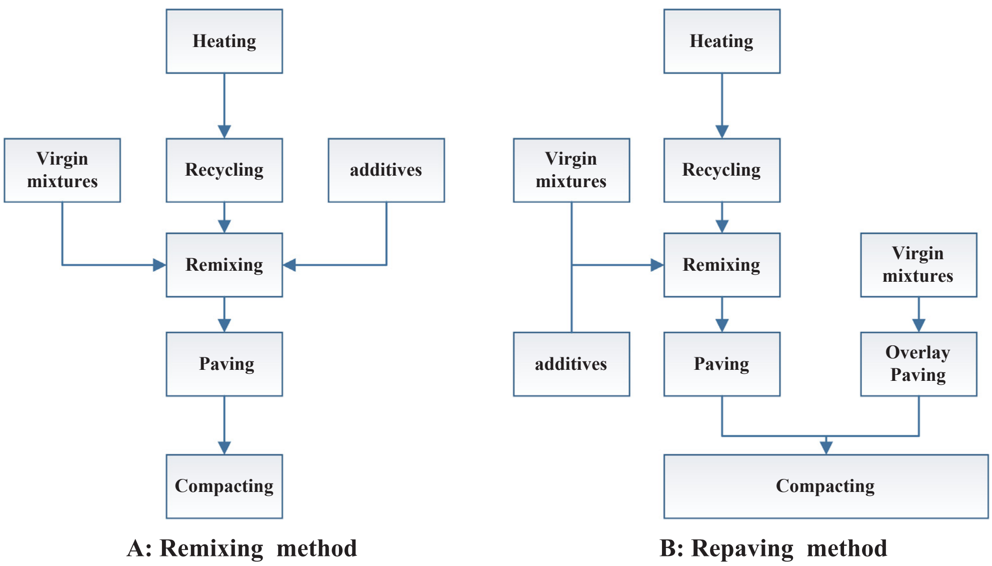

Fig. 1. Construction process of the two HIR methods.