Sustainable Cities and Society 12 (2014) 31–45

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

Eco-burden in pavement maintenance: Effects from excess traffic growth and overload

Corinthias P.M. Sianipar[a,b,*], Kiyoshi Dowaki[a]

[a] Department of Industrial Administration (IA) – Tokyo University of Science (TUS), 2641 Yamazaki, Noda-shi, Chiba-ken 278-8510, Japan
[b] School of Business and Management (SBM) – Institut Teknologi Bandung (ITB), Jl. Ganesha 10, Bandung, West Java 40132, Indonesia

ARTICLE INFO

Keywords:
Eco-burden
Traffic growth
Overload

ABSTRACT

Road pavement is designed to support certain usage conditions. However, many abnormal usages above regulated level often happen. Excess traffic growth is considered as a factor influencing road life-performance. Overload phenomenon has also long been recognized as an unexpected force causing extreme decrease of road performance. This study investigates the eco-burden effect of road construction in its maintenance phase along with the influence of above factors in shortening road life-cycle. Because of that, life-cycle assessment (LCA) is used to calculate the eco-burden impact. Furthermore, they are two different options taken for pavement materials: hot-mix and recycled asphalt. They are compared in order to provide comprehensive investigation results for decision makers. Eco-Indicator 99 is used as the impact database in order to standardize calculation processes. Seven sections of Pantura (Pantai Utara – North Beach) road, Indonesia, are picked up to be the case studies as a basis in understanding correlation between all factors to eco-burden impact in road maintenance. This study concludes that each of excess traffic growth and overload is positively correlated with the increase of eco-burden impact. The more extreme shortening of road life-cycle, the more eco-burden will be produced, and it will increase faster in polynomial functions. By looking at previous studies which tend to focus on eco-burden in ideal condition of road life-cycle, this study throws new light on the effects of abnormal phenomena on road usage which shorten pavement life-performance as well as increase eco-burden impacts.

1. Introduction

Road construction is one of the main concerns in urban development. Continuous positive growth of a city or region and its connection with other places are parallely connected with the need of transportation, which then the growth of transportation traffic means that road will also grow together with it (Lvarez-Herranz & Martnez-Ruiz, 2012). Road as one of the main urban infrastructure has become one of crucial problems in city or regional development (Alminas, Vasiliauskas, & Jakubauskas, 2009; Flores, Chatziioannou, Segura, & Hernández, 2013) which correlates the interests of related stakeholders. As the connecting medium between interests in different areas, road is developed as a set of designed network nodes (Chekuri, Shepherd, Oriolo, & Scutellá 2007; Klunder & Post, 2006). Road network design is often integrated with city planning or bigger ones such as district or national strategic planning. However, as an expertise, road design is commonly included in planology as well as civil engineering disciplines. It includes pavement design as a core knowledge, especially but not exclusively in road construction. In designing a road pavement, existing field data in which road pavement will be laid are taken as calculation inputs; however, roads are often used above their basic specification, outside regulated usage frame and designed loads. It causes the decrease of roads life-performance, along with continuous inappropriate as well as insufficient usage on road pavements.

On the other hand, as environmental movement is continuously spreading across disciplines including civil engineering, pavement maintenance shall start to pay attention to eco-burden impact of road life-cycle. Also, it has become an integral part of knowledge in city or regional development due to its tight relation with urban development (Liu, Dong, Liu, & Liu, 2013). Assessment of environmental impacts/eco-burdens, therefore, has gained strong attention from both practitioners and academia, meaning that studies on such issue are increasingly conducted to figure out both actual and theoretical eco-burdens imposed by any related activities in any phase in road life-cycle. In fact, previous studies tend to see life-cycle assessment in road construction based on its inventory data in normal condition (Chang, Chou, Lin, & Hsu, 2013; Chiu, Hsu, & Yang, 2008; Huang, Bird, & Heidrich, 2009; Nicuţă & Frunză,

* Corresponding author at: School of Business and Management (SBM) – Institut Teknologi Bandung (ITB), Jl. Ganesha 10, Bandung, West Java 40132, Indonesia. Tel.: +62 813 285 87187.
E-mail addresses: morgana.sianipar@sbm-itb.ac.id, morgana.sianipar@gmail.com (C.P.M. Sianipar).

2210-6707/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.scs.2014.01.002

2013; Stripple, 2001), meaning that such approach is inappropriate with reality in which road life-performance is always vary influenced by variability on road usage. The changes of road life-performance will also change eco-burden impact in annual basis. Because of that, any abnormal phenomena which affect road life must be included into account. Therefore, this study aims to answer following research questions:

RQ1 How much eco-burden impacts produced from the changes of road life-performance?
RQ2 What kind of correlation between each abnormal phenomena to eco-burden impacts?

2. Review of literatures

2.1. Road pavement: its early life

Pavement is commonly understood as any surface material used for supporting traffic by way of lying durable material on a designated area. For centuries, many materials had been used as main substances in pavement composition (O'Flaherty, 2002a). Some old roads still use gravel surface, but asphalt and concrete have dominated on heavy-duty roads following the growth of chemical manufacturing industries for decades. The main difference between asphalt and concrete is on the Average Annual Daily Traffic ($ADT_{average}$). While asphalt is used in common heavy-duty roads, concrete is intended to be used for highways with high volume of $ADT_{average}$ (Gerbrandt, Makahoniuk, Borbely, & Berthelot, 2000). As the common material, asphalt has been used for long time. Since 1800s it was used in traditional way without any additional chemical substances, but today with additional ones as performance optimizer such as cement or other geosynthetic products (Anonymous, 1991; Cornell Local Roads Program, 2009; NUAE, 2007). Furthermore, asphalt is categorized to three types based on temperature around paving area. Hot and warm mix asphalt are applied for working temperature about 150 °C and 95 °C–120 °C, respectively. On the other hand, cold mix asphalt is a tricky way to overcome significant temperature decrease of mixed asphalt from manufacturing plant to pavement sites (U.S. Department of Transportation, 2012). The longest and oldest used category is hot mix asphalt (HMA) (Cornell Local Roads Program, 2009; O'Flaherty, 2002a). Asphalt is mostly laid on gravel surfaces which are placed above native subgrades, and the rests are directly used by using native subgrades as the basic layer. As a means for maximizing durability, asphalt layers with each specific characteristics are also laid above native subgrade (O'Flaherty, 2002b). However, basically, pavement composition can be divided into three groups (Brennan & O'Flaherty, 2002; Chiu et al., 2008; Hislop & Coree, 2000). The first two are crushed stone and sand. While crushed stone is used as the though foundation for pavement construction, sand is used as the filler for empty space between stones. These two materials are also useful for decreasing the required amount of asphalt chemical substance for certain pavement volume. Crushed stone is commonly mined from rocky mountain or river, while sand can be gathered from same river with crushed stone or by digging another resourceful area. On the other hand, the chemical substance of asphalt composition is produced by chemically reacting some organic substances.

In the beginning of road pavement, construction is done through several stages. Mining activities of raw materials are basically implemented based on economical calculation (O'Flaherty, 2002c). Supply and demand are considered to get lowest mining cost with maximum result. Nearest mining area is commonly choosen, even though it is very possible to dig raw materials from farther area for certain purposes. By optimizing costs and benefits, crushed stone and sand are mostly collected from a same source area. On the other hand, chemical composition is reacted from several chemical substances mostly distillated from fossil oil, which are then stated as organic chemical substances. Because of that, the mining of all substances in asphalt composition is done together in an integrated oil mining and distillation system which results on several substances with each own characteristics. After mining activities, all materials are transported to manufacturing plants. Crushed stone and sand are directly collected in asphalt manufacturing plant, but required chemical substances are processed in separated manufacturing plant(s) dedicated in composing them into ready-to-mix asphalt, which then transported to same plant with previous two materials for being processed further. After they arrive at designated manufacturing plant, all materials are gathered together and stored for being used in pavement activities. Chemical material is processed with additional adjustment in its characteristics based on required application on fields. When an order of pavement activity is placed, all materials are then transported in separated trucks as a means for conforming the amount of each material based on site data. When materials arrive at a designated site, pavement activity is then began. Non-mixed crushed stone and sand are laid as the base. Then, HMA is laid above them. On-site mechanisms are operated by using integrated module on a special-purpose truck which uses propeller shaft as the medium for transmitting truck power into electricity as well as heat generator.

2.2. Road operations and pavement maintenance

After the finishing of pavement layers, vehicles can start to use the road. This phase is stated as the operations of a road pavement (MRA, 2008). In operations, all vehicles are supposed to use a road by using such limitations as the rules. By considering maximum performance in a reasonable cost, roads are divided into several lanes. Each lane has a designated specification for certain types of vehicle and speed. However, for special purpose roads such as toll, highways, or heavy transportation road, the specifications are often maximized and basically uniform for all lanes due to function interchangeability. Furthermore, each type of pavement material has its own life-performance. HMA is supposed to be normally used in 6 years (Chiu et al., 2008). A normal use is defined as road usage with same or less load than designated capability in holding traffic loads which can be interpreted from several points. The points shall be understood by dissecting each variable in Traffic Equivalent (TE) formula (Bina Marga, 1983; Papagiannakis & Masad, 2008), one of the first formula used in designing a road:

$$TE = Average\ TE \times AF \tag{2.1}$$

$$Average\ TE = (TE\ Beginning + TE\ End)/2 \tag{2.2}$$

$$TE\ Begin = \sum (ADT_j \times C_j \times E_j) \tag{2.3}$$

$$TE\ End = \sum (ADT_j \times (1+i)^U \times C_j \times E_j) \tag{2.4}$$

AF = Adjustment Factor []
ADT = Annual Daily Traffic [%]
C = Traffic direction distribution coefficient []
E = Equivalent number for load weight []
j = Type of vehicle
i = Traffic growth per year
U = Road life

Traffic Equivalent (2.1) is the predicted load which shall be held by a certain length of road pavement. It is adjusted by approximately 10% of expected life due to slight variabilities in construction techniques as well as specifications of raw materials. Before adjusted, *TE* is resulted as the average (2.2) between *TE* in the beginning of road usage (*TE Begin* (2.3)) and in the end of its life (*TE End* (2.4)). In each *TE*, calculations are processed for each