ABSTRACT. Asphalt pavement plays an important role in providing basic amenities to the users. However, widespread use without any maintenance can reduce the life cycle of the pavement. Social and economic progress of mankind leads to increased vehicle use. Consequently, service life span of road became shorter than the expected life span. Life Cycle Assessment (LCA) is a common tool used for investigating the environmental impacts that are associated with pavement construction and maintenance. However to ensure the effectiveness of pavement LCA, the component within the LCA itself need to be adequate and expanded comprehensively. The component related are functional units that need to be standardized, systems boundaries extended, improvement of data quality and reliability and study scopes expanded. Improving these insufficiencies can help the futures research to do a better assessment. These enhancements will put the body of pavement LCA in a better place and assuring to guide the private sector and government department towards the sustainability objective. Although life cycle assessment (LCA) widely used to quantify and to assess the environmental impact of pavements, there is some factor that need to review the state and all supporting utility. Where, there are some incomplete data as part of pavement LCA framework. Such as traffic delay, rolling resistance, concrete carbonation, pavement surface reflectance, lighting, leachate and end of life distribution. The incomplete data sources of pavement LCA create gaps in the assessment methodology and failed the accuracy of results and conclusions. Therefore in order to perform pavement LCA comprehensively, there need to include the best information available and evaluation of any doubt related. Furthermore, in finding the weaknesses in the area that supporting pavement LCA can give a clear assessment of framework and performs a better development in research. This paper examines existing pavement LCA research and applications case studies, and provides recommendations for future research to improve our understanding of pavements and the environment.

KEYWORDS: Life Cycle Assessment (LCA); Pavements; Asphalt.

INTRODUCTION

Asphalt pavement is one of the very important components in the transportation system as well as to give good basic utility to mankind. However, as a result of economic and social development, a vast amount of non-exhaust particulate emission emitted to the atmosphere contributing global climate change. To effectively reduce these emissions there must be a method for the related agencies and government to quantify and to assess the emissions released. Life cycle assessment (LCA) is the most common tools to quantify and to assess the environment impacts of the pavement construction and maintenance.

LCA offers an inclusive method for assessing the total environmental impact of a product, which helps to ensure that the method does not result in unplanned consequences in terms of net increase or decrease of the impact. While the International Organization for Standardization (ISO) has establish a series of standards for conducting LCA on product (ISO 14040 series), carrying out an LCA on pavement may be much more complicated than for general consumer products ((ISO, 2006a);(Santer et al, 2011)). For pavement, the life cycle includes material production, construction, use, maintenance and end-of-life (EOL) phases. Figure 1 shows a general pavement life cycle.
Pavement LCA is a “cradle-to-grave” tool for assessing and quantifying the environmental impacts from pavement construction and maintenance. “Cradle-to-grave” start from acquire raw materials from the nature to produce a product and finish by sending back the product to the nature. Pavement LCA can quantify the total of environmental impacts occurred from all phases in the pavement life cycle. Unfortunately, incomplete data sources being incorporated such as raw material acquisition, material delivery and extreme product disposal. Therefore, in order to incorporate the impacts during the pavement life cycle, pavement LCA furnish a holistic view of the environmental aspects of the product related (SAIC, 2006).

Pavement LCA gives a complete methodology to assess the achievement of pavements that incorporated with environmental metric and all important connection with mankind and environment (ISO, 2006a). Whereas implementing the pavement LCA together with life cycle cost analysis (LCCA) can help the private sector and government to establish a better option of a project or policy. LCCA had been used widely in U.S which start to use by the department of transportation whereby can improve the private sector and government capacity towards economic and environmental goals (Ozbay et al, 2004).

In fact, recent study proposes to incorporate LCA with the impacts of pavement construction and maintenance with the operational energy use and particulate matter emissions of on-road vehicles. These will increase approximately 10% of the environmental impact rather than estimating the vehicle operations separately (Chester & Horvath, 2009).

According to Santero et al. (2009), the environmental impact of pavement construction and maintenance has been expanded over the manufacture of pavement materials. There some data sources that incorporated in the pavement LCA that keeps on improving such as traffic delay, tyre and surface pavement interaction and pavement surface reflectance. Understanding each of these components will provide valuable awareness into best-practice methods to improve the environmental assessment.

Figure 1: Phases and components of pavement life cycles (Santero et al., 2011)

Figure 1 shows the phases and components of pavement life cycles. Pavement construction and maintenance have five main phases’ specifically raw materials and manufacturing, construction, usage, maintenance and end of life. Every phase of pavement construction and maintenance consisted of different components and each component show the interaction between pavement and
environment. These components show the environmental impact of pavement directly. Although the indirect processes are not display but the supporting processes for these components will be incorporated.

For example, equipment used during pavement construction produces direct and indirect impact to the fuel consumption, equipment manufacturing and other related processes. Pavement maintenance phase includes material and the construction phase as shown in figure 1. Even though the unique phase in the pavement life cycles, the impacts from maintenance phase are operated over with original components to the materials and construction phases. End of life recycling phase are operated over with a materials as an outcome response from maintenance processes, material operating and construction works (Santero et al., 2011).

THE PAVEMENT LCA LITERATURE

Pavement LCA started been used to quantify and to assess the environmental impacts of pavement construction and maintenance in the middle 1990s. However, previous study revealed that the application of LCA in pavement construction and maintenance assessment is relatively new (Santero et al., 2011). Normally, the pavement LCA model consists of five main phases specifically material, construction, usage, maintenance, and end of life but most of the pavement construction and maintenance work does not incorporate with the main components (Chan, 2007).

According to Yu et al. (2012), two main components in pavement LCA models specifically usage and traffic congestion output from pavement construction and maintenance are normally neglected caused by large complication. Huang et al. (2009) stated that the traffic delay during pavement construction and maintenance can cause a significant higher fuel consumptions and particulate matter emission emitted to the environment. As studied by Zhang et al. (2010), the gaps in usage and traffic congestion phases of pavement life cycle need to be improved. These gaps are data sources outdated, incomplete usage phase and end of life phase which simply taken as end point of pavement life cycle although most hot mix asphalt (HMA) is recycled and old Portland Cement Concrete (PCC) is crushed and used back as base course aggregates.

Preferably, pavement LCA can quantify and assess each of pavement life cycle phases and components comprehensively. Unfortunately because of time, data and knowledge constraints, pavement LCA assessment is really challenging. Practically, all environmental assessments had to simplify their scope and to limit their investigation on phases and process that rationally accomplishable. Nevertheless, many researches proceed with the guidelines and theory of LCA as much as possible to achieve at least partial of pavement LCA. Santero and Horvath (2009) recommended documents that can be used as a basis for pavement LCA research.
<table>
<thead>
<tr>
<th>Author (year)</th>
<th>Country</th>
<th>LCA Method</th>
<th>Assessed Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Asphalt Pavements</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HMA</td>
</tr>
<tr>
<td>Zapata &amp; Gambatese, 2005</td>
<td>U.S.</td>
<td>Process</td>
<td>●</td>
</tr>
<tr>
<td>Athena, 2006</td>
<td>Canada</td>
<td>Process</td>
<td>●</td>
</tr>
<tr>
<td>Chan, 2007</td>
<td>U.S.</td>
<td>Process</td>
<td>●</td>
</tr>
<tr>
<td>Huang et al, 2009</td>
<td>U.K.</td>
<td>Process</td>
<td>●</td>
</tr>
<tr>
<td>White et al, 2010</td>
<td>U.S.</td>
<td>Process</td>
<td>●</td>
</tr>
</tbody>
</table>

Note: HMA=Hot mix asphalt; SMA=Stone-mastic asphalt; CRCP=continuously reinforced concrete pavement; JPCP=jointed plain concrete pavement.

Many researches reviewed in this paper include only life cycle inventories (LCI) and not for life cycle impact assessment (LCIA) in their pavement LCA. Although LCI to be considered as separated research through the same ISO 14040 series guidelines that perform full LCA research (ISO, 2006a). Five researches reviewed in this paper represent the published pavement LCA and LCI works as of 2010. Particularly, this review does not include the works that focusing only on recycle pavement materials and will focus on the major aspects of each research as a critical assessment of methodologies quality or characteristics.
Table 1 shows some general perception of scope and methods that incorporated in the pavement LCA literature reviewed. This table display summarizes of pavement structures and pavement LCA method that applied in the analysis. Almost all researches carried out comparison between concrete and asphalt pavement and associated with asphalt concrete (AC) and jointed plain concrete pavements (JPCPs) examination that become most general. These comparisons describe the most common chosen material for pavement construction and maintenance works.

All of researches have engaged a process based LCA method that need detail data sources for every single process in the pavement life cycle. Obviously, the reviewed pavements LCA are concentrating on different type of pavements with various methodologies and geographical scope which involve big implications to their system boundaries and doubt in their results. The following parts of this review will investigate intensively the combination and discrepancies among these researches as of strengthens, weaknesses and requirement of the current body of work towards pavement LCA decision making. The review also includes the ability of pavement LCA to choose the most cost effective among pavement construction and maintenance materials.

The pavement LCA reviewed includes extensive and adequate samples to endorse the LCA assessment and to obtain early pavement LCA outcomes and data sources that frequently accommodate persistent effects towards the same product system. However, the fact is that original pavement LCA information frequently difficult to determine. The chronicle of pavement LCA is fulfilling with illustrates of early pavement LCA outcomes which information and determination are stated in reviewed researches. Therefore, the objective of this review is to discuss on the focus of the pavement LCA and to provide suggestion in advance so that the function of pavement LCA can be improved in quantifying and assessing the environmental impacts.

### MAIN FACTORS IN PAVEMENT LCA

The pavement LCA literature is assessed through four types of methodologies which are functional unit equality, system boundary equality, data quality and doubt related and environmental metrics. These four types are important to equality and assessing the outcomes from different researches and also to make particular decision about the environmental effects of various life cycle phase, components and type of pavements from substantial part of pavement LCA.

#### Functional Unit Equality

A main interference of overall current pavement LCA is the deficiency of agreement on the functional unit to assess pavements that equated and referred in the pavement LCA reviewed (Zapata & Gambatese, 2005). Table 2 shows the functional unit parameters used in pavement LCA for the reviewed researches. These features comprise general identifier for the functional unit used in the literature. There also parameters that used to determine the functional unit which are climate, relevant specification and guideline.

<table>
<thead>
<tr>
<th>Author (year)</th>
<th>Traffic</th>
<th>Analysis Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Zapata &amp; Gambatese, 2005)</td>
<td>$10 \times 10^6$ ESALS</td>
<td>10 years</td>
</tr>
<tr>
<td>(Athena, 2006)</td>
<td>50,000 AADT, 40% trucks</td>
<td>50 years</td>
</tr>
<tr>
<td>(Chan, 2007)</td>
<td>Variable</td>
<td>n/a</td>
</tr>
<tr>
<td>(Huang, Bird, &amp; Bell, 2009)</td>
<td>26,000 AADT, 40% trucks</td>
<td>n/a</td>
</tr>
<tr>
<td>(White et al., 2010)</td>
<td>“Moderate and high”</td>
<td>Annualized</td>
</tr>
</tbody>
</table>

The various functional units used in the pavement LCA literature was the main difficulties to find the most environmental friendly of pavements. Basically, the decisions of results are only applied to the circumstances that investigated in the research related. It is difficult to make a decision of results when involving various countries. Three different countries were shown in Table 1. The variability of research location will provide discrepancy in results because of various electricity...
mixes, production practises, maintenance programs, axle load and other location specific component. Therefore, the results of researches from different countries cannot be compared straightway.

The difficulty of various functional units is because the complexity of pavements instead of deficiency in coordination in the pavement LCA which pavements are not easy to determine with one or more functional units. This is caused by the pavement structure such as type, thickness and material properties of pavements that firmly effected by the traffic features, environmental situation, design life and other project specific inputs. The variability of these components generates a condition which two pavements with the same length can have various basic features.

Furthermore, functional unit in pavement LCA with the pavements structural attributes is not enough as an input. While loading transportation can be discovered precisely with tonne-kilometres or electricity generation with kilowatt-hours, pavement cannot be put into the same functional unit. Therefore, the wide features of pavement really difficult to set up a single functional unit to be used in pavement LCA.

Separate pavement LCA will need to set up a sole functional unit based on the aim and area of research. Therefore, the fundamental of describing the functional should refer to a standard set of features that precisely define the pavement structure and its material attributes, the pavement performance standard and appropriate variables. Furthermore, adding flexibility to the functional unit for a large range of pavements to be estimated by a dynamic, uniform and platform of the research situation. Pavement LCA users should aware that the results from every research will not appropriate for other research because of the various functional unit used. In depth investigation can assist to recognise the validity of results, to modify the functional unit and to define appropriate set of event which results are suitable.

**System Boundary Comparability**

The basic objective of any life cycle methodology is to assess a product or service life cycle incorporating both direct and indirect environmental impacts. Whereas, easy idea precisely modelling and investigating every phase of pavement life cycle is restrained by less comprehension of the system in research and problem in developing appropriate data sources. Eventually, the difficulties in reviewed pavement LCA literature acquired short sighted of the pavement life cycle, normally evaluating just for the extraction, manufacturing, transportation and pavement material placement.

Phases and components of pavement that provide a complete pavement life cycle showing that environmental impact really affected by more sources than those shown in figure 1. Some pavement LCA reviewed has extended their research area to incorporate traffic delay, lighting and carbonation. Unfortunately, there still lack of better understanding to the life cycle. Furthermore, pavement equality with inappropriate data sources caused the reduction of environmental impacts (Wang et al., 2012).

In addition, previous research found that the normally excluded phases and elements are firmly affected the whole environmental impacts of pavement construction and maintenance works (Santero & Horvath, 2009). For instance, rolling resistance and traffic delay can cause more environmental impacts compared to construction material and equipment and still lack of research considering these elements in early stage rather than the final stage of pavement LCA.

Table 3 show the life cycle components in pavement LCA as they are reviewed in the pavement LCA literature. Material extraction and production is the only elements define by every research selected. Moreover, there still lack of research has been incorporating the traffic delay element in their pavement LCA. Only two of the researches incorporating this element (Chan, 2007 and Huang et al, 2009). Most of the researches incorporate the component of onsite equipment used in construction but omitted the traffic delay component. Santero & Horvath (2009) revealed that the omission of the use phase can lead to a major error in the pavement LCA assessment. Whereas, it can produce potential effect to the environmental impact of pavement construction and maintenance works. Previous research had found the significant to incorporate the traffic delay in the pavement LCA framework (Lepert & Brillet, 2009). In the reviewed pavement LCA, only two research incorporating the traffic delay component in the early stage of pavement construction work (Chan, 2007 and Huang et al, 2009) and only one for maintenance phase (Athena, 2006).

The maintenance phase has the effectiveness to be significant provider to the whole environmental impacts. Furthermore, there has been lack of attempt to features it more widely or to
define the accuracy of the maintenance schedules option results (Santero et al., 2011). Previous research described a better instance of the data input which a maintenance schedule can be incorporated even though it acknowledged to disregard the smaller and routine maintenance works like diamond grinding and crack sealing. Possibly, the works disregard because of their narrow affect to the environmental impacts of pavement construction and maintenance works (Athena, 2006).

A research by Santero et al. (2011) had included the use phase in pavement LCA. Furthermore, the reference of pavement LCA studies which excluding the use phase was the most significant gap from a system boundary perspective. According to Zhang et al. (2010), the use phase of pavement life cycle obviously included the effect of pavement roughness on vehicle fuel economy. Unfortunately, the resulting relationship does not reflect any mechanistic component of the pavement-vehicle interaction, and because of its dependence on heavy duty trucks tested at non-freeway speeds, it is not well-suited to modelling freeway passenger vehicles and truck traffic.
Therefore, by adding just a specific phases and elements of the pavement LCA can help to identify the usefulness of the results. Not any of the researches that incorporate all complete pavement life cycle phase. The omitted components frequently provide significantly to the pavement LCA results, such effectively transform the results of a research. Unfortunately, there are frequently a limitation such as data accessibility and project scope to incorporate every element of the pavement LCA. Hence, the goal to get view on the effectiveness of unsealed parameters through accuracy assessment. Eventually, the omitted components should be entirely exposed to the public which the weaknesses are clearly defined.
Data Quality and Dubiety

The precision of pavement LCA frequently need the capability to get and to use better data sources. Such that less and dubiety of data sources make the pavement LCA not precise as it should be. Theoretically, this problems can be dealing successfully by getting the relevant and the best available data sources (Santero et al., 2011).

Even though cement and bitumen are significant to lead the pavement material extraction and production phase but the precision of the environmental impact is not discussed deeply in the research (Zapata & Gambatese, 2005). For instance, the research found that an energy intensity range of 4.6–7.3MJ/kg of cement; for bitumen, the range is 0.70–6.0 MJ/kg are expected because of the various research area with different system boundaries, technology hypothesis and countries specific production processes. Furthermore, environmental impacts need to be put in the wide range of values.

By using the extensive difference in providing the published and sole global factor, it is better to carry out sensibility and dubiety assessment to define the strengthened of the results. This is important not only for existing example of cement and bitumen but also for pavement structure, rolling resistance factors, carbonation rates, traffic delay and other relevant variables. Yet, pavement LCA always neglects this kind of method and normally adopt a sole published factor which not supporting the rational and sensibility assessment.

Eventually, the evaluation process is the last measure to determine better data sources in pavement LCA. Some of the reviewed researches evaluate from journals (Zapata & Gambatese, 2005; Huang et al, 2009) whereas, the others are in the form of academic, industry or government reports. Even though these reports evaluated deeply but the hardship and limitation of the evaluation not specified in their documents. Even the evaluation process is not ensuring the quality but it describe an opportunity for others experts in the field to review the robustness of the research. Therefore, the evaluation process need to expand the whole utility of field through defining discrepancies in the data sources and technique used to assess pavements. To bring out the pavement LCA in other form such as technical reports, an expressed designation as evaluation can provide better quality and assurance in the pavement LCA results.
Life Cycle Inventories (LCI) and Life Cycle Impacts Assessment (LCIA) scopes

The environmental impact of pavement construction and maintenance accomplishment can be assessed using several of metrics. Most of the reviewed researches choose energy consumption as an environmental metric considered as shown in table 4. Only one research that concentrate extensively on energy consumption as their environmental metrics (Athena, 2006). Two researches include an inventory of different kind of air emissions such as SO₂, NOₓ, CO, and particulate matter whereas the other three includes greenhouse gases. One research found that environmental impact not incorporated with energy consumption or air pollutant as can see in table 4.

Table 4: Environmental metrics considered in pavement LCA (Santero et al., 2011)

<table>
<thead>
<tr>
<th>Author (year)</th>
<th>Process energy</th>
<th>Feedstock energy</th>
<th>Greenhouse gases</th>
<th>NOₓ</th>
<th>SOₓ</th>
<th>CO</th>
<th>VOC</th>
<th>Particulate matter</th>
<th>Lead</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Zapata &amp; Gambatese, 2005)</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Monetized pollution damages</td>
</tr>
<tr>
<td>(Athena, 2006)</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Monetized pollution damages</td>
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<td>(Chan, 2007)</td>
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<td>Monetized pollution damages</td>
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<tr>
<td>(Huang, Bird, &amp; Bell, 2009)</td>
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<td>●</td>
<td></td>
</tr>
<tr>
<td>(White et al., 2010)</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
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</table>

Although energy consumption as main environmental metric considered in the review, the basic explanation of methodologies used is yet to agree. Such as hydrocarbon and bitumen has an exact amount of feedstock energy incorporated with energy consumption. The feedstock energy need to incorporated in every energy assessment (ISO, 2006b). Unfortunately, only one of the reviewed pavements LCA that incorporated the feedstock energy of bitumen in the pavement life cycle inventories (LCI).

Many of the reviewed pavement LCA lack of describing the environmental impact as an overall assessments. The goal that to investigate and to assess the effectiveness of environmental impacts can be derived from ISO 14040 (ISO, 2006b). Typically, this goal carried out by categorise emissions and other environmental contributor into impact group.
Most of the reviewed pavements LCA are best classified as pavement LCI due to some or entire omitted of impact assessment process. The pavement LCI give relevant data sources but still insufficient for decision making. The effect of emissions like SO₂, NOₓ, and CO is really hard to assess before they are classified more specific categories for instance, photochemical smog formation or human toxicity. Despite of the appropriate assessment for this impact categories set, which need space to separate the data for defining the sources of the pollutant emissions. This kind of data input need relevant numbers of data whereas is hard to discover or need wide hypothesis.

Pavement LCA Models

Typically, pavement LCA models is create to evaluate the environmental impact by incorporating material, distribution, construction congestion, usage, and end of life modules. Traffic delay energy consumption and greenhouse gases elements are related to traffic and fuel economy development. Dubieties happen in the usage module particularly for the pavement structure effect (Yu & Lu, 2012).

The first step is to provide a functional unit used to create the pavement LCA framework. A functional unit evaluate a relevant amount to be equalised among options that related to this function. Comparison functionality needs to be carried out for the whole pavement LCA model. For instance, same traffic data input need to apply with the same analysis length in the same operation. In order to evaluate the environmental impacts of pavement construction and maintenance works, pavement LCA model need to be produced.

There is several software tools that common used in developing the pavement LCA model. Unfortunately, most of the software tools only focus on life cycle cost assessment (LCCA) in order to get the pavement decision making (Nicholas, 2010). Nowadays, LCCA become a well-known amongst the pavement LCA user. Therefore, several software tools have combined to fulfil the assessment desire such as Federal Highway Administration’s (FHWA) and RealCost (Rangaraju, Amirkhanian, & Guven, 2008).

The major strength of the software is the capability to estimate user cost together with the conventional agency costs. To estimate the user cost, the RealCost calculation define the traffic delay with widely traffic attribution during pavement construction and maintenance works. Then the input data of time is included to the traffic delay that providing the user cost assessment. Unfortunately, concentrate extensively on the traffic delay without taking any consideration of other element like noise, safety, standard operation fuel consumption and tyre wear will produce insufficient user cost calculation. Typically, software tools that incorporate intensive method in order to assess the pavement life cycle are really uncommon. This review discovered three general pavement LCA model tools for more common use (Nicholas, 2010).

PaLATE

Pavement Life-Cycle Assessment Tool for Environmental and Economic Effects (PaLATE) is an Excel-based tool for pavement LCA model. PaLATE was developed in 2003 at the University of California, Berkeley. The tool represent the pavement life cycle by including material extraction, production, construction, maintenance and end of life phases. PaLATE mixes the economic input-output-life cycle assessment (EIO-LCA) data in order to provide a hybrid pavement LCA framework. PaLATE users need to enter data about the amount of every pavement layer and maintenance works as shown in figure 2.

PaLATE’s environmental results incorporate energy and water consumption, global warming potential (GWP), human toxicity potential (HTP), several of air pollutant and hazardous waste generated. Unfortunately, the environmental results are demonstrated as a raw data and this putting PaLATE as a LCI only but not to be LCIA. This tool often describes an easy life cycle cost process even though the assessment is only for material unit-weights basis and omits labour, overhead, user costs and other financial elements.

PaLATE has been reviewed for taking outdated data in its estimation (Nathman, McNeil, & Van Dam, 2009) as represent source that used in EIO-LCA model. The other PaLATE data are approximately used to fulfil the data gaps during the tools development. Besides that, PaLATE has an area that ignores significant phase of pavement life cycle like traffic delay and the usage phase.
ROAD-RES
ROAD-RES is a life cycle assessment model that assessing the environmental impacts of pavement construction and maintenance works. This model including all pavement life cycle phases (Birgisdottir, 2005). Again, there some lacking of data accessible which utilise probably incomplete phase of pavement life cycle. The model has been improved not only for pavements but also include the roadway like winter service works. ROAD-RES is specifically aimed on the recycle from waste material like burning process and can compare with the original material as shown in figure 3.

ROAD-RES deals with eight types of impact attributes which are GWP, photochemical ozone formation, nutrient enrichment, acidification, stratospheric ozone depletion, human toxicity, eco-toxicity, and stored eco-toxicity. Those characteristics describe environmental impacts to air, soil, and water. The main goal of this model is to concentrate on waste and water pollution. ROAD-RES has been used in some of the reviewed researches. Those researches concentrate on the recycle of waste pavement construction and maintenance works and evaluate their impact comparative to original materials.
UK Asphalt Pavement LCA Model
According to the work by Huang et al. (2009), explaining a pavement LCA tool that concentrated on asphalt pavement evaluation. The research described five causes the insufficient of existing pavement LCA tools which are applicability, suitability, fulfil, range and accessibility. These reviews reflect most of the main restriction in the pavement LCA reviewed. The unknown tools considered in the research focus at the materials manufacturing, construction (instruments used onsite), pavement maintenance phases and other required transportation. For instance, reused material like glass, bottom ash, and RAP are included in the material phases. The UK asphalt pavement LCA tool is created to investigate pavement in United Kingdom as shown in figure 4.
This tool described eleven types of impacts that used to classified the environmental impacts of asphalt pavement which are decreasing of materials, decreasing fossil fuels, decreasing stratospheric ozone, decreasing of landfill space, global warming potential, acidification; photo oxidant formation; human toxicity; eco-toxicity; eutrophication and noise. Huang et al. (2009) also suggests to group and weight the impacts classification through a process named ‘Eco-points’. ‘Eco-points’ is a rating system created by United Kingdom Built Research Establishment for the construction industry. Furthermore, the ISO 14044 standards do not support weighting for equality evaluation because it needs more value options (Huang et al, 2009).

The development of this tool is still in progress during reviewed. However, the scope of the tool is complying with the ISO 14044 series of standards (Nicholas, 2010). The combination between this tool and LCIA will give an important data compare to the existing pavement LCI. Unfortunately, the difficulty of LCIA classification regarded and relevant data requirement cause the LCIA tool to be reviewed before it can be apply in general. However, the traffic delay or the use phase does not incorporated in the reviewed research (Huang et al, 2009).

DISCUSSION AND RECOMMENDATION

The application of pavement LCA in quantifying and assessing the environmental impact is relatively new. The limitation in the existing pavement LCA reviewed must not be seen to be the problems of
applying the approach in the pavement construction industry but it should be improved and used widely to a huge infrastructure system. The role of the pavement LCA in completing the economic evaluation method of life cycle cost analysis (LCCA) has been applied throughout 60 years. However, the basic particular which are the proper discount rate and duration assessment are yet to be decided. Moreover, these discrepancies bring in LCCA to lead in the development of pavement economic fundamental. This can be proved by the widespread use of various transport departments (Ozbay et al., 2004).

From the existing pavement LCA reviewed, obviously the comparison between asphalt pavement and concrete pavement have been opt for the most (three of the five reviewed researched applied this comparison). Although it reflects only one of multi distinction chances to subtract the environmental impact. Moreover, the requirement of determining the distinction between asphalt pavement and concrete pavement is no doubt. However, the discrepancies in the functional unit, system boundaries, data quality and environmental metrics have caused the results of various researches are mostly unsuited for one to another. Furthermore, it is impossible to accumulate the results and to obtain any wide findings.

For example, there is no consent have been made among the researches reviewed on which material consume more energy to the pavement life cycle. In fact, it is indistinct if the researches have measured the main energy or energy used such as electricity. While the feedstock energy of bitumen is incorporated, the energy stability inclines more favorable to concrete. However, not all the reviewed researches rated the feedstock energy of bitumen in their energy estimation and there is no agreement among community on how it should be incorporated (Athena, 2006).

Nevertheless, most of the omitted element particularly from the use material of pavement which is not omit in their energy estimation is effectively provide huge impacts to the pavement life cycle (Santero & Horvath, 2009). Actually, if the energy stability is certainly support more of one kind of pavement to another, there are yet to accomplish most of the environmental issues as though greenhouse gas emissions, characteristic and toxic air emissions and water usage that as good as or even more crucial than energy use. Therefore, by applying the pavement LCA reviewed to force the environmental debates of the asphalt pavement in comparison with concrete pavement.

Nevertheless, there are difficulties to obtain findings entire regional boundaries. This is caused by distinction in electricity mixes, manufacturing implementation, pavement designs, available materials, local preservation implementation and other county-specific factor that will establish various results rely on the research location. A study by Athena (2006) also describe regional ratio and indicate minor but non-insignificant discrepancies between distinct locations. It is important to carry out more research towards the environmental impact assessment that caused by various regional.

Obviously, the application of pavement LCA is obstructed by the above mentioned discrepancies. So to get decision upheld concerning the environmental impacts of pavement construction and maintenance works, these discrepancies need to be solved. This can be done with standardization of the functional unit, extending the system boundaries, enhancement of data quality and investigating widely in a huge of environmental impacts, comparable evaluations with more reliability. Therefore, it can offer better benefits to the environmental performance of pavements.

A study by Nicholas (2010) revealed that the available pavement LCA model is developing to achieve a holistic assessment to simplify the application more extensively. Nevertheless, the area of existing models is limited by the general analysed phases of the pavement life cycle namely material production, construction, maintenance and end of life. The use phase and traffic delay factor also incorporated with less attention. Data sources are specified on certain locations. Therefore, it is not convenient to employ a certain model outside of the county that the practice was expected.

It is necessary to concern the benefit provided by this kind of models that assessing various type of pavements which is a significant progress over the static. Pavement LCA models also offered advantage on time and cost effective, extensive skill and proper assignment in performing better pavement LCA. Therefore in order to reduce these gaps, current pavement LCA models need to justify transportation departments, research community and any policy decision maker to commence in using pavement LCA as a key factor in their conclusion (Nicholas, 2010).
CONCLUSIONS

The reviewed pavement LCA in this paper offers an outline of the current information concerning the environment impacts of pavement construction and maintenance. It has been shown that pavement LCA is still growing as a research field and that many of the connections between pavements and the environment are still lack of understanding and well considered in the reviewed pavement LCA. Furthermore, the reviewed pavement LCA begin to improve and still growing. Apart from that such as traffic delay and the maintenance phase, are more well-known research areas which give an opportunity for immediate improvements in pavement LCA. Pavement LCA provides a valued prospect to reduce the environmental impacts related with a huge and important pavement construction and maintenance. Refining the insufficiencies in reviewed pavement LCA and supporting research fields will certainly help to increase environmental performance in order to guide transportation department and governments towards key of sustainability. By using the existing information and framework of pavement LCA model can help to create more feasible and comprehensive method that focus more in decreasing the environmental impact extensively.

REFERENCES


