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Traffic modelling in system boundary expansion of road pavement life cycle assessment

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ABSTRACT

This paper uses a case study of a UK inter-urban road, to explore the impact of extending the system boundary of road pavement life cycle assessment (LCA) to include increased traffic emissions due to delays during maintenance. Some previous studies have attempted this but have been limited to hypothetical scenarios or simplified traffic modelling, with no validation or sensitivity analysis. In this study, micro-simulation modelling of traffic was used to estimate emissions caused by delays at road works, for several traffic management options. The emissions were compared to those created by the maintenance operation, estimated using an LCA model. In this case study, the extra traffic emissions caused by delays at road works are relatively small, compared to those from the maintenance process, except for hydrocarbon emissions. However, they are generally close to, or above, the materiality threshold recommended in PAS2050 for estimating carbon footprints, and reach 5–10% when traffic flow levels are increased (hypothetically) or when traffic management is imposed outside times of lowest traffic flow. It is recommended, therefore, that emissions due to traffic disruption at road works should be included within the system boundary of road pavement LCA and carbon footprint studies and should be considered in developing guidelines for environmental product declarations of road pavement maintenance products and services.

Introduction

The life cycle assessment (LCA) of road pavements has been developing since the 1990s (Hakkinen and Makela, 1996; Stripple, 2001). The life cycle inventory of pavement materials has been researched thoroughly by material associations (Marceau et al., 2007; Eurobitume, 2011), compared to early studies of energy consumption only (Zapata and Gambatese, 2005). The work is strengthened by including recycled and secondary materials (Mroueh et al., 2001; Birgisdóttir et al., 2006), a growing practice in response to stakeholder calls for sustainable construction. More recent LCA research is focused on the methodological choices, for instance allocation (Chen et al., 2010; Sayagh et al., 2010; Huang et al., 2013), and comparison of design options (Cross et al., 2011; Santero et al., 2011a).

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It has been noted in the earliest of LCA research that traffic emissions in the use phase can account for the majority of emissions in the pavement life cycle (Piantanakulchai et al., 1999; Highways Agency, 2003). The proportion has been quantified by recent European research to be in the range of 93–99% (ECRPD, 2010) or even higher (Milachowski et al., 2011). Because vehicle fuel consumption is largely determined by many factors other than pavement performance (Hammarstrom et al., 2009; Lepert and Brillet, 2009), traffic emissions are typically excluded from pavement LCA. This is a limitation, in that pavement maintenance leads not only to additional construction activities, but queuing or diversion of traffic at road works. A few studies have investigated the additional emissions, but have been limited to simplified traffic modelling (Huang et al., 2009a) or hypothetical scenarios (Santero et al., 2011b), with no validation or sensitivity check on the traffic flow or traffic management (TM) options.

These problems are related to system boundary settings. Traffic emissions under the free flow state can be estimated by multiplying the length of journey with average emission factors (e.g., kg CO_2 per vehicle kilometre), typically tied to the age, engine size and fuel type of the vehicles (DEFRA, 2011), or they can be derived from commercial databases (e.g., Ecoinvent) (Milachowski et al., 2011). Managed traffic flows are better modelled in micro-simulation coupled with an instantaneous emissions model, because this type of tool is able to relate the emission rates to vehicle operation (e.g., driving pattern, speed profile) during a series of short time steps (Barlow et al., 2007), representing the restricted flow or congestion that may be caused by road works. There remains a need to explore system boundary expansion of road pavement LCA to understand the importance of this part of the pavement lifecycle.

Using a case study of a UK inter-urban road, this research investigates the emissions from traffic disrupted during pavement maintenance, with various TM options, compared to those from the construction and maintenance activities.

Case study and LCA model

System boundary

The case study site is located in Lincolnshire on the A17 between Sutton Bridge and Kings Lynn, an inter-urban road in the UK Midlands; with length 720 m including 200 m dual (22 m width) and 520 m single (11 m width) carriageway. While the results of such studies will vary widely, due to the very wide range of traffic flows on different roads, this site was chosen due to the appropriate level of construction and traffic flow data available at a location representative of many similar roads, with a variety of potential TM options.

The system boundary of the pavement construction and maintenance LCA is illustrated in Fig. 1. Construction data on pavement layout and thickness was provided by Lincolnshire County Council. The pavement consisted of 40 mm surface course, 60 mm binder course and 200 mm base, all courses being made with bitumen bound materials (asphalt). Material recipes for asphalt mixtures were based on UK asphalt material specification in compliance with BS EN 13108 (BSI, 2010). Blast furnace slag (BFS), a by-product from the iron making process, was used as aggregates in DBM base (200 mm thick) and binder (60 mm thick) courses, and as coarse aggregates (>2 mm) in HRA surface course (40 mm thick). Assumptions are made on the distance of transport and payload of the trucks. Quarry aggregates and BFS are transported for 50 km, and bitumen for 200 km, to the mixing plant using 20–28 t truck. New asphalt and milled recycled asphalt pavement (RAP) are transported for 80 km to site and stockpile, respectively, using 20–28 t truck. Allocation of environmental burdens of iron making to BFS has followed the zero impact route[1] recommended by a UK industry standard tool for asphalt carbon footprinting (Wayman et al., 2011). No processing energy and emissions were allocated to BFS before transport to the asphalt plant. The Eurobitume 2011 inventory, which is based on a mixed allocation by mass and economic value (Eurobitume, 2011) between oil refinery products, was used for bitumen. Asphalt production followed the 'cut-off' method for end-of-life (EOL) scenario,[2] in compliance with a UK public specification for measuring greenhouse gas emissions of products (BSI, 2011). The impact of the above allocation methods on the LCA results has been reported (Spray et al., 2012) and thus was not investigated in this study.

Functional unit

Original construction was undertaken in 1989. This case study starts in 2009, when a major rehabilitation was undertaken. Twenty years was selected as the analysis period to be consistent with the design life of the 2009 rehabilitation. In other LCA studies, justification of maintenance strategy will need to be provided. This rehabilitation involves milling out of 200 mm of the old asphalt pavement and replacing with inlay of new asphalt mixtures. The rehabilitation is modelled using real project data, except that the asphalt mix design uses BSI guide values, to eliminate the variables between suppliers. All removed materials are assumed stockpiled for reuse. The functional unit (FU) is defined as the carriageway pavement area of the rehabilitation site, i.e., 520 m single carriageway (11 m width) and 200 m dual carriageway (22 m width) bearing the design traffic for 20 years, which includes the rehabilitation at end of year 20. The modelling was carried out in SimaPro using sub-licensed databases, supported by data from contractors and UK specification. The

[1] Alternatively, allocation can be made based on mass or economic value of the outputs.

[2] In the 'cut-off' method, each product is assigned only the burdens directly associated with it; in other words, all benefits of recycling are given downstream to using the recycled material. 'Substitution' is an alternative method of allocation; it gives all benefits of recycling to the original manufacture but requires an assumption of the EOL recovery rate.