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Field investigation and parametric study of greenhouse gas emissions from railway plain-line renewals

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ABSTRACT

Railway transportation is becoming increasingly important in many parts of the world for mass transport of passengers and freight. This study was prompted by the industry's need to systemically estimate greenhouse gas emissions from railway construction and maintenance activities. In this paper, the emphasis is placed on plain-line railway maintenance and renewal projects. The objective of this study was to reduce the uncertainties and assumptions of previous studies based on ballasted track maintenance and renewal projects. A field-based data collection was carried out on plain-line ballasted track renewals. The results reveal that the emissions from the materials contribute more than nine times the CO_2-e emissions than the machines used in the renewal projects. The results show that extending the lifespan of rail infrastructure assets through maintenance is beneficial in terms of reducing CO_2-e emissions. Analysis was then carried out using the field data. Then the results were compared to two ballastless track alternatives. The results show that CO_2-e emissions per metre from ballasted track were the least overall, however, the maintenance CO_2-e emissions are greater than those of ballastless tracks over the infrastructure lifespan, with ballasted track maintenance emitting more CO_2-e emissions at the 30 and 60 year intervals and the end of life when compared to the ballastless track types. The outcome of the study can provide decision makers, construction schedulers, environmental planners and project planners with reasonably accurate GHG emission estimates that can be used to plan, forecast and reduce emissions for plain-line renewal projects.

Introduction

Rail transportation is becoming ever more attractive especially in Europe, Japan and Asia. In Australia, the railway infrastructure is built to carry either passengers or freight, or both, uni- and bi-directionally (Remennikov and Kaewunruen, 2014), and the nation's heavy haul rail network is one of the world's best and most efficient transport systems (Kaewunruen and Remennikov, 2010). The railway track (also called 'railroad' in the US) is a complex system built upon many supporting elements within the track corridors. The operational and logistic point of view adds another layer of the complexity. Railway infrastructure is constructed to have a design life ranging from 10 years to 100 years, depending on construction type (ballasted or ballastless), construction materials, loading and weathering conditions, and operational parameters.

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Nomenclature

C_i	energy content factor of type i fuel (GJ/kL)
CO_2-e	carbon dioxide and equivalents, including CO_2, CH_4, N_2O and synthetic gases
E_{CM}	CO_2-e emission per unit track length for construction machinery (kg/m)
EF_k	the embodied emissions factor for type k material (kg/kg)
E_{IC}	CO_2-e emissions per unit of track length for the initial construction (kg/m)
E_{ij}	amount of emission of gas species j relating to fuel i (kg)
E_l	CO_2-e emission per unit track length per year of lifespan (kg/m year)
E_m	CO_2-e emission due to maintenance per unit track length (kg/m)
EM	embodied CO_2-e emissions per unit track length (kg/m)
EM_{ic}	CO_2-e emission per unit track length for materials used in initial construction (kg/m)
EM_r	CO_2-e emission per unit track length for materials used in renewals and maintenance activities (kg/m)
E_u	CO_2-e emission per metre of track from ballasted track maintenance activities (kg/m)
F_{ij}	emission factor for gas j by fuel i (kg/GJ)
L	lifespan, or the time period of construction and operation phases of the lifecycle (year)
M	types of maintenance activities
MF	maintenance frequency
N	total number of material types used in track construction
Q_i	quantity of type i fuel (kL)
QM_k	quantity of material k required per metre of track construction (kg/m)
T	track length processed in a renewal maintenance project (m)

Subscript

i, j, k	fuel, gas species and material indices
n	maintenance activity index

Throughout this period, maintenance and renewals of aged components are required to assure the safety and reliability of the rail network for passengers and cargo (Remennikov and Kaewunruen, 2008; Kaewunruen et al., 2015).

In general, there are two railway infrastructure construction types: ballasted and ballastless tracks. Ballasted track is laid on crushed aggregates and capping layers that are placed on the formation, with the combination commonly referred to as the 'substructure'. It supports a combination of sleepers, rails, and fixings which is commonly referred to as the 'superstructure' (Manalo et al., 2010; Burrow et al., 2007). Ballastless track uses a concrete slab system and special fixings to support the steel rails which transfer the loads from passing trains to the concrete slab. Michas (2012) explains that ballastless track is superior to ballasted track due to its higher stability, less frequent maintenance, reduced height and longer lifecycle. The disadvantages of ballastless track are inflexibility and higher initial construction costs due to the increased concrete and steel content. Ballasted track has been used since the early 1800s and is still very common but the popularity of ballastless track has increased over the last 40 years (Michas, 2012).

In recent decades, the issue of greenhouse gas (GHG) emissions in railway systems has attracted much attention in response to the concern created by climate change (Schwarz, 2009). The impact of railway systems on the global environment is becoming a more and more important part of their life cycle analysis (Chester and Horvath, 2009). Inevitably, the decision on the choice of track type in railway construction projects will depend on the outcome of greenhouse gas emission analysis as well as on social, economic and other environmental considerations. This has prompted investigations into the GHG emissions from the construction and maintenance of track beds (Kiani et al., 2008; Milford and Allwood, 2010; Chang and Kendall, 2011; Schwarz, 2009; Chester and Horvath, 2012; Ueda et al., 2003).

The planning and design are the first steps in developing a railway system. Some major considerations include construction type, track characteristics, routes and intended use. Construction follows and with the assistance of diesel engine driven machines, a reduced timeframe can be achieved. Once construction of the railway is complete, the railway becomes operational. Maintenance is then carried out for the railway's lifespan as it is crucial to ensure the track system operates successfully. Maintenance and renewal of ballasted track bed includes ballast resurfacing (ballast tamping, regulating and stabilising), rail grinding, ballast cleaning, continuous track renewals and switch renewals, with all these activities relying on diesel engine driven machines to reduce the timeframe and increase the scope of maintenance. The end of life activities include the demolition and recycling of materials. An illustration of the railway system and inclusions of the current study are shown in Fig. 1a.