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Life cycle cost assessment of bitumen stabilised ballast: A novel maintenance strategy for railway track-bed

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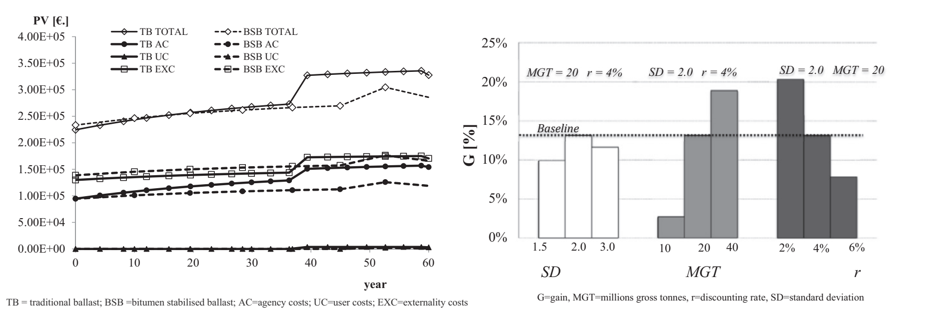
HIGHLIGHTS

- LCCA-based model integrated with the results of the LCA have been defined and applied to TB and BSB solutions.
- BSB is a convenient construction/maintenance solution with respect to traditional ballast.
- Percentage of gain reached with BSB depends on traffic and discount rate.

GRAPHICAL ABSTRACT



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ABSTRACT

In railway sector, the high quality of the track is ensured by adequate construction methods and frequent maintenance. To reduce the maintenance frequency diverse techniques have been recently developed. Among others, bitumen stabilised ballast (BSB) represents an innovative solution designed to increase ballast service life and reduce overall maintenance burdens. This technology, which can be used for new track-beds as well as to reinforce existing ones, consists of the use of bitumen emulsion (BE) poured or sprayed at ambient temperature onto the ballast. The objective of the present work is to assess the economic feasibility, encompassing the estimation of the costs of the environmental impacts, of this innovative technology (BSB), compared to the traditional ballast (TB). This purpose is achieved using a lifecycle approach where economic and environmental impacts are combined to return an integrated model. Results of Life Cycle Cost Assessment carried out for the baseline scenarios (with respect to traffic level and quality level set for the infrastructure) indicated that: the BSB technology, used since the construction stage and during the routine tamping, can provide economical savings. Sensitivity analysis to main parameters affecting results showed that these savings can vary significantly, especially in relation to the traffic and the discount rate.

1. Introduction

Railways require relevant resources to ensure efficiency and functionality along the time. In Europe, the construction cost of track ranges from 2 to 4 million of euros/km for single track, while the maintenance costs can vary from 30.000 to 100.000 €/km per year [1–3]. The main part of the total cost of maintaining the

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railway infrastructure arises from the track, thus the interest towards innovative and effective construction and maintenance techniques of the track is continuously growing.

"Climate and resource challenges require drastic action" [4], this is the imperative priority declared in the European strategic energy and climate targets for Smart, sustainable and inclusive growth and Smart, green and integrated transport by 2020. Indeed, greenhouse gas (GHG) emissions and their negative effects on global warming has urged the international community to strength the worldwide commitment to implement fair-reaching actions towards low-carbon and climate-resilient growth. Transport sector contributing to around a quarter of the European Union's (EU's) GHG emissions. Road transport is the biggest emitter accounting for more than 70% of all GHG emissions from transport in 2014. In the light of this, the railway mode can play a crucial role in the EU's low-emission mobility strategy [5]. Indeed, rail is the only major mode of transport that is currently able to shift from using fossil fuels to renewable energy without the need for further major technological innovations [6]. Therefore, at least in EU, rail represents a preferable mode of transport for achieving in the future a satisfactory balance in terms of environmental, economic and social impacts, as demonstrated by programs such as s2rail (http://shift2rail.org/). The construction of new and the improvement of the existing railway infrastructures is expected to continue its growing trend in the next years as the EU aims for implementing and completing the Trans-European Transport Network (TEN-T) core network by 2030 and the TEN-T comprehensive network by 2050 [5,7]. This is in line with the EU objective that aims to achieve a sustainable growth exploiting modern, sustainable infrastructure. Sustainable growth means building a resource efficient, sustainable and competitive economy, through the development of new processes and technologies, including green technologies. In order to meet these targets and ensure the transition to a low-carbon economy, it is necessary to modernize infrastructures, especially railway, through the application of best practices, optimizing recycling chains and promoting an efficient infrastructure management. This will allow reducing costs of maintaining the existing surface transport infrastructure networks.

Ballasted track is the most common type of track superstructure supported on a layer of granular material (ballast) [8,9] Despite the benefits of this track-bed structure and the robustness of experiences in this type of construction, it presents certain limitations and drawbacks, mainly associated with geometry degradation due to ballast settlement [10–14]. Settlement occurs in different phases of lifecycle: 1) immediately after track construction, tamping or renewal, due to the consolidation of ballast; 2) in a second phase, during the exercise, with a slower settlement rate that generally can be approximated by a linear deterioration with the logarithm of the number of load cycles. This settlement is associated to a further reduction of volume due to ballast particles rearrangement and breakdown caused by fracture and abrasive wear of the individual stones; 3) a third phase with a quasi-exponential degradation that would mark the end of track life that occurs if the track does not undergo to a correct frequency of maintenance [13].

Due to the different mechanisms of settlement, periodic and costly minor and major maintenance operations are required to provide a granular layer with adequate characteristics.

Automatic tamping is the most used method worldwide to correct track geometry defects. The vibrating action induced by tamping machine allows re-arranging the particle positions, thus restoring the original position of the track. However, this operation causes certain detrimental effects: i) vibrating tines disturb and dilate the densely packed ballast layer, degrading particles and reducing track stability [13–15]; ii) track profile may quickly revert back to its original state, a phenomenon known as *ballast memory* [16]; iii) tamping produces high amount of fines (up to 4 kg of fines/sleeper/tamp) [17] increasing progressively the contamination (fouling) of the ballast layer. For this reason, tamping typically reduces its efficiency after every application [18] and may not produce a durable high quality level of track geometry.

In order to face the discussed drawbacks of the tamping diverse maintenance-based solutions, such as polyurethane-based ballast stabilisation, ballast bonding by resins, cement grouts, etc. have been developed in last decades with the aim of reducing maintenance frequency [19].

In this context, given the need to develop innovative solutions to increase the durability and geometric quality of ballasted tracks while reducing costs associated with their maintenance, bitumen-stabilised ballast (BSB) has recently been proposed by [20–23] because of its easy and quick applicability and the relatively low cost of the bonding agent. This technology, designed to be used for new track-beds as well as to reinforce existing ones, consists of the use of bitumen emulsion (BE), which is poured or sprayed at ambient temperature onto the ballast. BSB has been developed through model-scale and full-scale laboratory tests simulative of field conditions, optimising the main factors affecting the stabilising process and BSB behaviour.

The bitumen stabilisation would be ideally applied during a routine maintenance operation to correct track geometry such as tamping or stoneblowing by a system analogous to that used by the stoneblower when the sleeper is raised during the maintenance process.

Further details of BSB maintainability over the whole service life are reported in [23].

The mechanical behaviour and the durability have been analysed in simulative laboratory tests [20–22], nevertheless the use of BSB needs to be supported by environmental and economical evaluation to highlight the potential benefits in terms of reduction of costs, natural resources employed in the construction and maintenance/rehabilitation and mitigation of negative impacts for the community.

To this purpose, the main goal of this work is to evaluate the economic feasibility and quantify the potential benefits arising from the use of BSB technology as construction and maintenance practice, encompassing the estimation of the costs of the environmental impacts. The results are compared with the costs arising from the application and use of traditional ballast.

This purpose is achieved using a lifecycle approach in which economic and environmental aspects are modelled and integrated [24].

A comparative attributional and process-based Life Cycle Cost Analysis (LCCA) study is performed according to the ISO 15686-5 2008 [25] integrating the contributions and the outcomes of Life Cycle Assessment (LCA) [26,27]. The proposed method calculates and compares the potential economic benefits associated with the construction and maintenance of traditional ballasted and BSB track-bed. The study includes also a sensitivity analysis to ascertain the effects on life cycle costs of possible variation of certain input parameters.

The integrated approach may represent a useful tool in decision-making process for implementing and optimizing track management system, taking into account long-term costs and environmental impacts.

2. Methodology

2.1. Principles of life cycle cost analysis

Life-Cycle Cost Analysis (LCCA) is an effective technique that enables to quantify the costs of alternative options for a given project. Life Cycle Cost Analysis is a systematic process that taking into