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Research article

Life cycle analysis of mitigation methodologies for railway rolling noise and groundbourne vibration

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ABSTRACT

Negative outcomes such as noise and vibration generated by railways have become a challenge for both industry and academia in order to guarantee that the railway system can accomplish its purposes and at the same time provide comfort for users and people living in the neighbourhood along the railway corridor. The research interest on this field has been increasing and the advancement in noise and vibration mitigation methodologies can be observed using various engineering techniques that are constantly put into test to solve such effects. In contrast, the life cycle analysis of the mitigation measures has not been thoroughly carried out. There is also a lack of detailed evaluation in the efficiency of various mechanisms for controlling rolling noise and ground-borne vibration. This research is thus focussed on the evaluation of materials used, the total cost associated with the maintenance of such the measures and the carbon footprint left for each type of mechanism. The insight into carbon footprint together with life cycle cost will benefit decision making process for the industry in the selection of optimal and suitable mechanism since the environmental impact is a growing concern around the world.

1. Introduction

The greatest challenge of railway noise and vibration mitigation methodologies is their relative effectiveness compared with the effort (cost, time, maintainability) needed to place or install them. The first thing that needs to be taken into consideration is the physics behind such phenomena (more details in Appendix 1). Depending on the type of noise and vibration generated, there is always a physical difficulty to control the noise and vibration waves, which require appropriate control mechanisms that are practical and suitable (Fahy, 1998; Canadian Transportation Agency, 2011; Setsobhonkul and Kaewunruen, 2016; Binti Sa'adin et al., 2016a, 2016b). In addition, railway systems usually extend for many thousand kilometres and these noise mitigation implementations are often expensive to be built along all the railway line. In order to select an optimal methodology, there must be a comparison between their effectiveness and the need for maintenance in order to predict the whole-of-life cost necessary for the industry to the implementation of such solutions (Remennikov and Kaewunruen, 2008). In general, the type of mitigation methodology relies on the source of noise and vibration that is being resolved; however, the perception of noise is derivate from an interaction between different sections of the track as shown in Appendix 2 (Remington, 1994; Muller and Kostli, 2008).

The major source in this study is the wheel/rail interface that generates nuisances such as rolling noise, impact noise, curve squeal, flanging noise, and ground-borne and structural-borne vibrations (Thompson, 2010; Craven, 2013; Kaewunruen et al., 2016; Kaewunruen and Remennikov, 2016). The amount of noise generated by this source is highly connected with other problems that the railway track may experience such as track degradation, differential settlement near bridges, loosen and pulverised ballast, and others. The issues of wheel/rail contact have been studied and evolved over the years in order to withstand the dynamic forces imposed and at the same time reduce the friction that is a major responsible for generating such disturbances (Remington, 1979; Remington et al., 1983). With this stated, the mechanism of noise control consists of geometry of wheel and rail with support of other systems such as noise barriers and rail dampers that are going to be analysed in this work.

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The secondary major source of disturbance is from the ground conditions. The dynamic loading condition transmitting from the rails to the ground foundation produces a great amount of energy and affects the surrounding areas of the track in the form of vibration, which can compromise the people living around and the constructions that could collapse under such disturbances. The amplitude of vibration depends on many factors such as the constituent materials of substructure of the railway and their ability to absorb impacts and constitute the ability to damp out due its physical properties (Zapfe et al., 2009; Kouroussis et al., 2014; Connolly et al., 2015; Kaewunruen et al., 2015). The problems around rolling noise and its associated ground-borne vibration have motivated this study. This paper presents the key mitigation methodologies for rolling noise and ground-borne vibration in railway corridor. The mitigation concepts and their life cycle performance have been evaluated and obtained from field data in the literature. This study highlights the life cycle evaluation of such the methodologies in terms of both cost and carbon footprint. The insight into economic and environmental benefits and costs will help rail engineers and managers to improve the environmental management within the rail environment.

2. Rolling noise and its mitigation measures

2.1. Introduction to rolling noise

The measurement of noises on track is usually carried out by placing microphones at a certain distance of the track in order to capture the sound pressure and its sources. The most notorious source within Europe is the rolling noise. When the train approaches the microphone, there is a gradual increase in the sound and a same gradual decrease after the whole train has passed the points of passage. It is important to notice that the sound increases when the bogies passes, indicating the importance of the wheels. The result is a high frequency vibration that is transmitted to the structure of the track creating new sources of vibration and to the air.

The impact in terms of noise and vibration generated by rolling noise is the one that brings greater problems to railway industry because it generates the higher pressures from the public and politicians. Some key factors influencing on the level of the sound and vibration include:

- **Speed**: there is an increase in the sound pressure in higher velocities, which can be a real concern when dealing with higher train speed.
- **Constituent materials and design**: the constituent materials, especially at the wheel and rail interface; the design of components and their area of contact; and how the load distribution to the substructure happens is significant to the final noise produced.
- **Conditions of track**: the lack of maintenance of railway systems leads to deterioration and corrosion of the components. These outcomes increase the roughness of the track that increase the sound pressure level.
- **Weather:** there is not a direct relation between the weather conditions and the rolling noise, but the occurrence of floods in the track can lead to flanging noise due oxidation of the track. Also, increased damping due to higher moisture content could suppress overall sound radiation.

2.2. Life cycle analysis of mitigation measures

To mitigate railway noise and vibration problems, there are several methods that have been studied over a period of time to reduce those disturbances (Pan et al., 2013; Metro Rail Transit System, 2015; Thompson et al., 2009; Kaewunruen and Remennikov, 2016; Kaewunruen, 2016). The most common methodologies that are going to be analysed in this paper are:

- Reduction of roughness
- Noise barriers
- Structure modifications and damping system

The life cycle cost calculation is based on discounted cash flow analysis while the carbon cost is evaluated from carbon accounting of carbon embedment in materials and estimated emissions from fuel and energy used for construction and maintenance activities (Krezo et al., 2016; Department for Environment Food and Rural Affairs, 2014). The discount rate of 5% is used as recommended for governmental projects.

2.2.1. Reduction of roughness

A polished and smooth rail is an important element in reducing railway rolling noise. There are many techniques to maintain the surface regularity of the rails by removing corrugated layers or surface defects of the rails (Fischer, 1979). Rail lubrication is the most known measure to maintain the low friction and the use of products like this are vital not only to reduce the noise produced but also to keep good conditions of rails. When the rail surfaces are allowed to degrade, the vibration levels can increase by as much as 20 dB compared to a new or well-maintained system (Transportation Research Board, 1997; Lakušić and Ahac, 2016).

The use of lubricant must be done carefully: creating a surface that reduces the roughness of the surface but at the same time avoids the derailment. There are many different products available in the market using different chemical compounds and the products with lower pollutant emission are preferable in order to reduce the final carbon footprint of this measure (Goodall, 2007; Fields and Walker, 1977; Edwards, 1996). The use of lubricants is common for curved track maintenance, and compared to rail-wheel life improvement and the noise reduction it offers its costs are relatively low. Table 1 shows the maintenance cost comparison of wheel sets between using and not using lubrication methods (reducing friction type) in a passenger rail environment.

The regular grinding of railways is also an essential part of good track maintenance. The grinding is responsible for the removal of damaged or corrugated layer and it is a regular activity that extends the life of the track, being cost saving as track defects and safety issues decrease. 'Acoustic grinding' implies that an additional grinding is executed dedicating only to noise reduction of rolling. This additional grinding improves the smoothness and helps in noise reduction (UIC, 2012; Thompson, 2014). Table 2 shows the cost assumptions for life cycle study of roughness issue. (see Fig. 1).

2.2.2. Noise barriers

A noise barrier reduces the sound level of receiver by braking the direct line of sound and obligating the noise to diffract with a solid wall, as displayed in Fig. 2. The barrier creates a noise shadow

Table 1
Reduction of Wheel maintenance by lubrication (Behr, 2013; Australian Cooperative Research Centre, 2011).

Track/vehicle condition	Wheel life in (km)	Wheel life in (week)	Annual wheel cost in (£)
No lubrication	170,000	20	1.6 million
Rail lubrication	300,000	35	825,000
Vehicle lubrication	1,000,000	118	250,000