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ABSTRACT

Abatement of noise and vibration at rail turnouts is one of the significant areas of major interest for the rail industry to improve the life standard in vicinity of railway lines. In order to properly implement the measure, the abatement ought to be investigated by considering budget and timeframe limitations; both of which comprise the estimation of costs, setting a fixed budget, and managing and controlling the actual costs of construction and maintenance, along with inspection. In order to reveal the sufficiency of the suppressing application to noise and vibration, whether the environmental impact of the

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abatement meets intended purposes should be examined. In this research, a life cycle costing analysis is adopted by considering the total costs of implementing various measures with different consequences and environmental conditions. As such, the most cost-effective control method for abatement of noise and vibration is identified. More specifically, the lowest total costs over the life span of various kinds of turnout materials, which might help to suppress noise and vibration are revealed, evaluated and discussed throughout the suggested methodology based upon the different aspects of life cycle costing theory.

1 INTRODUCTION

As the standard of living and life quality rise, and as a high level of urbanization seems to prevail in most countries, railway is becoming more and more the preferred mode of transportation to meet the essentialness of urbanization in a desirable way. The noise emitted by this kind of transportation, particularly in densely populated urban areas, becomes a striking concern; moreover, the abatement of the emitted unsettling noise remains one of the major areas of interest for rail industry professionals and governments. As continuing urbanization and population growth are envisaged to add a further 2.5 billion people to the world's current urban population by 2050[1]. Rolling noise, commonly known as train noise is projected to be the major source of railway noise in Europe; across which densely populated cities and urban rail network exist.

Aside from the technical side of why the rail industry needs abatement of the rolling noise, it is also worth noting that many national noise legislations across advanced rail countries (e.g. the UK, Switzerland, Italy) require rail infrastructure managers to take noise mitigation measures. Practically, the most preferred choices are track-related measures (e.g. rail dampers), vehicle-related measures (e.g. brake shoe retrofitting), measures at the receiver (e.g. double glazing) and measures in the propagation path (e.g. noise barriers)[2]. The costs of these different kind of measures vary, and crucial parameters when making a choice between them are often cost, operational life and reliability[3].

As a result, various acoustic-based research studies have begun to appear in engineering literature, over the last few decades. This paper presents an overview of noise propagation mechanisms, impact of climate of a few track-related measures against noise, and a life cycle costing (LCC) analysis. As the research is aimed at investigation of noise emitted from rail turnouts, noise mitigation methods on turnouts are described, and their effectiveness is evaluated.

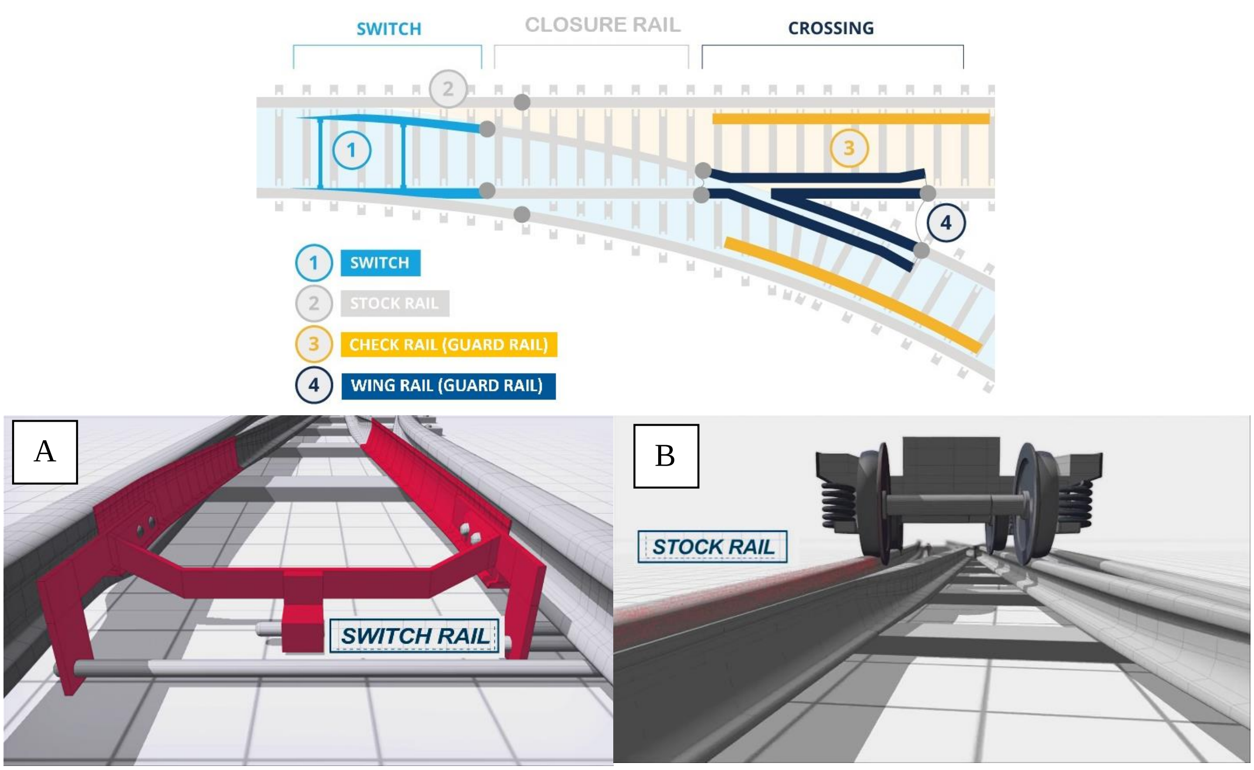
2 RAIL TURNOUTS

Railway turnouts, also known as *switches and crossings* in British jargon, are a mechanical rail infrastructure that composes of two or more movable rails to direct rolling stock onto its appointed route. Since the trafficability of the rail is only provided by means of rail turnouts, the rail operation relies indispensably on them[4]. In countries having a high railway density, it is stated that there is about one turnout per 1.18 track miles[5]. Additionally, as turnouts are exposed to high static and dynamic forces, both of which make them more susceptible to damage, intense maintenance is required to ensure a smooth rail operation, and unacceptable levels of noise and vibration (N&V) might often be created[6-8].

As seen in figure 1, rolling stock generally negotiates multiple turnouts, simultaneously, on a single junction; additionally, multiple trains may use the same junction, simultaneously, depending on traffic capacity of junction. This is highly likely to scale up noise propagation in regions without abatement measures in place. Therefore, it could be deduced that rail turnouts require a dedicated technical investigation to abate the noise, in relation to network density.

Figure 1 A widely prevalent rail junction with different kinds of turnouts

Although a wide variety of switch materials and crossing noses (also known as frog) exist to meet every track requirement, from light, medium to heavy traffic, the common characteristic of interaction between track and wheel is frequently identical.



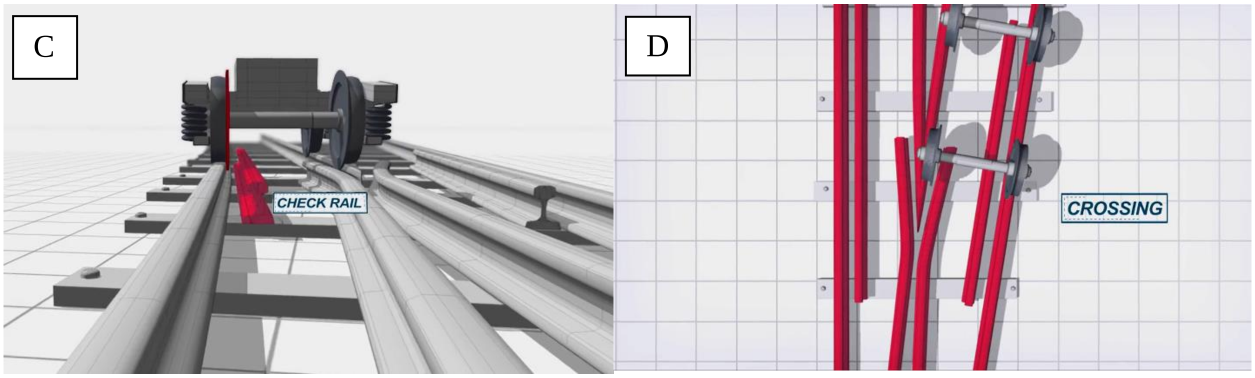


Figure 2 Fundamental elements of a rail turnout

Wheel-rail rolling noise, the dominant source of noise from railway operations, is created by vibrations of the rail and wheel which are excited at their contact by irregularities of the track surface[9]. This kind of noise presents despite the low speed that is obligated during passage of turnouts. In addition to this, the unique design characteristics of turnouts give rise to further noise sources.

Turnouts are mainly engineered with a switch and a crossing, both of which include unique turnout components, as illustrated Figure 2-a. In addition, some turnout components are a further source of noise and vibration during passage of a rolling stock. That is, aside from wheel-rail rolling noise, the impact noise generated by such discontinuities of turnouts as crossing nose (see Fig-2b), switch (see Fig-2c), rail joint (see Fig-2d) could be pronounced[8,10,11].

By virtue of the nature of tight curves at crossings, high pitched tonal noise, which is termed as squealing, is generated as wheels of a rolling stock traverse curves of tight radius (see Fig-2d). Rolling stock frequently engages, at least, with a few consecutive turnouts at depots, sidings, junctions and stations, which results in high frequency of noise - an acute cause of annoyance to those being adjacent to such rail locations[12].

3 NOISE ABATEMENT MEASURES

In railway engineering, certain cases and circumstances that adopt various noise abatement measures require a different level of priority. To appreciate the impact of noise reduction, different techniques should be applied, considering the characteristics of a turnout/turnouts (e.g. design of sleepers, switch mechanism, presence of check rail and wing rails, proximity to an urban area). Applicable noise abatement measures might be categorized into four different groups, namely; reduction at source, reduction of noise propagation, isolation of receiver, and economic measures and legislation. As this paper investigates some noise-mitigating components, railway noise at source, generally emitted from a nearby location close to contact patch between the track and the wheels of the vehicle, will be discussed.

One of several noise management practices is the use of noise barriers (see Fig.3-A) alongside the railway track. Barriers reduce noise energy, in the form of sound waves carried throughout air, by preventing direct propagation between the source and the receiver. The level of noise mitigation provided by noise barriers relies on: its height, length, design, position relative to the source and receiver, and the soil on which the barrier is placed[13,14]. Noise barriers are found out to abate noise level by up to 10 dB and are claimed to be an expensive solution to the mitigation of noise[13-15]. As the design of noise barrier varies, it is difficult to estimate total burden of a turnout to rail operator. Therefore, the study tends to investigate jointless turnout instead, which start to be used .

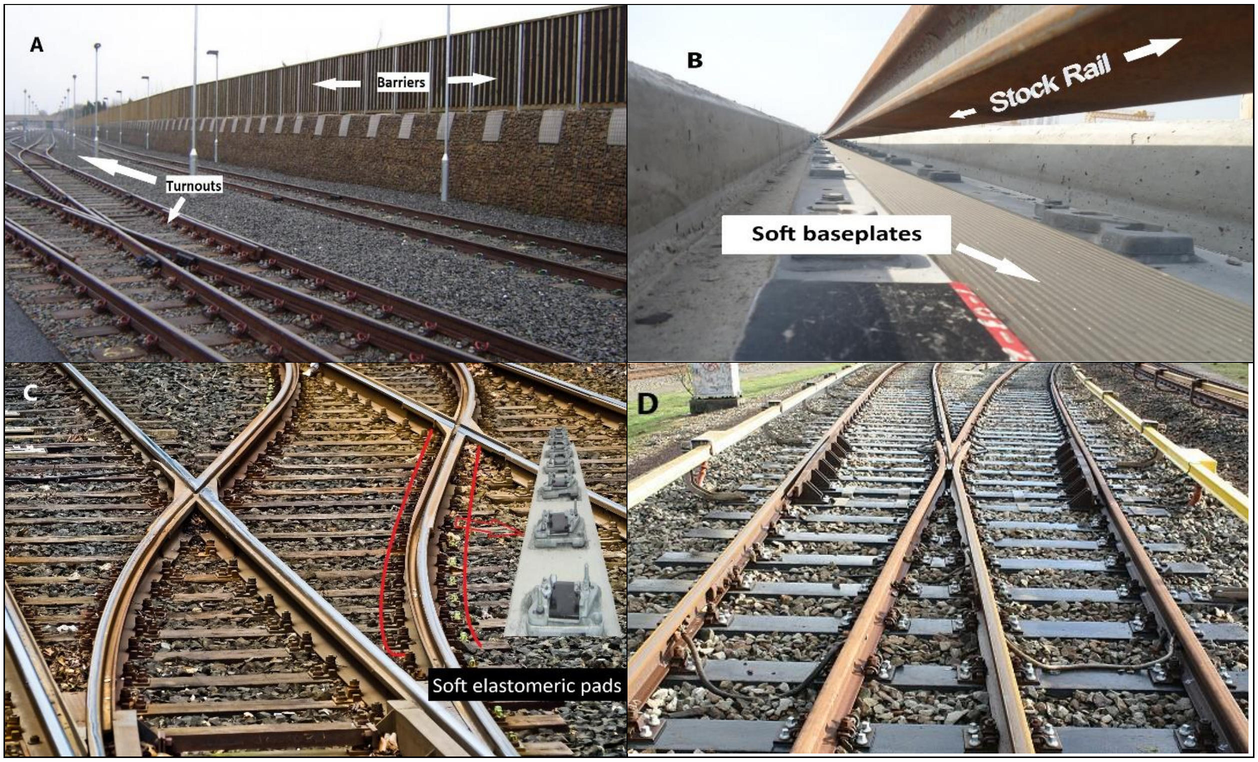


Figure 3 Noise and Vibration Mitigation Strategies for rail turnouts

Soft baseplates and elastomeric pads (see Fig.3-B and Fig.3-C) ensure the distribution of load by rolling stock over a larger surface, the elimination of load concentrations and the absorption of uneven contact patch between support and rail. This proves essential to reduce shocks and vibrations in rail turnout systems[16]. Yet, due to its design (click mechanism), the ingress of dirt and water between the rail and its support might be present and affected by climate patterns[17-19].

Composite sleeper application (see Fig.3-D) are ideal for ballasted railway tracks, e.g. switches and crossings. It is asserted that they can be a cost-effective, eco-friendly and long-term solution, due to its long-life span and durability, along with the fact that recycled materials are often used to produce composite sleepers[20-22].

4 METHODOLOGY

The study adopts Life-Cycle Cost Analysis (LCCA) as an engineering economic method that enables existing transportation assets (turnouts) to be quantified according to the differential costs of alternative investment options. LCCA gives rise to the estimated total cost of turnout ownership and might identify the best option among alternatives or determine the viability of a purchase.

To compare cost and revenue occurring over multiple years to a common metric (present values), discounting, as a commonly used method, is used. In other words, the net present values (NPV) of N&V applications are calculated in the following equation[2,23].

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} \quad (1)$$

where

$T = period\ of\ time\ (years)$
$C_t = cost\ of\ application$
$r\ = discount\ rate$

NPVs of the abatement applications often include the total cost of operation, maintenance, replacement, and disposal values. Thus,

$$NPV = I + O_A + M_A + R_A + O_{NA} + M_{NA} + R_{NA} + D + \mathrm{R} + \mathrm{C_C} \quad (2)$$

where

I = initial or investment cost
O_A = the present value of annually recurring operating cost
M_A = the present value of annually recurring maintenance cost
R_A = the present value of annually recurring repair cost
O_{NA}= the present value of non-annually recurring operating cost
M_{NA}= the present value of non-annually recurring maintenance cost
R_{NA} = the present value of non-annually recurring repair cost
D = the present value of disposal costs
R = the present resale value (recycling)
C_C = Cost of climate effect

A result of equation 2 is illustrated in Figure 4 which only shows the cost intervals of a noise mitigation strategy. In other words, the mitigation strategies might draw unique length of one lifecycle in years, and require unique initial cost, annual costs and non-annual costs. These costs are revealed to be affected by environmental patterns, as rail turnouts and engineering applications for them are quite vulnerable[24,25] .

In order to determine the time and the other elements required in the computation process, table 1 is prepared. There are 3 kinds of fundamental costs; namely, initial (I), maintenance (M_{NA}), and climate impact (revised cost of maintenance due to harsh climate conditions). The value assigned to the discount rate (r) plays a significant role in the use of discounting. Inaccuracy in the estimate of NPV is likely to stem from an incorrect value used for the discount rate. Various European government agencies, in general, provide a suggested discount rate. To identify total maintenance cost ($M_A + M_{NA}$), three discount rates are assigned from 4 to 6 with an interval of one percent, as per the suggested rates in the literature and official reports[26-29].

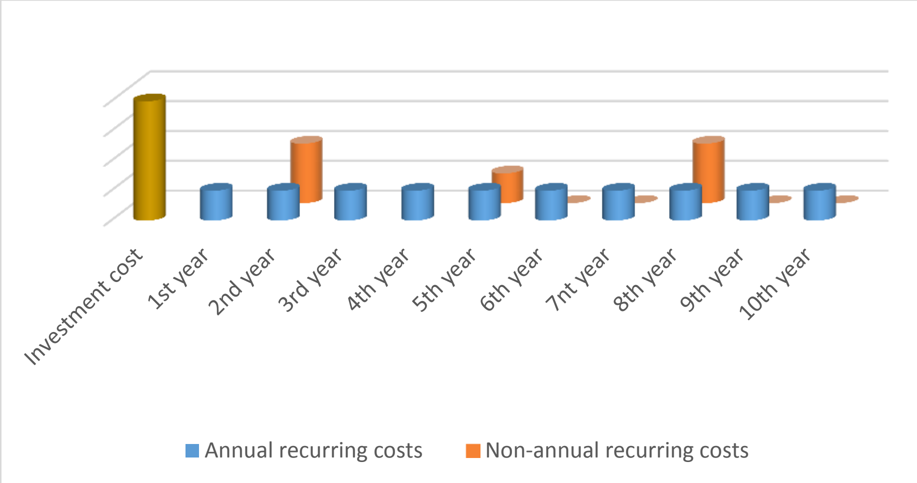


Figure 4 Illustration of lifecycle costs for any possible mitigation strategy of 10 years

Table 1 Various kind of cost and lifespans of the abatement applications for a case study

		Cost and Time Identification (USD & Year)			
		Jointless Switch	Soft baseplates	Elastomeric pads	Composite sleeper
Costs	Initial	600,000	610,000	540,000	680,000
	Maintenance ρ	-	8,000	1,350	7,350
	Climate impact ρ	-	37,500	10,700	14,700
Time	Lifespan (years)	50	25	10	50
	NARC span (years)	10	1	0.25	2
	NARC span (years) for climate	8	0.25	0.25	1

5 RESULTS AND DISCUSSION

Based on the equations in methodology, and using current cost values per a standard left/right handed turnout of 20m, an overall assessment was made evaluating both the NPVs and effectiveness of noise mitigation options. In this frame of this research, an attempt was made to analyze to what extend the impact of discounting values presents on managing rail turnouts with N&V mitigating applications throughout their all lifespans. The intention, herein, was to compare the applications with particular discounting values in an EU country to the same applications in the other member countries with a different discounting value.

As seen in Figure 5, three different (r) values, i.e. 4, 5 and 6, are investigated. Adopting high values of NPV (e.g. in the UK) offers more cost effectivity and, thereby, incentive to rail operators. Depending on the amount of NPVs and lifespans of the abatement applications, it seems to be that the NPVs with a r-value of 6% are 15% to 25% lower than the values with a r-value of 4%. The NPV (total material, maintenance, labor and possession costs) of softplate

ρ annually calculated average cost

application is observed to be the highest burden, whereas composite sleeper poses the cheapest option to the rail operators.

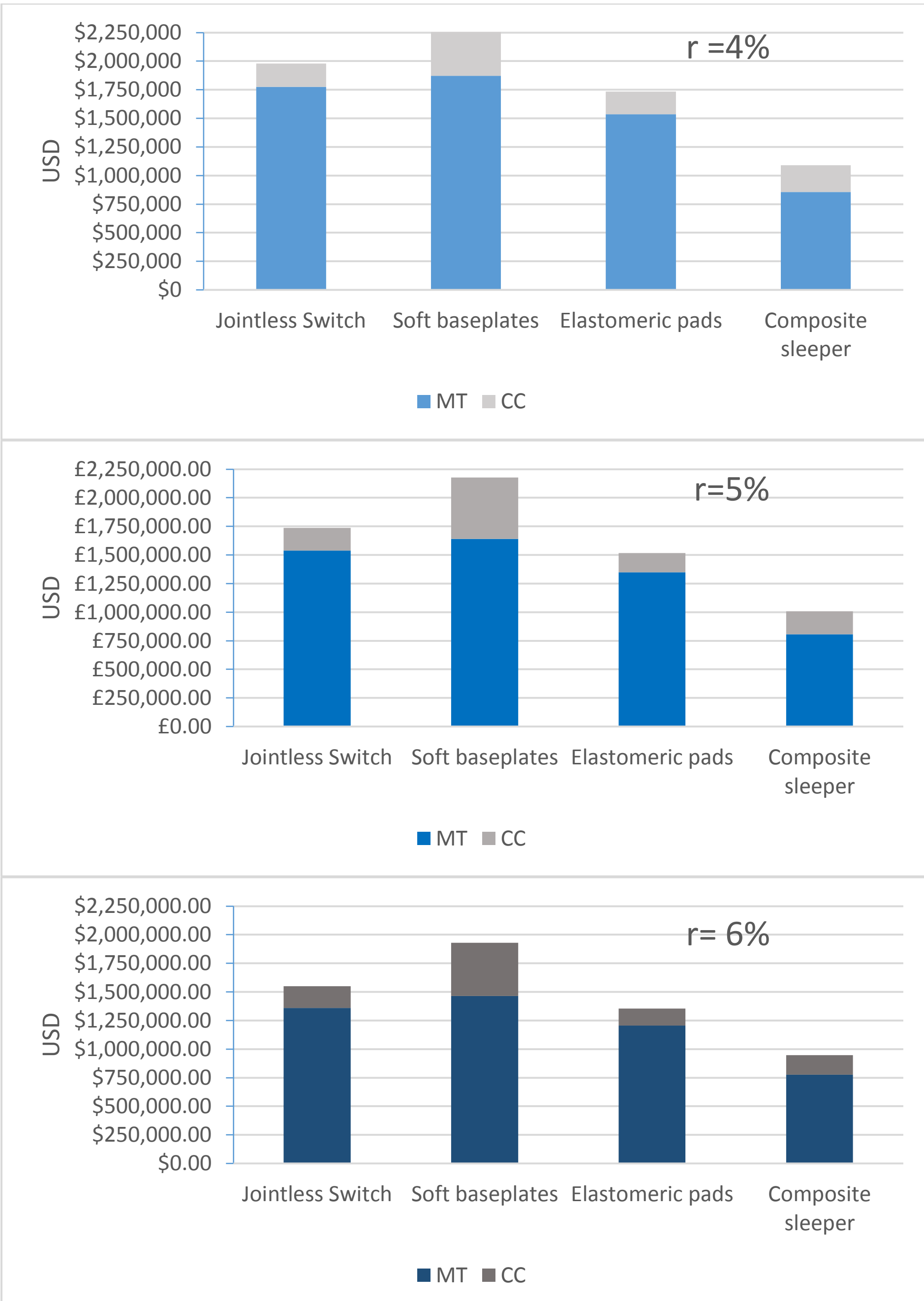


Figure 5 Distribution of NPV values of various N&V mitigation methods through different r values

As can be seen in Figure 5, bars were created with two elements, one of which is M_T (colored with blue), representing a total of M_A and M_{NA}. The impacts of climate (C_C) by each chosen method was added on M_T. It is identified that all abatement methods are affected by climate in various ways, likely due to material characteristics. The application of soft baseplates on rail turnouts is observed to show the most vulnerability to the climate, alongside lifespan. On the other hand, elastomeric pads seem to better tolerate adverse effects of climate while performing maintenance and rail operation.

It is also worth noting that elastomeric pads do not endure extreme heat; moreover, the service live of this material is reduced by half during service life under such conditions[30]. Considering this, elastomeric pads, one of the resilient fastening systems, might be identified as currently being a costly solution to N&V for rail turnouts.

6 CONCLUDING REMARK

A European railway project design that quite often requires noise and vibration abatement in urban areas needs different priorities for consideration. In this research, Life-Cycle Cost Analysis (LCCA) has been adopted to address various costs of some N&V for a specifically designed, standard switch and crossing. The suitability of four N&V abatement strategies, namely; jointless switch, soft baseplates, elastomeric pads and composite sleepers, were analysed by considering budget and timeframe limitations, which consist of constructing, inspection and maintenance costs and time allocation, while also aiming at identifying environmental impact on total cost during their lifespans.

Owing to its high cost values and the inherent vulnerability to extreme heat, soft baseplates are found not to be cost effective. However, both elastomeric pads and composite sleepers are observed to be relatively economical for rail operators. Considering the noise reduction level of the two most cost-effective applications, it might be expressed that elastomeric pads offer to be the most feasible method over the other as N&V abatement provided through them is quite striking (reducing noise by about 3-6 dB). On the other hand, it is found that discounting rate across the EU results in a fluctuation of 15-20% in NPVs of the N&V applications.

7 ACKNOWLEDGEMENT

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