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Article

Life Cycle Cost Evaluation of Noise Control Methods at Urban Railway Turnouts

Rodrigo Tavares de Freitas [1] and Sakdirat Kaewunruen [2,*]

[1] Department of Civil Engineering, University of São Paulo, 13215720, São Paulo, Brazil; ro.tavaresf@gmail.com
[2] Department of Civil Engineering, School of Engineering, University of Birmingham, Birmingham B15 2TT UK; s.kaewunruen@bham.ac.uk
* Correspondence: s.kaewunruen@bham.ac.uk; Tel.: +44-121-1414-2670

Abstract: The railway industry focus in the past years was to research, find and develop methods to mitigate noise and vibration resulted from wheel/rail contact along track infrastructure. This resulted in a wide range of abatement measures that are available for the professionals of the industry today. However, although there are many options in the market, their practical implementations depend upon general constraints that affect most technological application in the engineering world. The progression of these technologies have facilitated the selection of more adequate methods for each best case scenario, but further studies are ought to be made to proper assess if each one is fit for their purpose. Every method implementation must be analyzed through budget and timeframe limitations, which includes building, maintenance and inspection costs and time allocation, while also aiming to meet different benefits, such as environmental impact control and wear of the whole infrastructure. There are several situations and facilities in a railway project design that need noise and vibration mitigation methods and each design allocates different priorities for each one of them. Traditionally the disturbance caused by railways to the community are generated by wheel/rail contact sound radiation that expresses in different ways, depending on the movement of the rolling stock and track alignment, such as rolling noise, impact noise and curve noise. More specifically, in special trackworks such as turnouts, the main area of this study, there are two noises types that must be evaluated: impact noise and screeching noise. With respect to the second, it is similar to curve squeals and, being such, its mitigation methods are to be assigned as if it was to abate curve squeal in turnouts and crossings. The impact noise on the other hand, emerges from the sound made by the rolling stock moving through joints and discontinuities (i.e. gaps) that composes these special components of a railway track. A life cycle analysis is therefore substantial for this reality and in this case will be applied to Squeal and Impact Noise on Special Trackwork. The evaluation is based on a valid literature review and the total costs were assumed by industry reports to maintain coherency. The period for a life cycle analysis is usually of 50 years, hence it was the value assumed. As for the general parameters, an area with high density of people was considered to estimate the values for a community with very strict limits for noise and vibration.

Keywords: railway noise; railway vibration; squeal noise vibration; screeching noise vibration; impact noise vibration; abatement; mitigation; life cycle analysis

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1. Introduction

The railway industry focus in the past years was to research, find and develop methods to mitigate noise and vibration resulted from wheel/rail contact along track infrastructure. This resulted in a wide range of abatement measures that are available for the professionals of the industry today. However, although there are many options in the market, their practical implementations depend upon general constraints that affect most technological application in the engineering world. The progression of these technologies have facilitated the selection of more

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adequate methods for each best case scenario, but further studies are ought to be made to proper assess if each one is fit for their purpose. Every method implementation must be analyzed through budget and timeframe limitations, which includes building, maintenance and inspection costs and time allocation, while also aiming to meet different benefits, such as environmental impact control and wear of the whole infrastructure [1].

There are several situations and facilities in a railway project design that need noise and vibration mitigation methods and each design allocates different priorities for each one of them. Traditionally the disturbance caused by railways to the community are generated by wheel/rail contact sound radiation that expresses in different ways, depending on the movement of the rolling stock and track alignment, such as rolling noise, impact noise and curve noise. More specifically, in special trackworks such as turnouts, the main area of this study, there are two noises types that must be evaluated: impact noise and screeching noise. With respect to the second, it is similar to curve squeals and, being such, its mitigation methods are to be assigned as if it was to abate curve squeal in turnouts and crossings. The impact noise on the other hand, emerges from the sound made by the rolling stock moving through joints and discontinuities (i.e. gaps) that composes these special components of a railway track.

From the broad spectrum of methodologies to mitigate this specific sounds, from rolling stock to infrastructure measures analyzed and already put in practice in the railway industry, some already stands out due to this previous experience. For railway impact noises, jointless switches and swingnose crossings are the most recommended, as for curve noises in these components, such as squeal and screeching, rail friction modifiers, flange lubrication and wheel dampers happens to be mostly commonly used. Recent studies shows that mitigation methods are more efficient if aimed to the noise source, i.e. the wheel/rail contact interface mostly, rather than having specific infrastructure for it. Still, special bogie design presents significant results in the general abatement of noise generation.

As sound is seen as an environmental impact, which can cause hearing damage if its level are high enough or disrupt daily activities and living conditions even if low, its tolerance by the neighborhood and overall communities varies from site to site. Engineers and managers involved in the railway industry often receive noise complaints all around urban areas and to avoid such there are limits already established in order to give a standard level of comfort for the stakeholders, independent of people complaints. Besides, having a manageable noise and vibration abatement methodology impairs indirectly in avoiding other maintenance related problems which are as critical as noise and vibration [2], [3]. Thus, railway track maintenance and sound related mediation can be correlated as two parts of the same condition, and fixing or repairing one can affect the other. The effects of vibration can result in rapid track degradation, ballast pulverization and track settlements, alongside ballast dilation at turnouts and crossings, which can on the other hand all deteriorate the level of railway noises if not solved [4].

Therefore, to properly assess how to conduct assets life cycle involved in this objective and develop a life cycle cost evaluation a cross cutting analysis is ought to be made, considering the measures and its effects in maintenance and railway operators finance. Thus, this work will rely on a thorough study which starts from understanding the facilities, i.e. the special trackworks involved, and its noise related problems and finishing with their economic impacts based upon a life cycle costing analysis, with regards to extreme weather conditions investigation. The methods for noise control at railway turnouts and crossings are highlighted in this paper and their effects on the maintenance cost of the whole special trackwork components are evaluated. Moreover, the life cycle costs are presented through analysis of industry reports and past studies review, which allowed a cross cutting economic analysis of the methods implementation, operation and maintenance.

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2. Materials and Methods

2.1. Turnouts & Crossings

The proposed study has as a major subject in railway engineering the special trackwork systems that are essential components in railway infrastructure, since they provide flexibility to traffic operation. More specifically, this work will focus on Turnouts, basically composed of switches and crossings, which, according to maintenance databases, stands for one of the major causes of track failures and defects, requiring high maintenance costs [5]. Hence this topic will describe its components and its effects on railway noise generation sources, as well as its impacts on life cycle costs.

Turnouts are comprised of a switch panel and a crossing panel, connected by closure panel in between. As part of each of these panels, minor components integrate the whole of the turnout and each of them can be seen in Figure 1.

Because of its complexity, the interactions between the train and the rail in these elements are the principal issue in the design and maintenance of railway systems and thus these are among the most sensitive parts of the railway systems. The wheel/rail contact changes along the turnout, transferring the interaction from the stock rail to the switch rail and, finally, to the crossing nose through the closure rails.

Due to this level of interaction and quantity of components, these special trackworks are involved in noise propagation in railways [6]. Particularly the type of noise involved in this elements are the impact noises generated from joints and also the screeching noise, that will be further explained in the next section of this report.

2.2. Noise related problems

In rail systems, wheel/rail interaction is in most of the cases the primary source of noise. The ones generated by this contact are generally categorized as squeal, impact or roar noise [7]. Each of these have their particularities and occurs depending on different causes and exhale different effect in railway tracks and general infrastructure. Even though not all of these types affect turnouts and crossings, especially the roar noise, is a good exercise to acknowledge their existence to have a broader comprehension of the whole subject.

Squeal, or screeching, noise relates to the intense noise, occurring with one or more tones, generated by railways when vehicles round curves of small radius [7]. When the rolling stock enters a curve its wheels cannot keep their tangent direction since the axles are strict to the railway alignment and track geometry, so the intense contact of this special condition produces the squeal of a curve. The impact noise, on the other hand, is a term that describe the banging noise due to several situations, such as: coupling and decoupling vehicles and marshalling yards, discontinuities in the rail or flat spots on the wheels. The sound generated is therefore due to a quick change in the dynamics of the wheel/rail interaction related to its vertical velocity, this results in a large force at the interface that causes vibration and irradiate sound [8].

Finally, roar noise or rolling is one that is always present in railways since it derives from tangent continuous welded rail with absence of wheel flats. It is possible to simplify it as due to basic friction between rail and wheel, due to roughness on wheels and rails. The movement of the train along the track pushes the wheel to either rise up over small bumps or push the rail down to move out of the way. This interaction resumes how the roar noise is generated.

In summary, to reduce each of these types of noises, some action plans are recommended, as noted by [7]:

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Squeal noise

- Reduce lateral creep during curve negotiation
- Alter friction-creep characteristics at wheel/rail interface
- Minimize resonant wheel response
- Block sound radiation

Impact and rolling noise

- Minimize wheel tread and rail surface discontinuities and roughness
- Prevent wheel tread discontinuities
- Minimize wheel/rail response to surface irregularities
- Block sound radiation

3. Results

3.1. Mitigation Measures

The most general approach to noise control is reducing and limiting the generated noise by targeting their principal cause. This principle is proven effective as a strategy as it is one of the most basic engineering problem solving approach, so it also applies to railway engineering.

In special trackworks, as the wheel passes through switches and its other components it encounters gaps that provokes as a majority impact noises, and also squeal (or screeching, in the case of turnouts and crossings) due to the small curves that composes these elements. *[9]* To prevent or mitigate this condition a plethora of methods is available, which are listed below:

- Jointless switches;
- Resilient wheels;
- Noise barriers;
- Vehicle skirts;
- Rail grinding;
- Top of rail friction modifier - lubrication;
- Wheel damping;
- Welded rail

The following sections will give a broader understanding of some of these methods, that you then be evaluated through a life cycle cost analysis in section 5.

3.1.1. Resilient Wheels and Wheel Damping

Resilient wheels are an all-around mitigation measure that reduce most types of noise generation. This kind of wheels are structurally different than the regular ones by having the metal tire isolated from the wheel hub by an elastomeric material, see Figure 2. This not only reduce roar and squeal noises by reducing the vibration of wheels, but also recent studies on these types of wheel show that impact forces are lowered by up to 40% [7].

Aside from that, even though wheel/rail damping is a specific measure for rolling noise, their use showed promising results (see table 2) for reducing impact and squeal noise. The principle of a damping system is that it abates the vibration waves along the rail and hence reduce the noise emitted.

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3.1.2. Correction and Maintenance of Rail Profile

Another preferred option is maintaining and correcting the rail profile, being effective in the frequency range up to 50 Hz, reaching reductions close to 10 dB. With this in mind, railway grinding have been in use for several years now, with a broad range of specific purpose works such as grinding of switches and crossings and removal of defects and specific sites harder to reach by other mitigation methods. The process of grinding a rail produces a much more consistent profile, transversely and also longitudinally and can remove shallower depths of metal than most of other measures, such as milling and planning, which increases rail life. Along with that, acoustic grinding stands as a much better developed method for this target. For this reason, rail acoustic grinders are the most used equipment for corrective maintenance of railways [2].

Alongside that, the usage of a ballast mat is beneficial too when thinking about as derivative approach of maintaining rail profile measures. Through this method, soil vibration levels are reduced substantially by a scale of 2 to 5 dB in the range of 40 to 200 Hz frequencies. When used in conjunction with other measures such as track resilience improvements, rail profile correction can result in valid rail and soil vibration reduction by numbers of 7.5 for rail and 10 dB for soil [10].

3.1.3. Jointless Switches

More specifically, the gaps that are part of the turnouts can be described physically by its width, the step height (vertical level difference on either side of the gap) and the dip angle, which is caused by the rail edge that is pushed down by the wheel [11]. Further investigation already showed that the noise is mostly increased by variations on the depth and the dip angle of the gaps and the velocity of the train relates to the sound emitted by a single joint with a function of 20 log V, which means that a train running at 80 km/h is emitting about 6 dB more than one at 40 km/h [12]. So an efficient measure to mitigate the impact sound alongside the ones already highlighted is to develop a better calculated design for these components of the special trackwork.

Furthermore, using joints that smooth the interaction of the wheel changing from one rail to another have been already proven that reduces the impact in railways, especially in turnouts. Hence, recent designs of track have been often composed of trackworks with bonded joints or insulated joints with bonds and bolts. Although, having a well planned maintenance program is nearly as much effective [7].

Finally, for rattling noises, jointless switches are state of the art nowadays, reducing the noise emission by 2-4 dB [8]. This is applied especially for railways in which speeds over 40 km/h are expected to be achieved in this elements. In these cases, the turnout length is much longer to allow this level of velocity.

3.1.4. Friction Modifiers

Since switches are also composed of small radius curves, which depends on operating speeds and may vary from 90 and 2000 m, the high pitch noises that occur in these elements have the same origin as the ones in general curves. However, it's important to have clear which type of noise is more evident, as there can by flanging noises and curve squeal noises in a switch as both have different solutions depending upon their intensity and economic feasibility. The wheel squeal noise is related to a lateral stickslip between the vehicle and the rail and is a very high tonal noise related

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to wheel frequencies, as for the flanging noise it can be described as a non-tonal which sound more life high level noises of the consonants 'f' and 's'.

These types of noises can be solved by applying friction modifiers or lubrication, although the friction coefficient shouldn't reach low values as it would provoke adhesion problem for traction and even braking, the last being very critical in special trackworks. So, friction modifiers are designed to control friction rather than reducing it to zero, and are applied on top of rail as this is the most critical part of the wheel/rail contact and its use aids the reduction of wear and corrugation in curves alongside reducing squeal noise and flanging noise, when applied at the wheel flange and against the gauge corner of the rail or at the check rail.

As for practical feasibility, track mounted systems are state of the art machinery nowadays, composed of wiping bars, drains and water spraying. In this procedures, the modifier is applied on top of the head of the inner rail and also, when suits the track maintainer, between the wheel flange and gauge corner of the outer rail as it aids to reduce flanging noise [13]. Aside from that, vehicle mounted systems also exist, but represents a very costly measure yet.

Despite having many benefits from using friction modifiers in railways, precautions should be made since there is a variety of defects that correlate to their poor usage: wheel flats and loss of traction at curves due to grease on top of rail, variation of properties of lubricant such as viscosity and its effectiveness due to temperature and aging, increase in wear on the wheel and rail by using water based lubricants that can also freeze or evaporate on harsh weather conditions [7]. Anyhow, the mitigation of squeal and flanging noise in switches can help reduce the amount of sound emitted in this facilities by 5 to 20 dB [14].

Aside from that, even more important is the cost that this measure implies on the railway operation. Having no use of lubrication along the life cycle of the track effects strongly the wheel life as can be seen in the study made by Larke and Reddy. Furthermore, the use of vehicle lubrication stands out as the most efficient method for expanding wheel life in railway maintenance.

3.1.5. Other Methods

Is worth pointing out that an ideal geometry on turnouts, especially of the crossing nose, helps avoid loss of contact between the wheels and the rail at these elements, hence the effects of impact forces generated due to this conditions are generally lower than is regular conditions of degraded track or track geometry [10]. Furthermore, noise barriers are considered to aid establish noise control everywhere as they are cheap infrastructure with a maximum height of 2 meters above rail head. In total, 280,000 km of the European network is fringed by these barriers which culminates in an annual cost of 70,000 euros per km for noise barriers with a total annual cost for Europe of 20 billion euros, which is called the equivalent barrier cost [15].

There are two main alternatives for noise barriers. The normal ones, are built at distances of about 4.5 meters from the track axis, being as high as 4 meters above the railhead. The second type, named low-close barriers, are usually at 1.7 meters from the axis and with heights reaching only 1 meter.

A summary of most wheel/rail treatments for noise control, with their expected outcomes in the industry use over the three types of noises exposed here, can be seen at the end of this section.

3.2. Methodology

In order to properly access the most feasible options in practical and economic terms a life cycle costing analysis will be followed based upon the different aspects of each method and their impacts. Railways are already known as highly costly to construct and operate, but maintenance also plays a very important part of its life cycle as it helps stretch the durability of its components. Because of all of these aspects of railway, is vital that maintenance walks alongside noise control measures and each supports the other so a secondary improvement and solution as noise abatement measures don't work as a threat to the economic viability of railways.

According to LCC theory, the decision of opting for one option over another should be made in a way that it results in the lowest total costs over the life span of a determinate process, which in this case is the whole of the railway system [16]. Railways already operate with restricted budgets even without having to consider noise control, so following an action plan that proves to be an efficient method to calculate the whole network costs of implementing such measures with different consequences is obviously very important [17].

Maintenance of the wheel/rail interface have two fundamental aspects, the control of friction and control of wheel and rail profile, which thankfully correlates with the approach for abating sound emission as already seen in section 4. Even though the stake holders would enjoy having a railway in a perfect state, the key motivation for maintaining either rail and freight is economics, so it's more about how economically the railway operates than the state of it, although some level were already mentioned to be necessary to reach [18].

In recent studies, life cycle cost analysis shows that the overall costs of noise control measures at source are lower than the ones of noise barriers or façade insulation only. These barrier costs evaluated (pointed as the equivalent barrier cost) can be compared to the total annual cost of track maintenance and renewal, which are 70 billion euros, as around 30% of this [16].

3.3. Results and Discussion

3.3.1. Assumptions

Based on industry reports, assumptions from the railway industry have been addressed. The benefits acquired for each method can be seen below, as well for the cost assumptions for the whole life cycle evaluation, in Table 3. The discount rate considered in all projections is of 5% along 50 years of cash flow.

- Benefit for Track and Rail based Lubrication: £3,500.00
- Benefit for Resilient Wheels: £3,000.00

The values were assumed taking into account that routine maintenance is often undertaken to a fixed cycle whose period is previously defined by rail operators and maintainers and determined by terms of the passage of traffic.

3.3.2. Friction Modifiers

In order to compare more efficiently the viability of using lubricants in railways special trackworks the two categories of friction modifiers mentioned before were compared using the assumptions exposed above.

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The outcome of this analysis show that even though vehicle based lubricants are considered a state of art method, with higher initial costs (£30,000 compared to £20,000), the benefits of choosing this measure stands out by thinking in the long-term. The maintenance of this method is also cheaper and the replacement period is wider due to the conditions applied to this.

3.3.3. Noise Barriers

Again, two types of the same methodology were compared regarding their cost life cycles. The low-close noise barriers are already a good alternative theoretically as they can be installed nearer the track and in most locations with similar results to noise abatement of conventional ones (see Figure 7).

The results show that the low close noise barriers are a better option across a long period of analysis. The high investment costs for the conventional barriers blocks the viability of using them for all the extension of track, but the conditions of which the properties of each type works better should be considered. In twin tracks, low close barriers aren't as effective and the use of conventional ones should be studied. Since special trackworks are complex systems, the feasibility of having to opt to one over another might be a downside to this method.

3.3.4. Jointless Switches

This is the most specific measure for impact noises, hence there should be special considerations regarding it's feasibility as the reduction of noise vibration acquired by this method is substantial (see Table 2). The final costs seen in Table 5 show that this method, as it is applied by a state of art technology, is the most expensive amongst the other ones and therefore should be analyzed as an alternative for only when is strictly necessary to properly abate the impact vibration due to the special trackworks components.

3.3.5. Rail Damping

[20] As rail damping can be used as a complement to other methods, with reasonable results, it is important to know if this addition to railway maintenance methodology is feasible economically speaking.

The costs to apply this technology aren't as high as jointless switches, hence it can be used in conjunction with more basic options such as resilient wheels and friction modifiers. The outcome of this relation is a good reduction of both impact and squeal noises (see Table 2 for values).

3.3.6. Resilient Wheel

Finally, resilient wheel already are considered an efficient and cheap method for reducing railway noise emission, as seen by Kurzweil, 1983, and the results prove that previous knowledge. Being such, a good option is to complement other methods with this, since wheels aren't usually a responsibility of the railway contractor, being delegated by the operators of the trains.

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3.4. Figures, Tables and Schemes

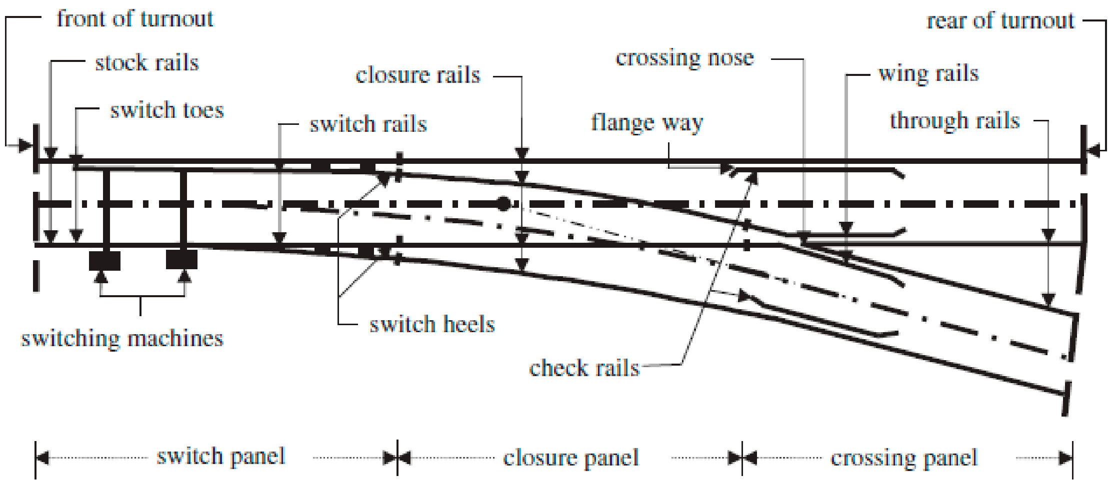

Figure 1: Components of a Turnout [5].

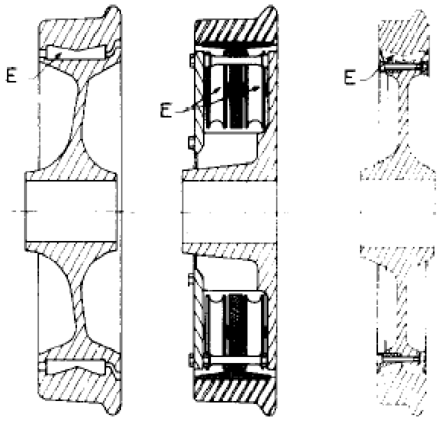

Figure 2: Various resilient wheels. E stands for the location of the elastomeric damping material [7].

(a) (b)

Figure 3: Examples of Rail damping systems [21].

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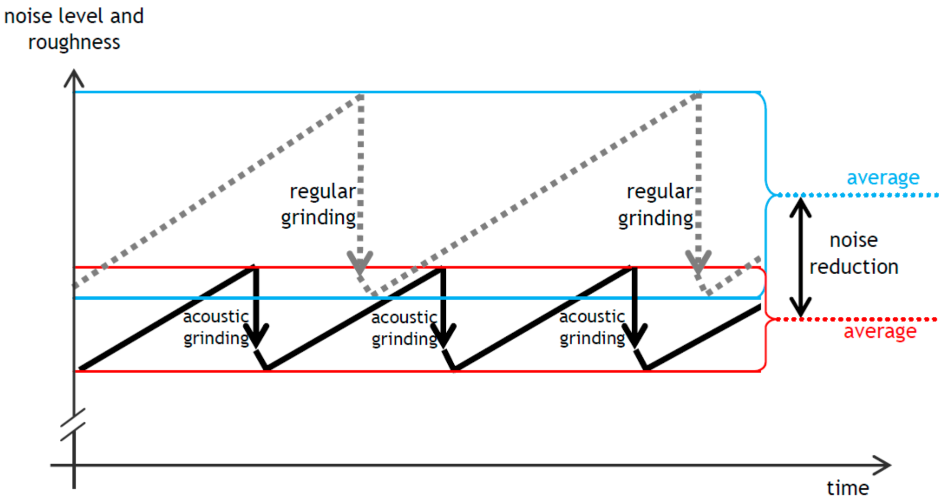

Figure 4: Effects of maintenance grinding and acoustic grinding along time [21].

(a) (b)

Figure 5: Examples of switches with swingnose crossing and jointless switches [21].

(a) (b) (c)

Figure 6: Example of Rail based and Vehicle based lubrication [19].

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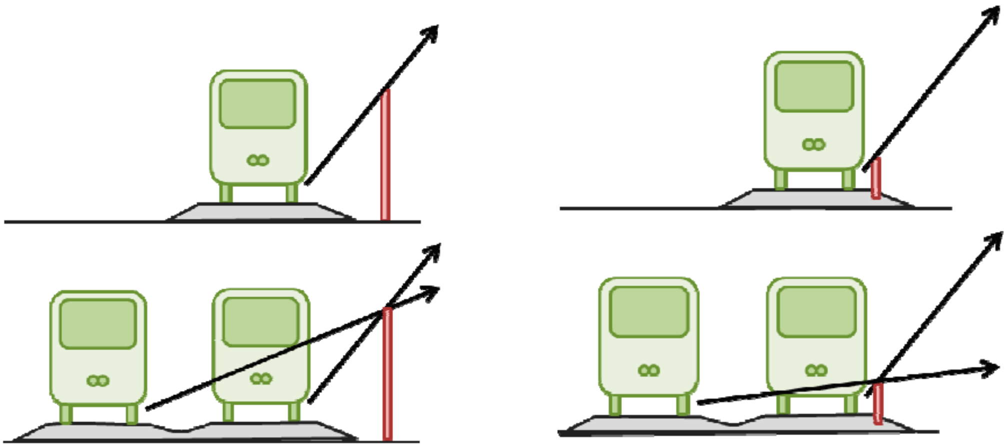

(a) (b)

Figure 7: Schematics of conventional (a) and low-close noise (b) barriers [21].

Table 1: Reduction of Wheel maintenance due lubrication [22].

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

Table 2: Noise mitigation measures reduction values [15].

Treatment	Wayside Noise Reduction db(A)		
	Squeal	Impact	Roar
Resilient Wheels	Reduces or eliminates	0 to 2	0 to 2
Damped Wheels	Reduces or eliminates	0 to 6	0 to 6
Resilient Treaded wheels	Undetermined (thin-tread) Eliminates (Nitinol-tread)	5 to 10	5 to 10
Wheel Truing	2 to 5	Eliminates flats	2 to 6
Rail grinding	0 (Unpredictable)	1 to 3 (joints and welds)	2 to 9 Uncorrugated rail 8 to 15 Corrugated rail
Welded rail	0	Eliminates joints	0
Rail joint maintenance	0	2 to 5 (joints)	0
Rail (or wheel) lubrication	Reduces or eliminates	0	0
Resilient or damped rail	Unpredictable	0 to 2 At grade 4 to 6 Steel elevated	0 to 2 At grade 4 to 6 Steel elevated
Resilient rail fasteners	0	3 to 6 Steel elevated	3 to 6 Steel elevated
Wayside barriers (3-6,5 ft high)	5 to 15	5 to 15	5 to 15
Vehicle skirts	0 to 3	0 to 3	0 to 3
Composition (vs. cast iron) tread brakes	0	Prevents small flats	5 to 7
Vehicle speed reduction	Reduces likelihood of squeal	6 to 12 per halving of speed	6 to 12 per halving of speed

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Table 3: Cost assumptions for life cycle analysis regarding squeal and impact noise abatement measures [23].

Mitigation Measure	First Cost	Control Case		Replacement	Climate Cost	Control Case for Climate Cost	
Track Based Lubrication	£20,000.00	£4,000.00	yearly	13 years	£20,000.00	£5,000.00	4 * a year
Conventional Barriers	£850,000.00	£850,000.00	25 years	Yes	£850,000.00	£850,000.00	15 years
Jointless Switches	£450,000.00	£450,000.00	25 years	10 years	£450,000.00	£450,000.00	8 years
Low-close Barriers	£650,000.00	£650,000.00	20 years	Yes	£650,000.00	£650,000.00	10 years
Rail Damping	£174,000.00	£8,000.00	yearly	13 years	£174,000.00	£11,000.00	4 * a year
Resilient Wheels	£30,000.00	£1,000.00	yearly	30 years	£30,000.00	£1,200.00	12 * a year
Vehicle Based Lubrication	£30,000.00	£2,800.00	yearly	15 years	£16,000.00	£4,000.00	4 * a year

Table 4: Net Present Values for two categories of friction modifiers.

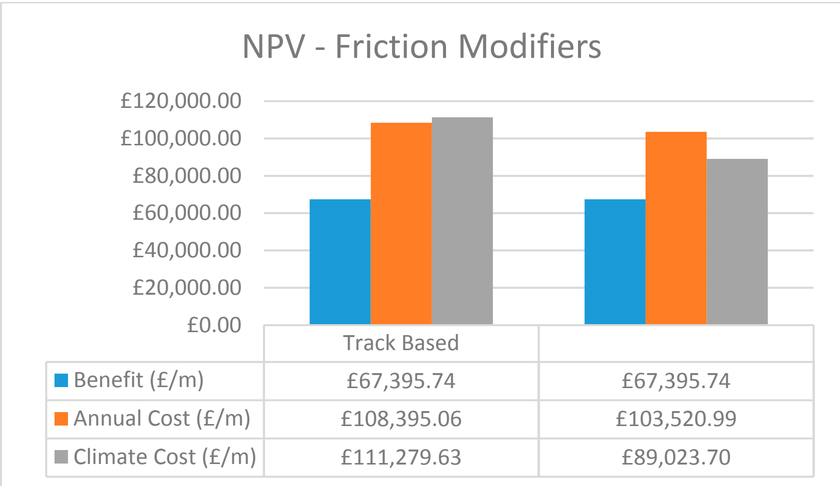

Table 5: Net Present Values for two categories of noise barriers.

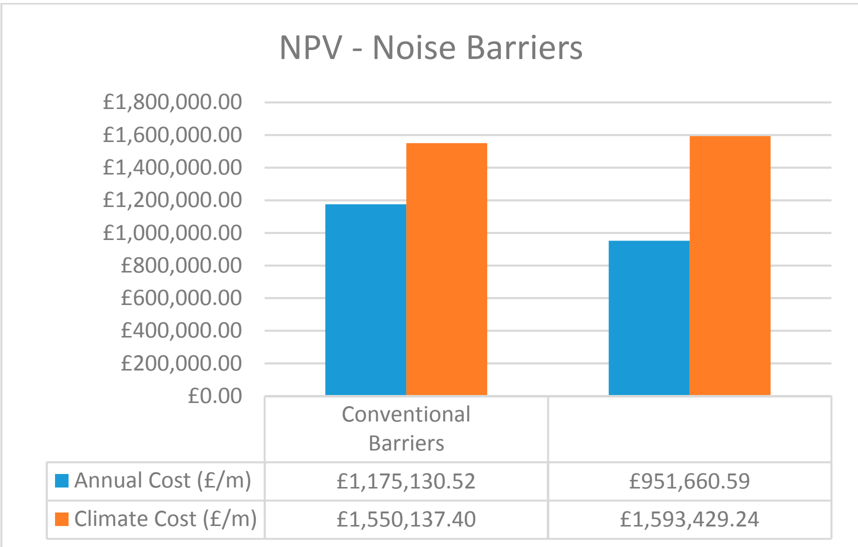

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Table 6: Net Present Values for jointless switches.

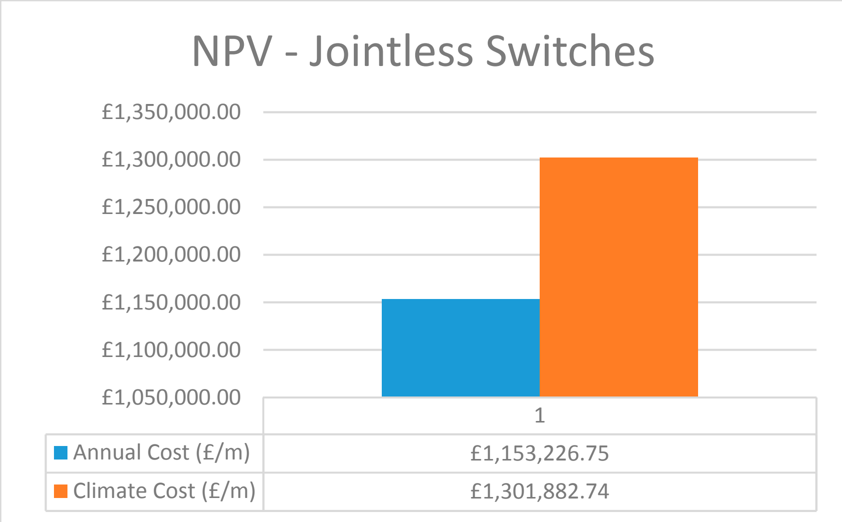


Table 7: Net Present Values for jointless switches.

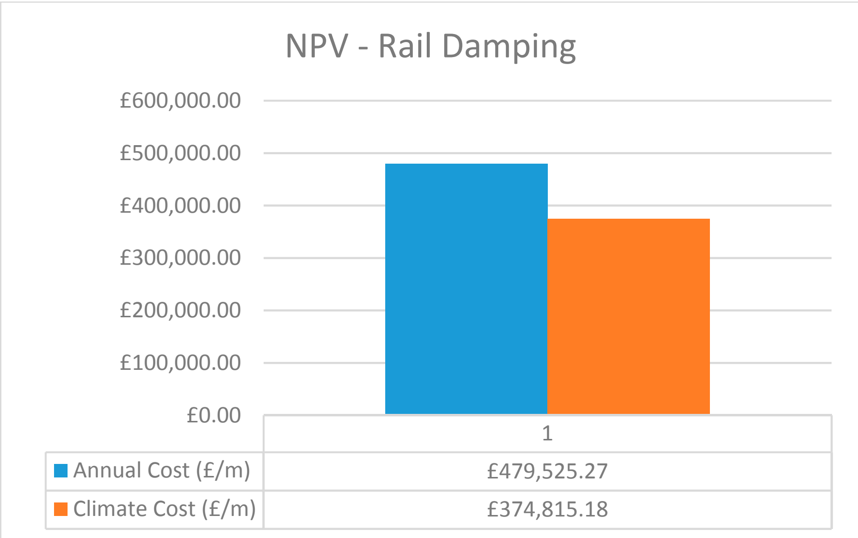
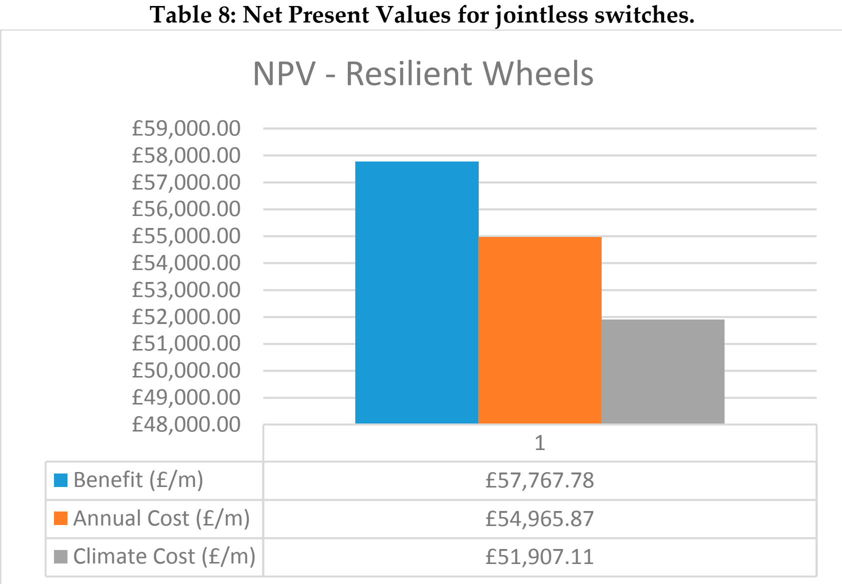


Table 8: Net Present Values for jointless switches.



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4. Discussion

4.1. Assumptions

Based on industry reports, assumptions from the railway industry have been addressed. The benefits acquired for each method can be seen below, as well for the cost assumptions for the whole life cycle evaluation, in Table 3. The discount rate considered in all projections is of 5% along 50 years of cash flow.

- Benefit for Track and Rail based Lubrication: £3,500.00
- Benefit for Resilient Wheels: £3,000.00

The values were assumed taking into account that routine maintenance is often undertaken to a fixed cycle whose period is previously defined by rail operators and maintainers and determined by terms of the passage of traffic.

4.2. Friction Modifiers

In order to compare more efficiently the viability of using lubricants in railways special trackworks the two categories of friction modifiers mentioned before were compared using the assumptions exposed above.

The outcome of this analysis show that even though vehicle based lubricants are considered a state of art method, with higher initial costs (£30,000 compared to £20,000), the benefits of choosing this measure stands out by thinking in the long-term. The maintenance of this method is also cheaper and the replacement period is wider due to the conditions applied to this.

4.3. Noise Barriers

Again, two types of the same methodology were compared regarding their cost life cycles. The low-close noise barriers are already a good alternative theoretically as they can be installed nearer the track and in most locations with similar results to noise abatement of conventional ones (see Figure 7).

The results show that the low close noise barriers are a better option across a long period of analysis. The high investment costs for the conventional barriers blocks the viability of using them for all the extension of track, but the conditions of which the properties of each type works better should be considered. In twin tracks, low close barriers aren't as effective and the use of conventional ones should be studied. Since special trackworks are complex systems, the feasibility of having to opt to one over another might be a downside to this method.

4.4. Jointless Switches

This is the most specific measure for impact noises, hence there should be special considerations regarding it's feasibility as the reduction of noise vibration acquired by this method is substantial (see Table 2). The final costs seen in Table 5 show that this method, as it is applied by a state of art technology, is the most expensive amongst the other ones and therefore should be analyzed as an alternative for only when is strictly necessary to properly abate the impact vibration due to the special trackworks components.

4.5. Rail Damping

[20] As rail damping can be used as a complement to other methods, with reasonable results, it is important to know if this addition to railway maintenance methodology is feasible economically speaking.

The costs to apply this technology aren't as high as jointless switches, hence it can be used in conjunction with more basic options such as resilient wheels and friction modifiers. The outcome of this relation is a good reduction of both impact and squeal noises (see Table 2 for values).

4.6. Resilient Wheel

Finally, resilient wheel already are considered an efficient and cheap method for reducing railway noise emission, as seen by Kurzweil, 1983, and the results prove that previous knowledge. Being such, a good option is to complement other methods with this, since wheels aren't usually a responsibility of the railway contractor, being delegated by the operators of the trains.

5. Conclusions

The maintenance of railway track consists of a significant area of interest for the industry due to its high cost values and the outcomes expected by its proper application [24]. More specifically, the noise and vibration reduction methods are a growing pursuit for solution by companies since their effects on the communities are becoming more and more noticed.

As a general perspective for noise generation and abatement in turnouts and crossings, the methodologies that stands out as better solutions are friction modifiers in conjunction with resilients wheels and rail damping systems. This combination will express a condition in which squeal noise is nearly reduced to 0 and for the impact noise values around 10 db of reduction.

For the impact noise, the most expensive option is using jointless switches with proven full reduction of impact noises or using damping and resilient wheels that can still reduce the noise, in a lower scale. So the option depends of how critical is the condition of the area and the complaints of the community and rail stakeholders.

Finally, for squeal noise the best solution is the low close noise barriers, although this is also the most expensive one and therefore should be only used in areas where is strictly needed and leaving the other parts of track evaluated to be applied other methods such as lubricants and damping.

In conclusion, the use of any mitigation measure here discussed is of vital importance for the planning of a successful plan of action that seeks to reduce or abate noise generation in railway systems, but the maintenance of their elements and components is even more essential so the condition of each one of them doesn't present itself deteriorated [25].

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