

Economics of track resilience

Ngamkhanong, Chayut; Nascimento, Ariana Tonan; Kaewunruen, Sakdirat

DOI:

[10.1088/1757-899X/471/6/062040](https://doi.org/10.1088/1757-899X/471/6/062040)

License:

Creative Commons: Attribution (CC BY)

Document Version

Publisher's PDF, also known as Version of record

Citation for published version (Harvard):

Ngamkhanong, C, Nascimento, AT & Kaewunruen, S 2019, 'Economics of track resilience', *IOP Conference Series: Materials Science and Engineering*, vol. 471, no. 5, 062040. <https://doi.org/10.1088/1757-899X/471/6/062040>

[Link to publication on Research at Birmingham portal](#)

General rights

Unless a licence is specified above, all rights (including copyright and moral rights) in this document are retained by the authors and/or the copyright holders. The express permission of the copyright holder must be obtained for any use of this material other than for purposes permitted by law.

- Users may freely distribute the URL that is used to identify this publication.
- Users may download and/or print one copy of the publication from the University of Birmingham research portal for the purpose of private study or non-commercial research.
- User may use extracts from the document in line with the concept of 'fair dealing' under the Copyright, Designs and Patents Act 1988 (?)
- Users may not further distribute the material nor use it for the purposes of commercial gain.

Where a licence is displayed above, please note the terms and conditions of the licence govern your use of this document.

When citing, please reference the published version.

Take down policy

While the University of Birmingham exercises care and attention in making items available there are rare occasions when an item has been uploaded in error or has been deemed to be commercially or otherwise sensitive.

If you believe that this is the case for this document, please contact UBIRA@lists.bham.ac.uk providing details and we will remove access to the work immediately and investigate.

PAPER • OPEN ACCESS

Economics of Track Resilience

To cite this article: Chayut Ngamkhanong *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **471** 062040

View the [article online](#) for updates and enhancements.

Economics of Track Resilience

Chayut Ngamkhanong ^{1,2}, Ariana Tonan Nascimento ¹, Sakdirat Kaewunruen ^{1,2}

¹ Department of Civil Engineering, School of Engineering, University of Birmingham, Birmingham B152TT, United Kingdom

² Birmingham Centre for Railway Research and Education, School of Engineering, University of Birmingham, Birmingham B152TT, United Kingdom

s.kaewunruen@bham.ac.uk

Abstract. Nowadays, railway infrastructure is a valuable asset throughout the world. Due to the increase in railway traffic, these may lead to the increase in the possibility of railway track deterioration. Thus, the investment in railway infrastructure improvement is growing to prevent disruption, deterioration and reduce maintenance. There are many methods to mitigate these problems. The use of elastic materials has been proposed as an alternative method to improve track resilience. It is seen that if these materials are used properly, track deterioration is decreased. This lead to expanding the service life of railway track and its components. However, track maintenance still needs to be carried out to maintain a railway asset. This paper presents the benefits of rail pad, under sleeper pad, and under ballast mat. Firstly, this study aims to discuss the main method of mitigation for those matters using elastic materials. The main features of these materials are to modify the vertical stiffness of the track, increase damping, reduce vibrations and noise, reduce impact load etc. It should be noted that different types of each elastic material are used for different locations and purposes based on the stiffness of the material. Moreover, elastic materials have a short lifespan as the temperature can affect their properties. This paper analyses the life cycle cost over a 30years time span of railway track with and without elastic materials. The construction and maintenance costs are considered. Based on the previous project, the use of elastic materials can significantly reduce the overall maintenance cost. The result shows that the use of elastic materials can give a fast payback within 4 years, which are still in the service life of elastic materials. However, it is recommended to consider more factors for further research.

1. Introduction

Presently, railway industry has played a significant role in transportation networks around the world. Due to the increase of freight and train speed, these lead to the growth of load applied to railway track [1-4]. It has been observed that railway track has easily experienced impact loading due to the track irregularities. The prone areas of the occurrence of impact loading are the area that the sudden change of track stiffness is observed such as bridge end [5], turnout and crossing [8], and track with irregularities [1, 9]. Moreover, track deterioration can be a results of component degradation, vibrations causing noise and track vibrations etc. To tackle these problems, many methods have been applied. The use of resilience materials, which are elastic materials, have proposed as an alternative method to attenuate those issues. The benefits of using elastic materials are the ease in material processing. Moreover, light weight, high ductility is also the adventurous of these materials [10].

Based on literature, it is clearly seen that elastic materials have advantages mainly in adapting the vertical stiffness of railway track. The other aims of using elastic materials are to attenuate noise and



vibration in railway track. It is noted that dynamic load generated by train running on abnormal wheel or rail is reduced by installing these elements. Elastic materials can improve track resilience, which is likely to reduce the maintenance cost. However, these elements have a short life span of about 20 years due to the effect of temperature, oxidation or hydrolysis [11]. Thus, it is necessary to evaluate the long-term economic effect and the feasibility of using these materials in railway system.

Life cycle cost analysis (LCCA) [12] has been introduced to the transportation decision-making process to help evaluate the feasible and outcome of the project. The purpose of this method is to evaluate the overall cost for the project. This method is adapted for determining the benefit of using resilience elements in long term. Moreover, this method provides the economic effects during the life span of the resilience materials. This paper presents an example of LCCA of railway track with and without elastic material considering annual maintenance cost and discount rate.

2. Elastic materials

2.1 Rail pad

Rail pads, which are located beneath the rails, are often used to reduce the differential track stiffness in the prone area. It is interesting that rail pads have become a standard practice when concrete sleepers are used. The benefits of rail pad are to provide a better train ride comfort, improve load distribution, and reduce track maintenance. Moreover, this can reduce track vibration transmitted from rails to sleepers as this is a one of the good vibration damping elements [13-14]. Rail pad also provides electrical and signalling insulation between track circuits. Cracking and wear rates of concrete sleepers can be reduced since rail pad can prevent concrete breakage [9].

Table 1 shows the materials used for rail pad with their vertical stiffness. The vertical stiffness is used to identify the type of rail pad. The thickness of rail pad is in the range between 4.5 and 15.0 mm. While, the dimensions of rail pad are usually 180 mm long and 140 mm wide for rail type UIC54. As for rail UIC60, the dimension of 180 mm long and 47/ mm wide is used.

Table 1. Dynamic stiffness of commercial railway pads [4, 15-17]

Type	Stiffness (MN/m)	Visual Identification
Rubber	20-100	Soft
Studded polymer	200-800	Soft
Polyurethane	800-1200	Medium
High density polyethylene (HDPE)	800-2500	Hard
EVA	3000-3500	Hard
Steel	5000+	Very stiff

2.2 Under sleeper pad (USP)

Under sleeper pads (USP), which can be made of polyurethane, elastomers, rubber, EVA etc., are installed under the sleepers to distribute the axle load over a larger number of sleepers as shown in figure 1. USP usually have two layers, upper layer for attenuating vibration and lower layer for protecting the sleepers from repeated impact load with ballast [18-21]. USP can increase the contact surface between sleepers and ballast. This can help stabilize the top layer of ballast. Moreover, one of the most benefits of USP is to reduce the dynamic load on ballast, which lead to the reduction of shifting of ballast and track settlement [22].

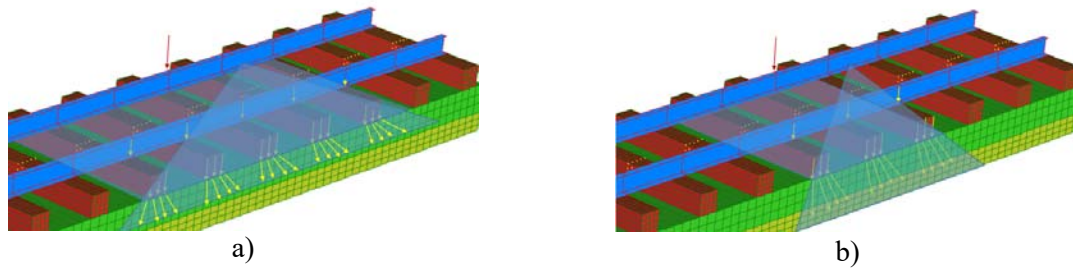


Figure 1. Load distribution of railway track a) with under sleeper pads b) without under sleeper pads

The USP can be classified by static bedding modulus into stiff, medium, soft and very soft, as shown in table 2. The benefits of USP presented by [23-24] are shown as follows:

- Improve track quality by reducing dynamic loading,
- Reduce ballast thickness while keeping track performance,
- Reduce ground borne vibration especially in the frequency range above 50 Hz, and
- Reduce long pitch rail corrugation in tight curves as rail pad can modify the natural frequencies of track components.

To be concluded, based on these benefits, the maintenance cost of railway track can be reduced. Table 3 concludes the USP applications and characterisations in order to fit the USP for those applications.

Table 2. Classification USP stiffness [25]

USP	Stiffness (N/mm ³)
Stiff	$0.25 < C_{stat} \leq 0.35$
Medium stiff	$0.15 < C_{stat} \leq 0.25$
Soft	$0.10 < C_{stat} \leq 0.15$
Very soft	$C_{stat} \leq 0.10$

Table 3. USP applications and characterisations [25]

Fields of application of USP	USP			
	Very soft	Soft	Medium stiff	Stiff
Improve track quality (reduce ballast breakage and track/turnout pressure)				
Transition zones				
On existing structures with reduced ballast thickness				
Reduction of long-pitch low-rail corrugation in tight curves				
Reduction of ground-borne vibration				

2.3 Under ballast mat

Under ballast mats (UBM), which can be made of natural rubber, polyurethane, rubber granulate etc., are used in ballasted track placed between ballast and sub-ballast. UBM can attenuate dynamic load, vibration and noise [9], and protect ballast breakage [26]. However, the main aim of using UBM is to reduce the stiffness of track especially placed on the stiffer portions such as bridge, tunnel, open track etc [27-30]. Moreover, can be applied in various operational environments such as conventional main lines, urban or high-speed lines or light rail and metro lines. The thickness of UBM are usually in the range of 15-30mm. The types of UBM can be classified into stiff, medium stiff, soft and very soft. It depends on dynamic bedding modulus, as shown in table 4. Table 5 shows the different types of UBM,

which are used for different locations and purposes. Even though UBM has many benefits in track, this can also cause problem when the same type of UBM are used for different purposes. For instance, very soft and soft UBMs can be used for high-speed track as these cause ballast dilation and destabilization. Moreover, the use of UBM on curved track is not recommended because UBM is likely to reduce lateral track resistance.

Table 4. UBM characterization [32]

Type of UBM	Expected increase of the vertical track deflection up to 225 kN axle load (measurement [SBB]) mm ^a	Dynamic bedding modulus N/mm ^{3bcde}
Stiff	1.5 – 2.0	$0.03 < C_{dyn} \leq 0.05$
Medium stiff	1.0 – 1.5	$0.05 < C_{dyn} \leq 0.09$
Soft	0.5 – 1.0	$0.09 < C_{dyn} \leq 0.22$
Very soft	≤ 0.5	$0.22 \leq C_{dyn}$

^a Measured with an SBB moving measuring car at 10 km/h (200 kN axle load “Einsenkungsmesswagen”).

^b Estimated values for the dynamic bedding modulus C_{dyn} are only valid for very stiff foundations (e.g. concrete).

^c For sleepers with smaller dimensions the C_{dyn} are shifted towards higher values. Lower axle loads imply a shift of the reference dynamic bedding modulus towards lower values. In contrast, higher train speeds in principle require a higher UBM bedding modulus in order to control ballast destabilization phenomena.

^d SBB: with 0.06 N/mm³ preload and ± 0.04 N/mm³ load at 20 Hz, using a flat steel plate.

^e Lower C_{dyn} values are expected using a ballast plate.

Table 5. UBM applications and characterisations [32]

Fields of application of UBM	UBM			
	Very soft	Soft	Medium	Hard
Vibration reduction and ground-borne noise				
Ballast breakage protection				
On existing structures with reduced ballast thickness				
Transition zones				

3. Economic analysis

The comparisons of construction and maintenance cost of railway track between track with under sleeper pads and without under sleeper pads were described in [33]. The 700km ballasted track with the axle load of 32T for high-speed train was considered. The construction cost of this track with and without sleeper pads is shown in table 6. It should be noted that the construction cost of under sleeper pads is about 10% of construction cost of other parts.

Table 6. Initial cost construction [33]

	Initial cost per km (€)	Total construction cost (€)
Construction rail track without sleeper pad	500.000	350.000.000
Construction of sleeper pad only	50.010	35.007.000

Table 7 shows the annual maintenance cost of railway track with and without under sleeper pads. It is interesting to note that the use of under sleeper pads can significantly reduce maintenance cost for about 50%. The annual depreciation can be also decreased by using under sleeper pads. Surprisingly, about 11.083.333€ of total cost reduction is noted. To be concluded, even though the construction cost of under sleeper pads is high, the use of under sleeper pads can significantly reduce an annual maintenance cost of railway track.

Table 7. Maintenance cost [33]

Cost	Annual maintenance cost (€)
Annual maintenance cost without USP	17.500.000
Annual maintenance cost with USP	8.750.000
Annual depreciation cost without USP	14.000.000
Annual depreciation cost with USP	11.666.667
Annual maintenance cost reduction	8.750.000
Depreciation cost reduction	2.333.333
Total cost reduction (annual earning)	11.083.333

4. Life-cycle cost analysis (LCCA)

An example of LCCA of railway system shown in previous section is presented. In this study, the UK discount rate of 6% is considered in order to determine the present value of future cash flows [34]. Two railway tracks, with and without USP, are compared to determine the outcome of USP. The initial costs (construction costs) are 350.000.000€ and 385.007.000€ for rail track without and with USP, respectively. It is assumed that only annual maintenance and depreciation costs are taken into account. The present values of these projects considering discount rate are present in figure 2. It is seen that railway track with USP obviously has lower annual maintenance cost even the investment cost is higher. However, annual maintenance costs of both projects reduce significantly.

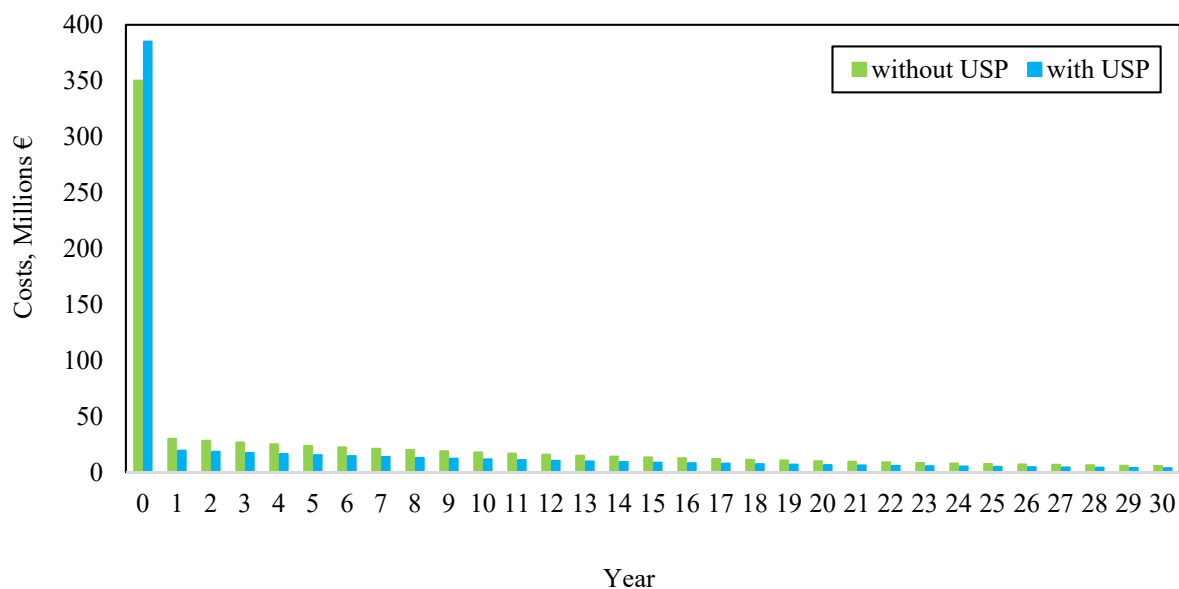
**Figure 2.** Costs of railway projects over a 30years time span

Figure 3 shows the cumulative net present value (NPV) of both projects in 30years. This represents the cumulative costs of the projects throughout its life cycle, including construction and maintenance costs. There is a crossing between both projects at about year 3.26, which means that it will take about 3.26 years to compensate the initial construction cost by using USP. The net present value of railway track with USP is slightly offset by a reduction in maintenance cost over time. If only construction cost of sleeper pad is considered as investment cost, while the annual cost reduction (table 7) is considered as annual benefits, NPV is shown in figure 4. This can also be calculated from the differential of NPV between both projects from figure 3. It is confirmed that the USP can give a fast payback time.

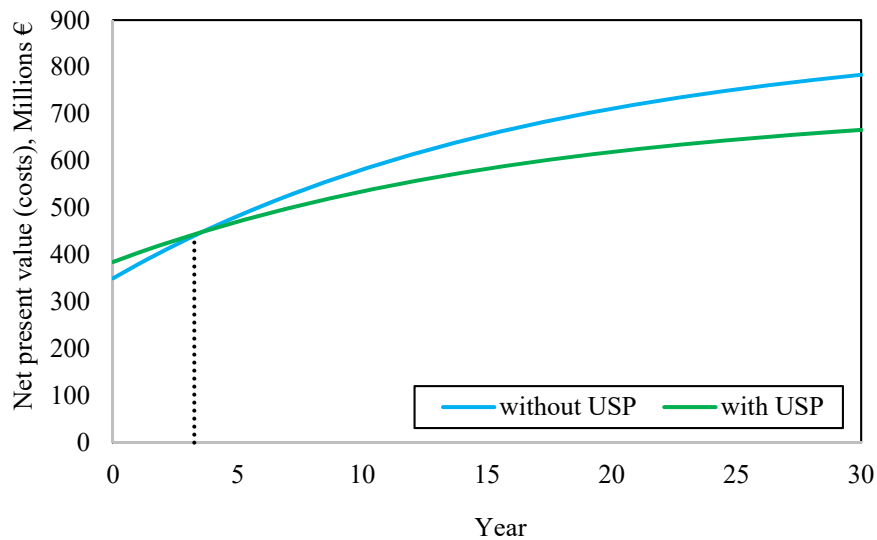


Figure 3. Net present value (NPV) (costs) of railway projects over a 30years time span

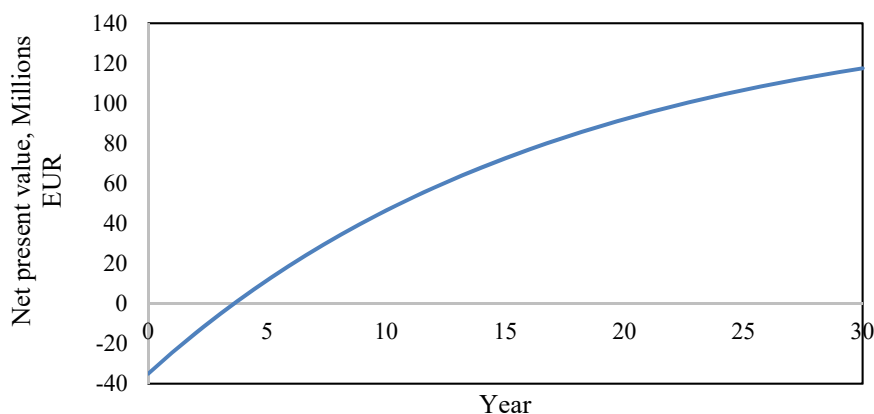


Figure 4. Differential NPV between railway projects with and without USP over a 30years time span

5. Conclusions

Elastic elements have been used as a component in railway track to improve resilience. These can help improve track performance and attenuate noise and vibration, impact load etc. The elastic materials presented in this study are rail pad, under sleeper pad (USP) and under ballast mat (UBM). However, economics of track resilience has become a concern due to the short life span of elastic materials. Life cycle cost analysis (LCCA) is a decision making process to help determine the future value of projects. This method is adapted for railway system in order to make decision and possibility of using improved methods or components. This study presents the life cycle and feasibility of using elastic material in railway track. It can be concluded that although the railway track with USP has higher initial cost, the maintenance cost decrease significantly. Economics of track is important over a long term period including all the stages of project as the value of project can be changed all the time. The future outcome of the project can be evaluated using LCCA. However, it is recommended that more factors, such as uncertainty, risk, operation cost etc., should be taken into account in further research.

Acknowledgements

The authors are sincerely grateful to the European Commission for the financial sponsorship of the H2020-RISE Project No. 691135 “RISEN: Rail Infrastructure Systems Engineering Network”, which enables a global research network that tackles the grand challenge of railway infrastructure resilience and advanced sensing in extreme environments (www.risen2rail.eu) [35].

References

- [1] A.M. Remennikov and S. Kaewunruen, “A review on loading conditions for railway track structures due to wheel and rail vertical interactions,” *Structural Control and Health Monitoring*, vol. 15, pp. 207-34, 2008.
- [2] S. Kaewunruen, S. Minoura, T. Watanabe, and A.M. Remennikov, “Remaining service life of railway prestressed concrete sleepers,” *In Proceedings of the International RILEM Conference on Materials, Systems and Structures in Civil Engineering, Lyngby, Copenhagen*, 2016.
- [3] S. Kaewunruen and K. Chamniprasart, “Damage analysis of spot replacement sleepers interspersed in ballasted railway tracks,” *In Proceedings of the 29th Nordic Seminar on Computational Mechanics, Gotenburg, Sweden*, 2016.
- [4] C. Esveld, *Modern Railway Track*, second ed, MRT-Productions, The Netherlands, 2001.
- [5] A. Paixão, E. Fortunato, and R. Calçada, “Transition zones to railway bridges: Track measurements and numerical Modelling,” *Engineering Structures*, vol. 80, pp. 435–443, 2014.
- [6] S. Kaewunruen, R. You, and M. Ishida, “Composites for Timber-Replacement Bearers in Railway Switches and Crossings,” *Infrastructures*, vol. 2, 2017.
- [7] E. A. Silva, D. Pokropski, R. You, and S. Kaewunruen, “Comparison of structural design methods for railway composites and plastic sleepers and bearers,” *Australian Journal of Structural Engineering*, vol. 18, pp. 160-177, 2017.
- [8] S. Dindar, S. Kaewunruen, and M.H. Osman, “Natural Hazards Risks on Railway Turnout Systems,” *Procedia Engineering*, vol. 161, 1254 – 1259, 2016.
- [9] C. Ngamkhanong, S. Kaewunruen, and B.J.A. Costa, “State-of-the-Art Review of Railway Track Resilience Monitoring,” *Infrastructures* vol. 3, 2018.
- [10] M. Sol-Sánchez, F. Moreno-Navarro, and M.C. Rubio-Gámez, “The use of elastic elements in railway tracks: a state of the art review,” *Constr. Build. Mater*, vol. 75, pp. 293–305, 2015.
- [11] Deutsche Bahn, A. G., and Hans-Joerg, T. “State of the Art Review of Mitigation Measures on Track Deliverable D3.1.,” Paris: International Union of Railways, 2011.
- [12] D. Langdon, “Life cycle costing (LCC) as a contribution to sustainable construction,” 2007.
- [13] S. Kaewunruen and A.M. Remennikov(2008) An experimental evaluation of the attenuation effect of rail pad on flexural behaviour of railway concrete sleeper under severe impact loads, *Proceeding of the 2008 Australian structural engineering conference, Melbourne, Australia*, 2008.
- [14] I. Carrascal , J.A. Casado, S. Diego, and J.A. Polanco, “Atenuacion frente a impacto en sistemas de sujecion ferroviaria de alta velocidad,” *J Anales Mecan Fract*, vol. 28, pp. 713–8, 2011.
- [15] S. Kaewunruen and A.M. Remennikov, “Applications of experimental modal testing for estimating dynamic properties of structural components,” *in: Proceedings of Australian Structural Engineering Conference, Newcastle, Australia*, 2005.
- [16] Z. Cai, “Modelling of rail track dynamics and wheel/rail interaction,” Ph.D. Thesis, Department of Civil Engineering, Queen’s University, Ont., Canada, 1992.
- [17] S. Kaewunruen and A.M. Remennikov, “Sensitivity analysis of free vibration characteristics of an in situ railway concrete sleeper to variations of rail pad parameters,” *Journal of Sound and Vibration*, vol. 298, pp. 453-461, 2006.
- [18] T. Dahlberg, “Railway track stiffness variations-consequences and countermeasures,” *Int. J. Civ. Eng.* vol. 8, pp. 1–12, 2010.

- [19] P. Schneider, R. Bolmsvik, and J.C.O. Nielsen, "In situ performance of a ballasted railway track with under sleeper pads," *J. Rail Rapid Transit*, vol. 225, pp. 299-309, 2011.
- [20] F. Müller-Boruttau and U. Kleinert, "Betonschwellen mit elastischer Sohle," *ETR*, vol. 50, 2001.
- [21] V.L. Marine, M.J.M.M. Steenburgen, and I.Y. Sheets, "Combating RCF on switch points by tuning elastic track properties," *Wear*, vol. 271, pp. 158-167, 2009.
- [22] Getzner, "Sleeper Pads for Ballasted Track,"
- [23] R. Schilder, "USP (under sleeper pads) – a contribution to save money in track maintenance," in *AusRAIL PLUS (Sydney: AusRAIL PLUS)*, 2013.
- [24] S. Setsobhonkul, S. Kaewunruen, and J.M. Sussman, "Lifecycle Assessments of Railway Bridge Transitions Exposed to Extreme Climate Events," *Front. Built Environ.*, vol. 3, 2017.
- [25] International Union of Railways, "Recommendations for the Use of Under Sleeper Pads," 2013.
- [26] C. Ngamkhanong, S. Kaewunruen, and C. Baniotopoulos, "A review on modelling and monitoring of railway ballast," *Structural Monitoring and Maintenance*, vol. 4, pp. 195-220, 2017.
- [27] P. Teixeira, "State-of-the-Art on the use of bituminous subballast on european high-speed rail lines," *Congress of bearing capacity of roads, railways and airfields, Barcelona, Spain*, 2009.
- [28] S. Potocan, "Ballast mats within areas of reduced ballast depth," *European railway review*, 2010.
- [29] Y. Kimura, "Control of ground-borne vibration from at-grade track using ballast mats," *Proceedings of American public transit association rapid transit conference*. 1995.
- [30] S.F. Brown, B.V. Brodrick, N.H. Thom, and G.R. McDowell, "The Nottingham railway test facility." *Proceedings of the Institution of Civil Engineers – Transport*, vol. 160, pp. 59-65, 2007.
- [31] G. Werkstoffe, "Ballast mats. Characteristics of solutions in service," Paris, UIC, 2006
- [32] International Union of Railway, "UIC Recommendation R917-1 Under ballast mat", 2011.
- [33] P. Guedelha, "Materiais Elásticos como Elementos de Proteção em Vias Balastradas," 2012.
- [34] P.A. Grout, "Public and Private Sector Discount Rates in Public-Private Partnerships," CMPO Working Paper Series No. 03/059, 2002.
- [35] S. Kaewunruen, J.M. Sussman, and A. Matsumoto. "Grand challenges in transportation and transit systems," *Front. Built Environ.*, vol. 2, 2016.