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A Life-Cycle Cost Analysis of Railway Turnouts Exposed to Climate Uncertainties

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Abstract. Turnouts are the critical components of modern railway tracks where the vehicle movement is transferred between two continuing tracks, inevitably resulting in high dynamic forces on the turnout system which eventually cause the turnout failures. Consequently, the turnouts have imposed operational restrictions such as operational limits for speed, axle load and headway, and high maintenance works on the system. Numerous studies have been carried out to find a mitigation method for turnout failures. Nonetheless, most of the studies consider the physical phenomena. Hence, it is believed that it would be beneficial to investigate the problem from the economic aspect. For this purpose, a life-cycle cost analysis is done for turnouts, particularly crossing nose in this study. Life-cycle cost analysis is a total cost estimate of a system or a component from acquisition to disposal, to find a cost-effective solution. It could be a simple analysis based on an expert's judgement to evaluate the feasibility or complex analysis using statistical theories covering the uncertainties to decide the budget. In this study, the life-cycle cost analysis relies on the breakdown work structure based on the reports published by the biggest Infrastructure Manager in the United Kingdom. Additionally, the effects of extreme weathers are also concerned while calculating the life-cycle cost. The results indicate that crossing renewal and tamping activities have high costs similar to miscellaneous maintenance costs. Another interesting result is that maintenance costs could be as high as acquisition costs. Finally, crossing nose renewal and maintenance costs seem to occupy high shares in the maintenance budget.

1. Introduction

Infrastructure Managers (IMs) in the Euro Zone have replied to the question "What infrastructure characteristics may increase the complexity of your network and impact performance". IMs indicated that Switches & Crossings (namely, turnouts) is the top concern[1]. Turnouts are special track systems designed to change the railway traffic from one route to another route since the railways are naturally guided systems where the track is continuous. At this section of the track, the dynamic behaviour of the vehicle transforms from relatively simple to complex and becomes more sensitive to environmental factors. Therefore, IMs take serious precautions to keep the safety standards high, which increase their costs. Furthermore, the turnouts restrict the operational speed and increase the possibility of derailment [2, 3]. As a result, numerous studies have been conducted to deal with the issue. In general, the studies focus on the physical phenomena such as material properties, dynamic characteristics of the vehicle, the wheel-rail interaction and environmental effects [4-8] or management strategies such as maintenance scheduling [9]. Although most of the studies have mentioned the importance of capital expenditure for switches and crossings, only a few studies consider the economic aspect [10-12]; however, none of them considers the extreme weather events affecting the system resilience.

Different methods are in use to evaluate the performance of a system from the economic aspect. Life-Cycle Cost (LCC) analysis is the common one to estimate the total cost originating from different stages of a long-term investment and to compare alternative systems. Switches & Crossings are expected to serve at least 30 years and manufactured with many variations, thereby being suitable for an LCC analysis. In this paper, it is aimed to carry out a life-cycle cost analysis to evaluate turnouts exposed to climate change from the economic aspect, which may help the Infrastructure Managers to focus on the specific areas affecting their maintenance and climate change adaptation policies.

2. Methodology

Life cycle cost is an estimate that considers the costs of acquisition, operation, maintenance and disposal of a system or component. LCC analysis could be used to evaluate the expected economic performance of a whole system or to compare different systems to achieve the best solution for a problem. Moreover, LCC analysis could be preliminary to assess the feasibility or elaborate to be used in a bid tender. The accuracy of LCC analysis relies on the collected historical data and expertise owned by analysts. Higher accuracy is aimed for tender level works and lower accuracy is acceptable for preliminary works. Due to the lack of collecting actual and accurate data, a preliminary LCC analysis is preferred in the scope of this study.

Acquisition, replacement, and maintenance costs are considered in this study. The disposal cost is included in the maintenance costs since it has relatively low value[12]. All direct costs are assumed as fixed costs. On the other hand, non-direct costs (i.e. operational delay…) are ignored. Regarding the nature of the track operation where every case is exclusive, learning ratio is low and so, learning costs are ignored[13]. Average inflation and labour rates are applied depending on the data published by Office of National Statistics (Table 1). The advised discount rate of 3.5% is used in order to calculate Net Presented Value (NVP)[14]. Life-cycle is expected as 30 years[15]. Costs are divided into two groups such as labour and materials. Estimated costs are presented in (Table 1). All the values estimated from public reports or the literature [10, 16-22] including labour hours, labour cost per hour and material costs. The uncertainties are included in the discount rate [14].

Table 1. Assumptions for Life-cycle Cost Analysis

Inflation Ratio [23]	Labour Rates [23]	Advised Discount Rate [14]	Estimated Acquisition Cost (2018) [16, 18, 19]	Estimated Replacement Cost(2018) [20]	Estimated Maintenance Cost(2018) [17]
2 %	2 %	3.5	80k-150k £	15k £	7.5k £

3. Results and Discussions

Switches & Crossings could be assumed as custom-tailored items. The acquisition costs show significant variations depending on the region, field or province that the work is conducted [15, 16, 24]. Similar behaviour is valid for maintenance costs since the different maintenance strategies could be adopted by different companies [24]. Therefore, the data used for LCC analysis should be collected from a single source as much as possible. In this study, the collected data is valid for the UK and the main data sources are Office of Rail and Road, responsible for regulations of the monopoly and health and safety in the UK railways, and Network Rail, the biggest IM in the UK. Other sources in the literature are also used [10, 12, 22].

The result shown in Figure 1 reveals that a significant difference between acquisition and maintenance costs could be observed throughout the life-cycle. Even though the material costs are estimated in a similar range (100-150k pounds), the difference is due to the higher labour share in the maintenance activities which are based on mainly manpower. As a consequence, the cost mitigation methods should focus on the labour-oriented costs.

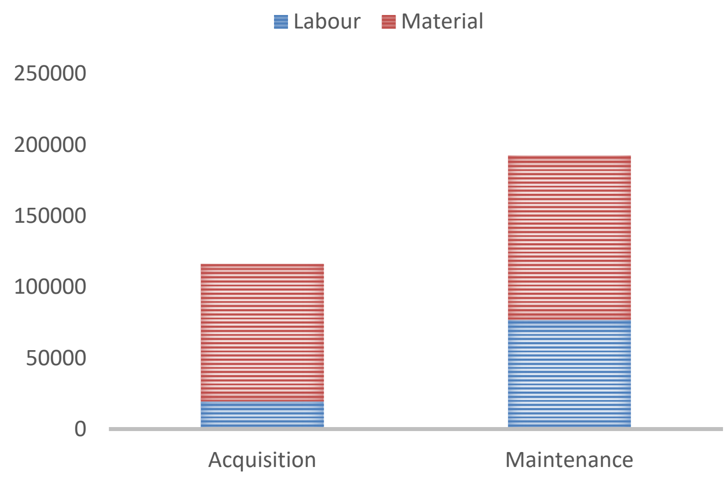

Figure 1. LCC comparison of acquisition and maintenance

The maintenance activities could exhibit many variations related to IMs' maintenance and data collection policy. A breakdown structure based on the IMs' experience, policy and database is effective to do a better LCC analysis. Unfortunately, IMs in the UK are not volunteered to share their experience and data with academia. For this reason, the breakdown structure and the cost estimation are based on the public reports. The information of different parameters such as the total number of S&Cs, unit prices, the estimated maintenance period has been extracted from several reports [15, 18-21].

Table 2. Assumptions for breakdown work structure

	Train Grinding	Stoneblowing	Switches Renew	Maintenance	Inspection	Weld Repair	Rep. of bearers	Tamping	Crossing Renew
MUC(£)	1582.15	4099.45	8402.05	43.06	18.77	337.85	251.73	5546.90	15065.18
Period	5 years	20 years	20 years	15 days	Monthly	2 years	2.5 years	5 years	40 years

For control case, it is assumed that the maintenance interval has been determined by the division of total S&Cs by yearly maintenance capacity. In other words, there is no corrective maintenance and no delayed maintenance. Maintenance Unit Cost (MUC) and maintenance period are presented in Table 3. As can be seen from the table, the period for crossing renewal is higher than the S&C life-cycle, which means that an S&C is likely to complete its life without any crossing replacements in contrast to switches. A significant difference between switches and crossings failures as regards the frequencies of occurrence has been observed[25]. Nonetheless, for the control case, the S&C is assumed to be subjected to at least one replacement since they occupy a significant amount of money in the maintenance budget. Under these assumptions, a life-cycle cost analysis based on the breakdown work structure is presented below.

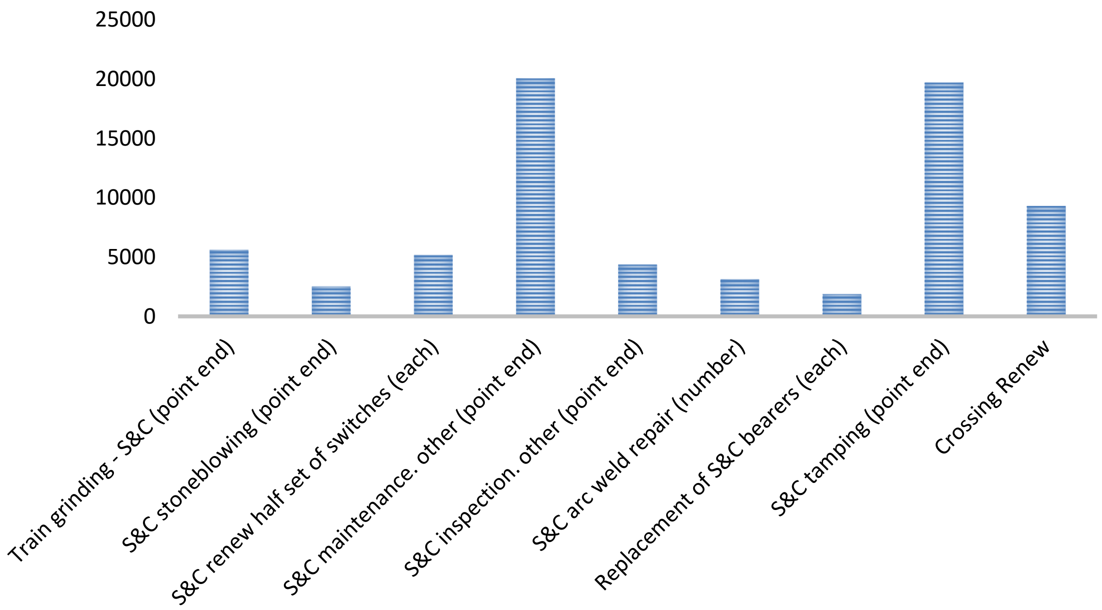

Figure 2. LCC analysis based on the breakdown work structure

As can be seen from Figure 2, three activities are dominant in the LCC analysis: miscellaneous maintenance, tamping and crossing renewal. Maintenance and tamping are regular activities to provide a safe operation. On the other hand, crossing renewal is a low probability activity. As a result, the contribution of crossing nose is more compelling with respect to the others.

As previously mentioned, maintenance strategies exhibit important differences from one company to another company or one case to another case. For this purpose, five different scenarios are produced to test the different maintenance strategies. The scenarios and the reasons are presented in Table 4.

Table 3. Estimated maintenance scenarios

	Train Grinding	Stone blowing	Switches Renew	Maintenance	Inspection	Weld Repair	Rep. of bearers	Tamping	Crossing Renew
Sc1	6	1	1	720	360	15	12	6	1
Sc2	6	1	1	720	360	15	12	6	0
Sc3	6	0	0	720	360	15	12	6	0
Sc4	6	0	1	720	360	15	12	15	1
Sc5	6	1	2	720	360	15	12	30	2

Sc1: Estimated from Network Rail's published data.
Sc2: Replacement of crossing is a low-frequency activity in S&C maintenance. It is disregarded in this scenario.
Sc3: Stone-blowing and Renew half set of switches are relatively low-frequency activities. All low-frequency activities are disregarded. Assumed as "Best Scenario".
Sc4: According to [22, 26], It seems that tamping activity is 2-year periodic activity. Stone-blowing is disregarded since it serves a similar purpose.
Sc5: Based on [27], this scenario is produced. Comparing with other scenarios, this scenario is accepted as "Worst Scenario"

In Figure 3 below, an LCC analysis for different scenarios is presented. Even though small changes have been applied to the scenarios, significant deviations are visible. It seems that crossing and switch replacements have a large contribution to the total cost but the LCC is more sensitive to tamping activities.

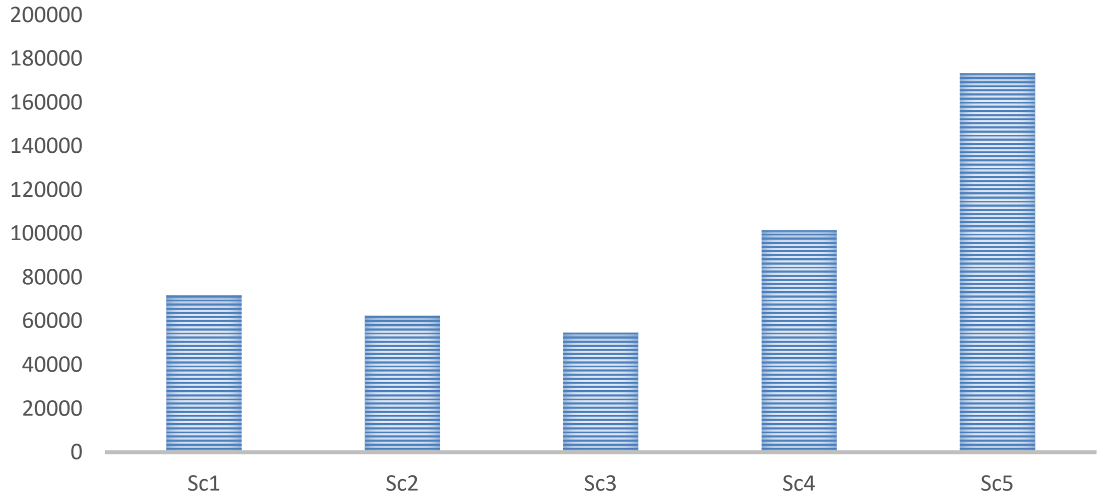

Figure 3. LCC analysis for different scenarios

It is well-known that the climate changes will have impacts on the systems in open environment such as turnouts[2, 7]. At that moment, the operations, responsibilities and functions of the IMs will be disturbed by climate changes.

Flood and High Temperatures are two major climate changes affecting the IM's performance[28] but the effects of these extreme events are different from each other. High temperatures generally influence the performance of the staff and satisfaction of the customers, which is not included in the LCC analysis. Apart from this, high temperatures are likely to cause track buckling. During hot weathers, the inspection could be increased depending on the severity [29] to prevent the track buckling. Similarly, IMs in the UK apply several safety measures such as increased inspection period and reduced train speed in different levels. Network Rail applies 'watchmen' inspection criterion where the threshold temperature (21^{o} Celsius) is exceeded [30]. It is assumed here that 30-days in a year are above the threshold temperature[30] and maintenance activities are increased during this period while calculating the LCC. Although there are some studies [22] suggesting lower tamping periods during hot weather, it is not considered in this study since Network Rail calls off maintenance schedules at high temperatures [30].

Flood could impair the S&C in two ways. It could cause line side equipment to fail or lead to earthwork problems such as embankment scour, culvert washouts, and landslips. Flood is a low probability event [7] since the tracks are designed with elevation and drainages are cleaned regularly. Therefore, it is assumed in this study that the S&C could suffer from flood once in a life-cycle and rectifying method is ballast and line side equipment renewals.

Figure 4 illustrates the LCC of the climate changes. Even though it is once in a lifetime, Flood has the highest life-cycle cost. It increases the total maintenance cost by approximately 22%. On the other hand, high temperature influences the total cost by approximately 15%. The estimated values are direct costs of extreme events. On the other hand, it is possible that indirect costs such as cancellation or delay costs will be higher than the direct costs [28, 31]. Specifically considering the frequency of the events, the indirect cost of high temperatures is likely to have more impact on the LCC cost of turnouts. Nevertheless, the calculation of indirect costs is extremely complicated and thus, it could be justified by an expert's opinion.

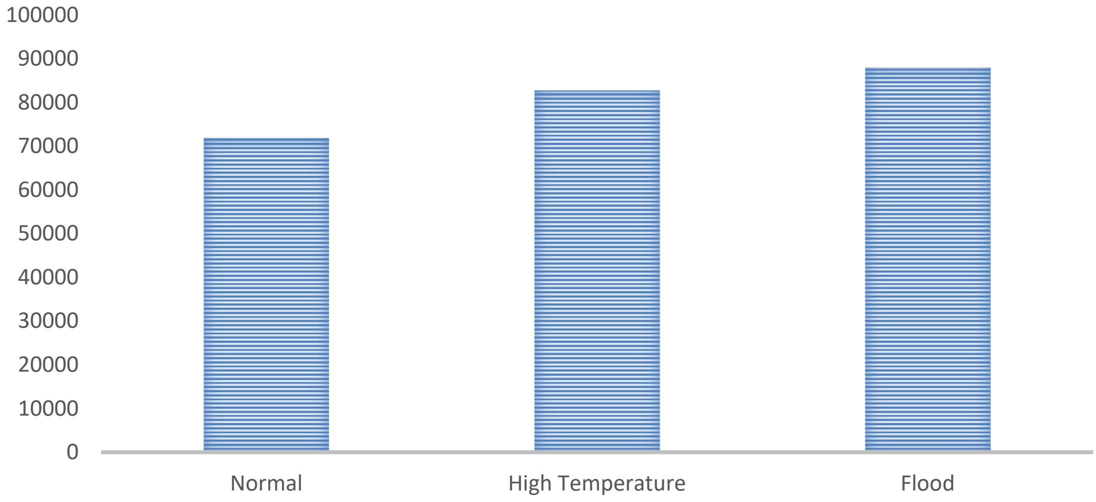

Figure 4. LCC analysis for extreme weather conditions

Figure 2 has shown that the crossing replacement cost is significant. Hence, a particular LCC analysis for crossing nose is also presented in Figure 5. Here, switch and closure panel failures or maintenances are ignored. As can be seen from the figure below, acquisition costs have the highest share.

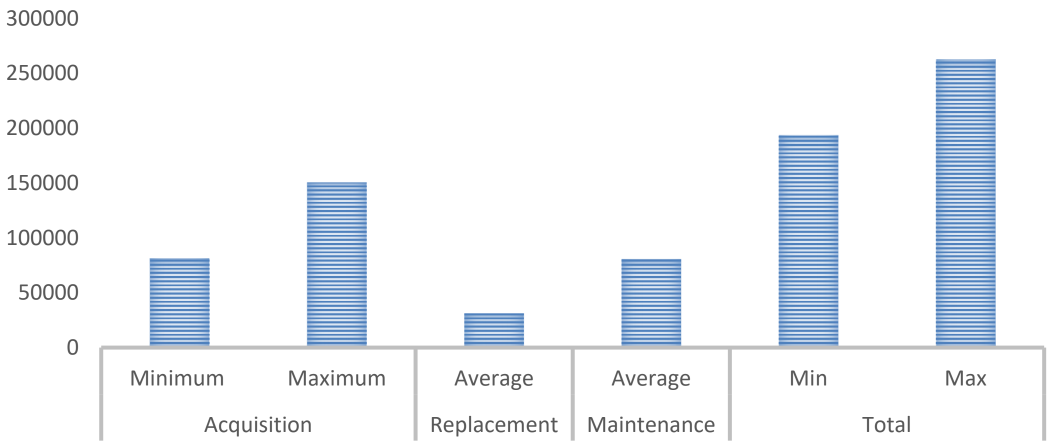

Figure 5. LCC analysis for turnout crossing nose

From the figure above, the costs of replacement and maintenance should be considered in the first place while seeking the cost mitigation methods, as they could contribute to the total cost more than the acquisition cost. In conclusion, it is crucial to understand the degradation process of a crossing nose (i.e. crack initiation, propagation).

4. Conclusions

This study has covered the cost issues of switches & crossings as a preliminary cost analysis. For better or detailed cost analysis, the historical and actual data and the field experience should be harmonised with advanced cost analysis methods. This kind of work requires a high amount of time and resources. The study shows that an LCC analysis could show significant variations as a consequence of different economical parameters, environmental conditions and maintenance policies. Another outcome is that the maintenance costs are expected to be higher than acquisition costs in the S&C. Besides, the difference is not because of the material costs as they are in same range but results from labour costs.

Depending on these results, it is recommended that IMs should focus on decreasing labour-oriented costs, increasing tamping periods and measures for the flood. A final observation is that when considering only crossing nose effect on the LCC cost, the replacement and maintenance costs have a serious impact similar to acquisition cost. In conclusion, an investigation providing a better understanding of the crossing nose degradation will considerably contribute to reducing the total cost.

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References

[1] EIM-EFRTC-CER, *Market Strategy Report - Track Maintenance & Renewal*. 2012, The Community of European Railway and Infrastructure Companies (CER): Brussels.
[2] Dindar, S., et al., *Natural Hazard Risks on Railway Turnout Systems.* Procedia Engineering, 2016. **161**: p. 1254-1259.
[3] Dindar, S., et al., *Derailment-based Fault Tree Analysis on Risk Management of Railway Turnout Systems.* IOP Conference Series: Materials Science and Engineering, 2017. **245**.
[4] Andersson, C. and T. Dahlberg, *Wheel/rail impacts at a railway turnout crossing.* Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 1998. **212**(2): p. 123-134.
[5] Kassa, E., C. Andersson, and J.C.O. Nielsen, *Simulation of dynamic interaction between train and railway turnout.* Vehicle System Dynamics, 2006. **44**(3): p. 247-258.
[6] Pålsson, B.A., *Optimisation of railway crossing geometry considering a representative set of wheel profiles.* Vehicle System Dynamics, 2015. **53**(2): p. 274-301.
[7] Dindar, S., S. Kaewunruen, and J.M. Sussman, *Climate Change Adaptation for GeoRisks Mitigation of Railway Turnout Systems.* Procedia Engineering, 2017. **189**: p. 199-206.
[8] Ma, Y., A.A. Mashal, and V.L. Markine, *Modelling and experimental validation of dynamic impact in 1:9 railway crossing panel.* Tribology International, 2018. **118**: p. 208-226.
[9] Bin Osman, M.H., S. Kaewunruen, and A. Jack, *Optimisation of schedules for the inspection of railway tracks.* Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 2017.
[10] Nissen, A., *LCC analysis for switches and crossings: a case study from the Swedish Railway Network.* International Journal of COMADEM, 2009. **12**(2): p. 10-19.
[11] Tavares de Freitas, R. and S. Kaewunruen, *Life Cycle Cost Evaluation of Noise and Vibration Control Methods at Urban Railway Turnouts.* Environments, 2016. **3**(4).
[12] Vitásek, S. and D. Měšťanová, *Life Cycle Cost of a Railroad Switch.* Procedia Engineering, 2017. **196**: p. 646-652.
[13] Nachtmann, E.P.H., *Life Cycle Costing*, in *Decision Making in Systems Engineering and Management*, G.S.P.P.J.D.D.L. Henderson, Editor. 2010, John Wiley & Sons, Inc. .
[14] Lowe, J., *Intergenerational Wealth Transfers and Social Discounting: Supplementary Green Book guidance*, H. TREASURY, Editor. 2008, Office of Public Sector Information: London.
[15] Cornish, A., *Life-time monitoring of in service switches and crossings through field experimentation*, in *Mechanical Engineering*. 2014, Imperial College London: London.
[16] Commission, E., *Maintenance, Renewal and Improvement of Rail Transport Infrastructure*. 2014, Mainline Project Office: Paris.
[17] Ling, D., *Railway renewal and maintenance cost estimating*. 2005.
[18] Rail, N., *Employment Costs Efficiency Review*. 2008: London.

[19] Rail, N., *Mandate AO/008: Network Rail Materials Costs Benchmarking Study*. 2011: London.
[20] Rail, N., *Part A Reporter Mandate AO/030:PR13 Maintenance & Renewals Review*. 2013: London.
[21] Rail, N., *Periodic Review 2013: Final determination of Network Rail's outputs and funding for 2014-19*. 2013: London.
[22] Setsobhonkul, S., S. Kaewunruen, and J.M. Sussman, *Lifecycle Assessments of Railway Bridge Transitions Exposed to Extreme Climate Events.* Frontiers in Built Environment, 2017. **3**.
[23] Statistics, O.o.N. 2018 [cited 2018 01/03/2018]; Available from: https://www.ons.gov.uk/.
[24] Daniels, L.E., *Track maintenance costs on rail transit properties*. 2008.
[25] Hassankiadeh, S., *Failure analysis of railway switches and crossings for the purpose of preventive maintenance.* Royal Institute of Technology, 2011.
[26] Antoni, M. *Modelling of the ballast maintenance expenses*. in *World Congress on Railway Research 2011*. 2011. Lille.
[27] Thomas, S. *Turnout grinding: why and how*. in *AusRAIL PLUS 2016, Rail-Moving the Economy Forward, 21-23 November 2016, Adelaide, South Australia, Australia*. 2016.
[28] Rail, N., *Climate Change Adaptation Report*. 2015: London.
[29] Esveld, C., *Modern railway track.* 2001, The Netherlands: MRT Productions.
[30] Rail, N., *Climate Change Adaptation Report*. 2011: London.
[31] Vu, M., S. Kaewunruen, and M. Attard, *Nonlinear 3D finite-element modeling for structural failure analysis of concrete sleepers/bearers at an urban turnout diamond*, in *Handbook of Materials Failure Analysis with Case Studies from the Chemicals, Concrete and Power Industries*. 2016. p. 123-160.