

# LOD BIM Element specification for Railway Turnout Systems Risk Mitigation using the Information Delivery Manual

Ángel Gigante-Barrera<sup>1</sup>, Serdar Dindar<sup>1,2</sup>, Sakdirat Kaewunruen<sup>1,2</sup>, Darshan Ruikar<sup>1</sup>

<sup>1</sup> Department of Civil Engineering, School of Engineering, The University of Birmingham, Birmingham, B15 2TT, United Kingdom

<sup>2</sup> Birmingham Centre for Railway Research and Education, Gisbert Kapp, The University of Birmingham, Birmingham, B15 2TT, United Kingdom

SXD319@bham.ac.uk

**Abstract.** Railway turnouts are complex systems designed using complex geometries and grades which makes them difficult to be managed in terms of risk prevention. This feature poses a substantial peril to rail users as it is considered a cause of derailment. In addition, derailment deals to financial losses due to operational downtimes and monetary compensations in case of death or injury. These are fundamental drivers to consider mitigating risks arising from poor risk management during design. Prevention through design (PtD) is a process that introduces tacit knowledge from industry professionals during the design process. There is evidence that Building Information Modelling (BIM) can help to mitigate risk since the inception of the project. BIM is considered an Information System (IS) where tacit knowledge can be stored and retrieved from a digital database making easy to take promptly decisions as information is ready to be analysed. BIM at the model element level entails working with 3D elements and embedded data, therefore adding a layer of complexity to the management of information along the different stages of the project and across different disciplines. In order to overcome this problem, the industry has created a framework for model progression specification named Level of Development (LOD). The paper presents an IDM based framework for design risk mitigation through code validation using the LOD. This effort resulted on risk datasets which describe graphically and non-graphically a rail turnout as the model progresses. Thus, permitting its inclusion within risk information systems. The assignment of an LOD construct to a set of data, requires specialised management and process related expertise. Furthermore, the selection of a set of LOD constructs requires a purpose based analysis. Therefore, a framework for LOD constructs implementation within the IDM for code checking is required for the industry to progress in this particular field.

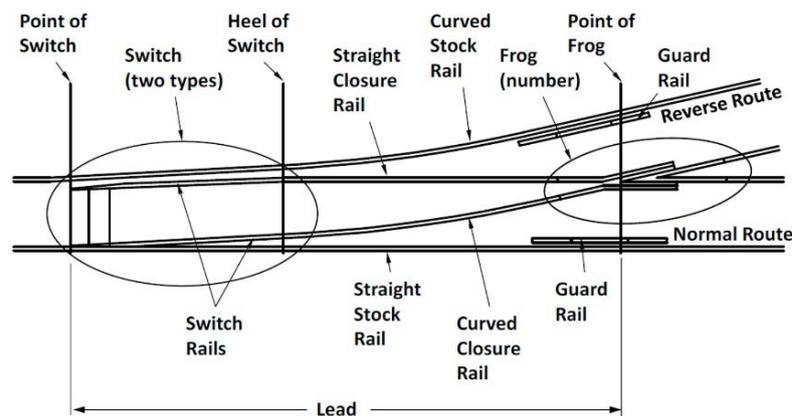
## 1. Introduction

Rail turnouts are complex assemblies of components used to divert a train from a particular rail track onto another track [1]. Rail turnouts are conflictive sections within a railway corridor as they constitute an exceptional discontinuity within the railway layout, [2-4]. Furthermore, they are compound of complex assemblies (see Figure 1), which are composed of unique elements with different risk profiles to railway operations [2]. Only from the year period 2010 to 2015, nearly 572 derailments has been reported in the EU [5], while they account for 200 million of Euros in losses per year [6].



A report created by the UK Rail Safety & Standards Board in 2004, reported that that 28 % out of 1657 derailments that occurred during the years 1992 to 2001 were due to tracks not being compliant with the pertaining standards [7]. Three factors relevant to track standards analysis are Track Access, Increases in Track Degradation and Staff Competencies [7,8]. Since rail turnouts are a critical source of risk within railway designs and the increase in track degradation affects the quality of the turnout manufacturer product, these combined factors are the focus of the present study.

Risk management can proactively help to mitigate risk at design stage. Previous studies have studied the relationship between building design mitigation process and construction health and safety, also called Construction Hazards Prevention Through Design (CHPtD) [9-11]. Apart from construction hazards prevention, risk management methodologies have the potential to be integrated into the design stages [12, 13]. Building Information modeling can bridge the gap between design and risk management [14]. However, there is a lack of research that study prevention through design in relation to BIM processes. Therefore, there are two objectives to this research 1) to explore the relationship between rail turnout degradation risk management and BIM design processes and 2) to study issues that should be considered to create a Level of Development (3D model and embedded data model element progression) driven BIM database. The study uses the Information Delivery Manual standard which is used to develop the interoperable data format Industry Foundation Class (IFC) and its Model View Definitions (MVD).



**Figure 1.** The geometry of a simple turnout from [1]

## 2. Background for LOD rule validation

In the last years Building Information Modeling has helped teams to generate value through early collaborative work [18]. This is seen as a solution to address the problem of fragmentation between design and construction which traditionally has resulted in inefficient work practices and costly changes late in the construction phase [19, 20]. The integration of early input from contractors, installers, fabricators, and suppliers as well as from designers allows to shift the decision making forward using BIM to model and simulate the project [21]. The use of BIM in the design process allows the potential to include project risk and value in the design review process, considered in parallel to engineering design, rather than as an activity performed separately, later in the design process (as it currently is)[21]. For example, the 2015 US National Model Railroad Association (NMRA) Technical Note TN-12, recommends a final visual and graphical check to evaluate rail turnout calculations consistency with Computer Aided Design (CAD) drawings. However, the automated checking of model quality and regulations' adherence could eliminate human prone errors from the design process [23].

In 2008, the American Institute of Architects (AIA), defined the Level of Development (LOD) [20], which is the term most used worldwide for defining BIM object content progress along the project development. It is used for coordinating modelling efforts between multiple parties [20]. This specification defines the model LOD as measure of model, estimate and schedule progression [20]. Currently, The LOD specification can be regarded as a measure standard and as such could be compared to a metric standard [21]. One example of this is the International System of Units kilogram, which as a controlled and fixed measure of mass could be considered as a benchmark against which all can compare [21]. However, its potential to serve as a measure of model progression for other uses rather than modelling, scheduling and cost (i.e risk management) has been underestimated. For the LOD to serve as a code validation tool the problem of domain expertise interpretation for the creation of the rules needs to be solved [22].

The Information Delivery Manual is used to create the Industry Foundation Class (common use data exchange interoperable format) Model View Definitions, which are contractual agreements that serve to include use case geometry, variables and rules relevant for the receiver of the data exchange [19]. The present research proposes modifying the Information Delivery Manual for the creation of a framework that allows the transformation of tacit turnout railway risk knowledge into appropriate LOD Exchange Requirements (data packages). Previous research has suggested attaching an LOD definition to an IDM Exchange requirement for IDM creation consistency [22, 23]. The creation of a risk LOD driven interoperable database will definitely have an impact on future design code checking and consequential risk assessment exercises.

### **3. Methodology**

In order to develop a BIM IS database, which could be used for rail turnout design risk mitigation, the authors modified the IDM data gathering process to adapt its methodology to the product LOD specification requirements. Although, the scope of this study is limited to rail turnouts risk management, the knowledge data mining methods presented below, could be applied to other BIM applications and Architectural, Engineering and Construction (AEC) products.

The IDM methodology steps proposed within the Wix and Karlshøj's (2010) IDM Guide to Components and Development Methods [24], is used within the present research (see Figure 2). However, the study is limited to the Process Discovery, Data Mining, Process Map and Exchange Requirements stages. The Process Map stage will be the focus of study within this paper and its impact within the Functional Part and Business Rules stages will be tested in further studies.

Therefore, the first step consists on identifying the principal processes for rail turnouts design. Furthermore, the link between design and risk has been studied by identifying the design factors influencing rail degradation.

The Data Mining stage consisted on studying the current literature published on Rail Turnout Design. This stage allows to deduct attributes associated with each of the design risk critical decision points. The following studies [25-30], [28, 29, 31-33] and the authors' experience on rail risk management were found sufficient to link attributes to critical decision points.

The process Map stage required studying the Business Process Modeling Notation language (BPMN). The organisational, behavioural and informational perspective were studied in relation to the LOD. Its intrinsic constituents: BIM use, Stage, LOD number of definitions, Geometry and Classification System were discretised to analyse its behaviour and impact within the functional perspective.

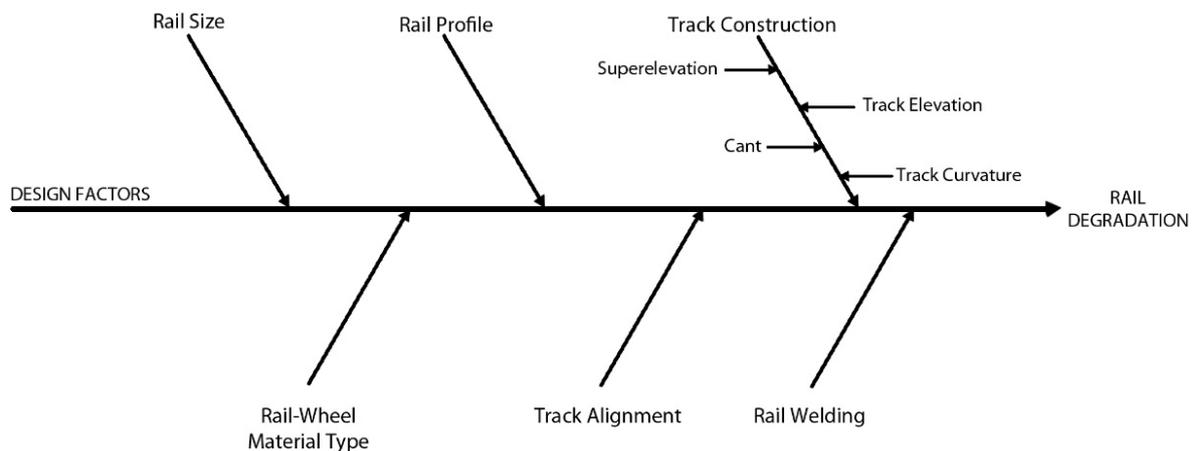
Finally, built on the previous stages, Exchange requirements associated to LOD definitions were identified and categorized for its inclusion within the BIM risk database.



**Figure 2.** Process discovery and data mining development sequence [21]

### 3.1. Process discovery of the design factors influencing rail degradation.

The discovery process entailed the analysis of various sources of information, including theses [25-27], journal papers [28, 29, 31-34] and engineering books [30]. The design factors contributing to rail degradation in order of occurrence are the following: Rail Size, Rail-Wheel Material Type, Rail Profile, Track Alignment, Track construction and Rail Welding. Track construction sub-factors account for Superelevation, Track Elevation, Cant and Track curvature. A cause and effect diagram summarises the factors contributing to rail degradation (see Figure 3).



**Figure 3.** Cause effect diagram on design factors causing rail degradation

### 3.2. Data Mining.

After deducing the design factors that lead to rail degradation, a data mining process is carried out. Within this section, we have analysed design factors related literature and found the attributes required to prepare the BIM model for a risk analysis based on design factors causing rail degradation. The critical factors analysed are the following:

**Rail Size:** The rail size degradation factor depends of the weight of the rail type expressed in kilograms per metre [27]. Therefore, when designing a rail for degradation mitigation purposes, the rail type should be selected based on the section weight given by the manufacturer.

**Rail Wheel material type:** Rail turnouts are critical points where the rail suffers maximum stress concentration [26]. Thus, manufacturers provide rails which tensile strength and toughness are increased by heat treatment to be used within this critical railway points [26]. The tensile strength of the steel measures the free propagation of a crack under stress and is measured in megapascals or newtons/millimeter<sup>2</sup> [35]. The fracture toughness is also an important mechanical properties of the steel and are measured in Pa·m<sup>1/2</sup> [32]. The types of steel are sorted out by their steel name, for example for check rails we can find the R200, R260, R320Cr types [33]. They give a measure of the tensile strength and material quality [36].

**Rail Profile:** Rail profiles are designed according to their operational requirements. For example, the section shape. The EN 13674-3:2006+A1 gives a list of check rail profiles, for example 33C1, 36C1, 40C1 and so on [38].

**Track alignment:** Track alignment irregularity causes lateral shift of a wheelset. Therefore, the rail-wheel geometry relationship is affected by a misalignment which is measured in mm. [38]. The effects of track alignment irregularity are wheel-rail wear. However, proper studied misalignment is beneficial to improve structure irregularity of turnout [38].

**Track construction:** The selection of appropriate railway curve parameters in combination with superelevation, track elevation plays a significant role to reduce rail wear [39].

- Superelevation or cant is measured in cm and is considered the difference in height between the inner and outer rail on a curve.
- track curvature: The main parameters to consider are curve radius, circular curve length and the transition curve length all measured in meters.

**Rail welding:** There are several weld techniques which can introduce defects into the rail such as porosity, blowholes, cracks or slag inclusions [40]. Rail welding is a critical operation that results in residual stresses which might be the cause of rail web failure [27]

### 3.3. Process Map

The IDM Process Map for rail turnout design code checking generated for this research is shown in Figure 5. The selection of the best LOD approach for the elaboration of a risk management database required a deep study of the LOD intrinsic constructs. Although many LOD specifications exist around the world, only three were analysed for its inclusion within the IDM. The LOD specification G202-2013 created by the American institute of Architects in the USA [41], the BIM Forum LOD Specification [42], and the PAS 1192-2-2013 [43] Level of Definition in the UK served to fulfill the sense of saturation needed to extract some preliminary conclusions. The following LOD constructs shown in Table 1 were compared: Classification, Stage, BIM use, LOD type and Illustration.

**Table 1.** LOD constructs compared

Year	Organisation and standard name	Classification	Stage and dependency	BIM use	LOD types	Illustrations
2013	[UK] PAS 1192-2-2013	NRM1, CESMM, Uniclass, NRM3 dependent on stage	End of project stage / Dependent	Design, Analysis, Coordination, Sequencing, Estimating, fabrication, capture of as installed information, operation, maintenance, performance	1: Brief, 2: Concept 3: Definition 4: Design 5: Build and Commission 6: Handover and closeout 7: Operation	Illustration
2013	[AIA] Document G202™-2013, Project BIM Protocol Form	UniFormat™, MasterFormat, Omniclass	Project milestones / Not dependent	Coordination, Analysis, Estimating, Scheduling, Other uses	100,200,300,400,500 which can be defined for each BIM use for each project milestone (20)	Not Found
2013	[AGC, AIA, BIM Forum] Level of Development (LOD) Specification v2013	UniFormat 2010	Not dependent	Geometry, Scheduling, Estimating, Coordination	100,200,300,350,400 (5)	Illustrations

The NMRA Technical Note TN-12 *Engineering Analysis and Geometric Design of Mode Railroad Turnouts* [1], sets the recommended design rationale used within this research to elaborate the Process Map.

### 3.4. Exchange Requirements

The LOD deduction process entailed analysing and comparing the LOD constructs against the design rationale from the NMRA. Furthermore, the cause effect diagram on design factors causing rail degradation (see Figure 3) helped to carry out the data mining exercise in section... The previous sections helped to deduct attributes as per LOD progression phases (Table 2).

**Table 2.** Rail turnout degradation attributes and units as per LOD.

LOD	Attributes	Units
200	Rail-Wheel material type	Material Type
	Tensile strength	Mpa
	Toughness	Pa.m <sup>1/2</sup>
300	Rail profile	Profile Type
	Rail size	Kg/m
350	Track alignment	mm
400	Superelevation	cm
	Curvature	m
	Rail welding	Weld Type

## 4. Results and Discussion

The present study has proposed the implementation of a framework for rail turnout code checking based on the LOD model progression (see Figure 4).

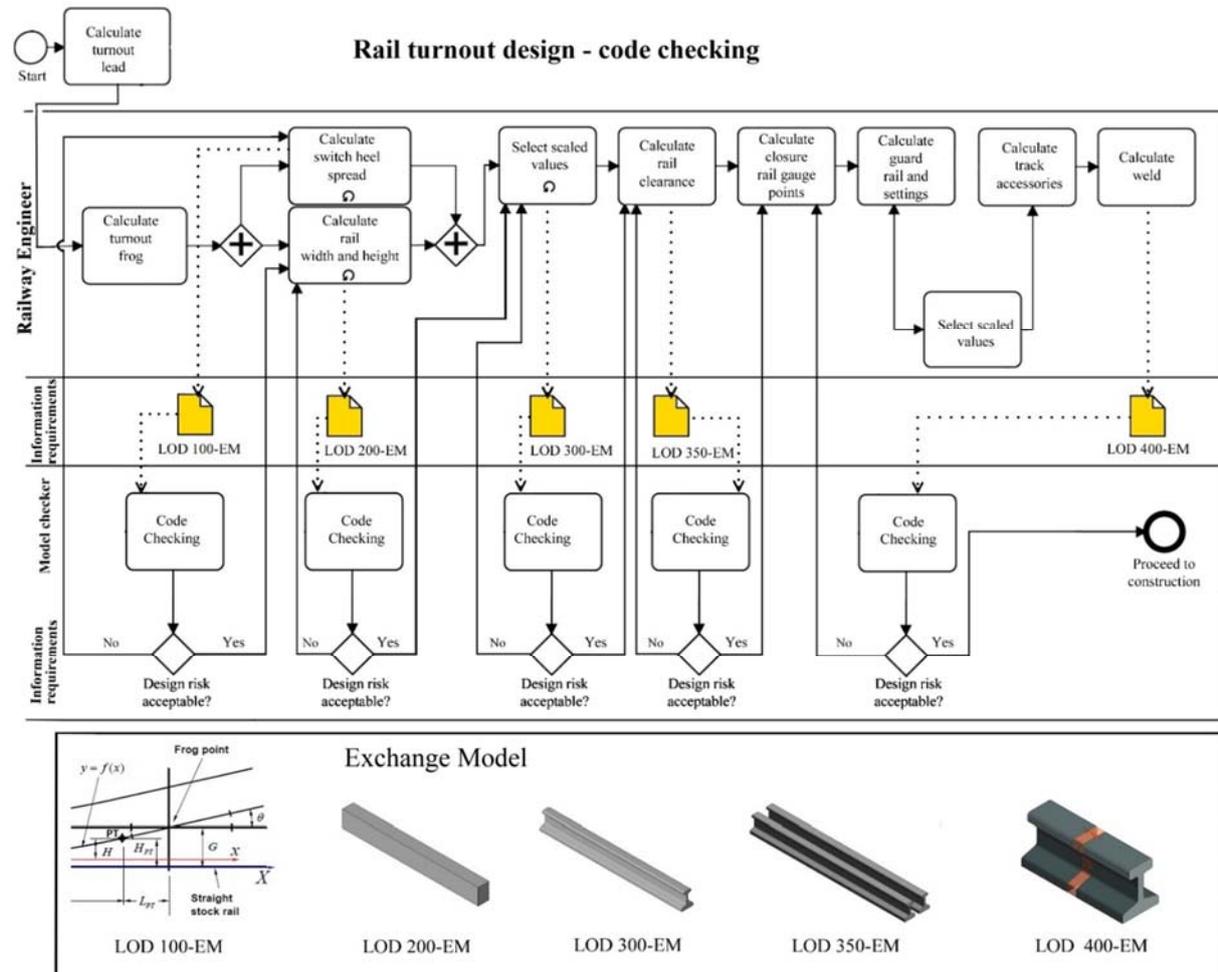


**Figure 4.** framework for rail turnout code checking based on the LOD model progression

The use of the framework yielded the following LOD progression to support design data checking for rail turnout risk mitigation (see **Chyba! Nenašiel sa žiaden zdroj odkazov.**):

- LOD 100 and LOD 200: The American Railway Engineering Association (AREA) and the NMRA sets tabulated dimensions for turnouts. First, the designer should generate an approximate design. For example, as stipulated within the NMRA Technical Note TN-12 scale-independent equations.
- LOD 300: Later, the designer should consider producing scaled models with consistent dimensions, i.e. based on AREA and NMRA tabulated dimensions. Thus, using interoperable dimensions for product manufacturing comparison and selection [1].
- LOD 350: At this stage, the rail clearance should be inferred from the model, i.e. this can be useful to set the minimum railheads distance in a switch heel, which will be a function of the wheel flange thickness. Other relationships between parallel rails can be inferred, for example track alignment.
- LOD 400: Finally, installation and construction requirements can be inferred from the model and weld type and position can be precisely indicated.

The criteria for choosing a LOD specification was based on its benefits for code checking validation and generation of a risk database. The following LOD constructs were analysed: Classification, Stage, BIM use, LOD type and Illustration.



**Figure 5.** IDM process map for rail turnout design code checking

The AIA G202-2013 LOD allows for 4 authorised uses (Coordination, Analysis, Estimating and Scheduling), while it sets 5 phases of model progression that ranges from 100 (Generic), 200 (Approximate), 300 (Specific), 400 (Installation) and 500 (As build). Similarly, the BIM Forum LOD Specification v2013, introduces the LOD 350 for clash detection purposes [42]. Within these two specifications there are not LOD-Stage bindings. Thus, making it an accessible specifications to carry out model checks at the designer’s interest as an activity parallel to design.

On the contrary, the PAS 1192, is a LOD-stage binding specification, which makes it difficult to specify product model progression independently of other products or assemblies [43]. The levels of model progression are the following 1 (Brief), 2 (Concept), 3 (Definition), 4 (Design), 5 (Build and Commission), 6 (Handover and closeout) and 7 (Operation).

Finally, the BIM Forum Specification gives a detailed description and illustration as per LOD, making LOD specification reliable both as model exchange input and output. Furthermore, it uses a classification system based on the Unifomat 2010 classification which could be used to identify products within BIM databases.

It was found that the best approach to code checking risk mitigation entailed selecting: LODs based on a classification system, non-stage dependent LODs, illustration based LODs and authorized uses which the designer can rely upon.

The advantage of LOD based design code checking over the previous approach (CAD files visual inspection) is that it can be used to minimize human prone design errors and mitigate its translation into the construction stages. The presented approach could also help to detect problems during design at periodical preset milestones without affecting later design stages. Thus, minimizing waste during design.

Furthermore, the wide LOD variety of constructs, gives place to freedom of choice for purpose-based LOD construct selection. However, a framework for LOD implementation must be adopted by the industry in order to be able to advance in the field of IDM LOD based rule creation.

## 5. Conclusion

The present paper modifies the IDM methodology to integrate risk assessment methodologies during the IDM process discovery stage. Furthermore, it studies various LOD constructs for its implementation within the IDM standard. The integration of design factors causing risk, i.e. risk of derailment in railway turnouts, during the data discovery process of the IDM methodology has helped to discretize only the required data to build a risk management BIM database. The assignment of an LOD construct to a set of data, requires specialised management and process related expertise. This study is limited to single type of manufacturing product and BIM use. However, once the LOD implementation process within the IDM has been established it sets the link for prevention through design BIM risk management. Notwithstanding, the authors acknowledge that other researchers might find difficulties on selecting the best LOD approach to code checking. Thus, future study will study the proposal of a LOD framework for IDM implementation with the aim to advance in the area of LOD based code checking.

## Acknowledgement

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

## References

- [1] NMRA. "Engineering Analysis and Geometric Design of Model Railroad Turnouts". In: V.S. Fehr, editor. NMRA Technical Note TN-12: National Model Railroad Association, Inc.; 2015.
- [2] S. Dindar, S. Kaewunruen, J.M. Sussman. "Climate Change Adaptation for GeoRisks Mitigation of Railway Turnout Systems". *Procedia Engineering* 2017;189:199-206, <https://doi.org/10.1016/j.proeng.2017.05.032>.
- [3] Dindar S., Kaewunruen S. (2018) Assessment of Turnout-Related Derailments by Various Causes. In: Pombo J., Jing G. (eds) Recent Developments in Railway Track and Transportation Engineering. GeoMEast 2017. Sustainable Civil Infrastructures. Springer, Cham, [https://doi.org/10.1007/978-3-319-61627-8\\_2](https://doi.org/10.1007/978-3-319-61627-8_2)
- [4] S. Dindar, . S. Kaewunruen and M. An, "Identification of appropriate risk analysis techniques for railway turnout systems," *Journal Of Risk Research*, pp. 1-21, E-pub ahead of print, 2016, <http://dx.doi.org/10.1080/13669877.2016.1264452>.
- [5] ERA. "Rail accidents by type of accident (ERA data)". In: E.R. Agency, editor. Luxembourg2014.
- [6] European Commission. "Final Report Summary – D-RAIL (Development of the Future Rail Freight System to Reduce the Occurrences and Impact of Derailment)". 2015.
- [7] RSSB. "Derailment mitigation-categorisation of past derailments (T078 Report)". London: Rail Safety & Standards Board; 2004 17/03/2004.
- [8] M. Gangolells, M. Casals, N. Forcada, X. Roca, A. Fuertes. "Mitigating construction safety risks using prevention through design". *Journal of Safety Research*. 2010;41(2):107-22.

- [9] T.M. Toole, J. Gambatese. "The trajectories of prevention through design in construction". *Journal of safety research*. 2008;39(2):225-30.
- [10] M.D. Martínez Aires, M.C. Rubio Gámez, A. Gibb. "Prevention through design: The effect of European Directives on construction workplace accidents". *Safety Science*. 2010;48(2):248-58.
- [11] Kaewunruen S., Remennikov A.M., Dindar S. (2018) Influence of Asymmetrical Topology on Structural Behaviours of Bearers and Sleepers in Turnout Switches and Crossings. In: Pombo J., Jing G. (eds) Recent Developments in Railway Track and Transportation Engineering. GeoMEast 2017. Sustainable Civil Infrastructures. Springer, Cham
- [12] S. Kaewunruen, J.M. Sussman, A. Matsumoto. "Grand challenges in transportation and transit systems". *Frontiers in built environment*. 2016;2:4.
- [13] S. Dindar, S. Kaewunruen, M. An. "Identification of appropriate risk analysis techniques for railway turnout systems". *Journal of Risk Research*. 2016:1-22.
- [14] D.C. Kent, B. Becerik-Gerber. "Understanding Construction Industry Experience and Attitudes toward Integrated Project Delivery". *Journal of Construction Engineering and Management*. 2010;136(8):815-25.
- [15] M. Murray, M. Murray, D. Langford. Rethinking construction: the egan report (1998): Blackwell Science, Oxford, UK; 2003.
- [16] S.M. Latham. Constructing the team: HM Stationery Office London; 1994.
- [17] AIA. "Integrated Project Delivery: A Guide". In: A.N.A.C. Council, editor. version 1 ed2007.
- [18] O.A. Olatunki, Sher, , G. W., N. . "Building information modelling and quantity surveying practice ". *Emirates Journals for Engineering Research*. 2009.
- [19] W. Solihin, C. Eastman. "Classification of rules for automated BIM rule checking development". *Automation in construction*. 2015;53:69-82.
- [20] BIM Forum. "Level of Development Specification" for Building Information Models: Specification BIM Forum; 2016.
- [21] R.H. Allen, R.D. Sriram. "The Role of Standards in Innovation". *Technological Forecasting and Social Change*. 2000;64(2-3):171-81.
- [22] A. Gigante-Barrera, D. Ruikar. "BIM maturity implementation for Electrical Manufacturers within the UK: Model Element LOD Creation Using the Information Delivery Manual Standard". In: N. Yabuki, K. Makanae, editors. *Proceedings of the 16th International Conference on Computing in Civil and Building Engineering*; July 6 - 8, 2016; Osaka, Japan. Osaka, Japan: ICCCB2016 Organizing Committee; 2016. p. 156
- [23] Y.-C. Lee, C.M. Eastman, W. Solihin. "An ontology-based approach for developing data exchange requirements and model views of building information modeling". *Advanced Engineering Informatics*. 2016;30(3):354-67.
- [24] J. Wix, J. Karlshøj. "Information Delivery Manual Guide to Components and Development Methods". BuildingSMART International; 2010 05/12/10.
- [25] R.B. Faiz. "An empirical rail track degradation model based on predictive analysis of rail profile and track geometry": © Rizwan Bin Faiz; 2010.
- [26] K. Karttunen. "Influence of rail, wheel and track geometries on wheel and rail degradation". Göteborg, Sweden: Chalmers University of Technology; 2015.
- [27] S. Kumar. "Reliability analysis and cost modeling of degrading systems". Luleå, Sweden: Luleå tekniska universitet; 2008.
- [28] A.R. Andrade, P.F. Teixeira. "A Bayesian model to assess rail track geometry degradation through its life-cycle". *Research in Transportation Economics*. 2012;36(1):1-8.
- [29] A.R. Andrade, P.F. Teixeira. "Uncertainty in rail-track geometry degradation: Lisbon-Oporto line case study". *Journal of transportation engineering*. 2011;137(3):193-200.
- [30] K. Tzanakakis. The railway track and its long term behaviour: a handbook for a railway track of high quality: Springer Science & Business Media; 2013.

- [31] Y.-J. Zhang, M.H. Murray, L. Ferreira. "Modelling rail track performance: an integrated approach". *Transport Journal*. 2000:187-94.
- [32] G. Chattopadhyay, S. Kumar. "Parameter estimation for rail degradation model". in *International Journal of Performability Engineering*. 2008.
- [33] C. Vale, S.M. Lurdes. "Stochastic model for the geometrical rail track degradation process in the Portuguese railway Northern Line". *Reliability Engineering & System Safety*. 2013;116:91-8.
- [34] I. Soleimanmeigouni, A. Ahmadi, U. Kumar. "Track geometry degradation and maintenance modelling: A review". *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit*. 2016:0954409716657849.
- [35] C.-j. Liu, Y.-h. Huang, M.-f. Jiang. "Effects and Mechanisms of RE on Impact Toughness and Fracture Toughness of Clean Heavy Rail Steel". *Journal of Iron and Steel Research, International*. 2011;18(3):52-8.
- [36] K. Mädler, A. Zoll, R. Heyder, M. Brehmer, editors. "Rail materials—alternatives and limits". *Proc 8th World Congress on Railway Research (WCRR), Seoul, Korea; 2008*
- [37] BSI. "EN 13674-3:2006+A1:2010". Railway applications Track Rail Check rails: British Standards Institution; 2006.
- [38] L. Wang, P. Wang, S. Quan, R. Chen. "The effect of track alignment irregularity on wheel-rail contact geometry relationship in a turnout zone". *Journal of Modern Transportation*. 2012;20(3):148-52.
- [39] J. Wang, X. Chen, X. Li, Y. Wu. "Influence of heavy haul railway curve parameters on rail wear". *Engineering Failure Analysis*. 2015;57:511-20.
- [40] G.N. Namboodiri, K. Balasubramaniam, T. Balasubramanian, J. James, Sriharsha, D.O. Thompson, et al., editors. "Rail weld inspection using phased array ultrasonics". *AIP Conference Proceedings*; 2013: AIP.0735411298
- [41] AIA. "AIA Document G202–2013". Project Building Information Modeling Protocol Form: American Institute of Architects; 2013.
- [42] BIM Forum. "Level of Development Specification ". for Building Information Models: Specification BIM Forum; 2013.
- [43] BSI. "PAS 1192-2 ". Specification for information management for the capital/delivery phase of construction projects using building information modelling: British Standards Institution; 2013.