

Automatic Analysis of Standards in Rail Projects

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Abstract – This research develops a system to check standards and specifications automatically for geometric railway projects, aiming to avoid high construction and operating costs, noncompliance with design requirements, and even fatal accidents. This study is important due to the increasing quality requirements for the design projects.

The methodology used consists of five stages: literature review on Code Checking and Building Information Modeling with the intention to search for the theoretical and methodological development of research grants; literature review on the specifications and requirements of geometric railway projects; development of a code checking system using the software Excel; application of the system developed to an existing railroad; analysis of the results found.

Keywords: Building Information Modeling, BIM, Code Checking, Geometric Project, Railway Standards.

I. INTRODUCTION

The increased demands on Brazil's national railway grid leads to the necessity of fitting existing railroads to current needs – duplicating lines, changing geometries, reducing logistics costs – and the construction of new structures.

Licensing is a mandatory stage of any project; it consists of checking compliance with standards. Automating this process is a solution which ensures that all specifications will be verified.

II. LITERATURE REVIEW

Building Information Modeling

Building Information Modeling (BIM) represents a new approach to the conception, construction and management phases of a Project. This approach is aided by tools capable of integrating and automating important data into a single, precise, virtual model [10].

BIM consists of an intelligent system that is not only used to create a project's geometry, but which also includes non-geometric data [9]. Each item represents a real object (not only an arrangement of points, lines and curves) containing descriptions such as dimensions, weight, material, manufacturer, fire resistance, cost, phase when it will be implemented, and other relevant information [1]. Beyond the isolated characterization of each component,

BIM works with the concept of parametric integrity of the elements, in which all the aspects of the project are related. In other words, an object knows about the existence of another object, as well as its hierarchical level [11].

The BIM model has 6 dimensions: 3 dimensions related to the tridimensional coordinates x, y and z; the fourth dimension is time; the fifth is cost; and the sixth is the project's life cycle [7].

A BIM model achieves clarification of the client's requirements in the early stages of a project; reduction of costs and materials waste; improvement in the use of labor; higher productivity and improvement of deadline achievement; quantification and estimation of costs; inclusion of requirement- and specification-checking; distribution of responsibilities, risks and rewards among stakeholders; and, creation of a collaborative project. Scheduling and logistics activities can also be included in the model [11]. In summary, one single model promotes integration among standardizations, processes and technology [17].

As if this were not enough, BIM model implementation brings the ability to share essential data to the team, making sure that all stakeholders have access to exactly the same information [20], thus providing consistent and non-redundant data [8]. Therefore, the systems' interoperability is ensured.

Communication between software, its packages and languages, is essential to keep information open and accessible among users, and to maintain its interoperability. Nowadays, the IFC format is the most supported among BIM software [14]. Revit, Bentley Systems, ArchiCAD, Digital Project, Auto-CAD based applications (Civil 3D), and Tekla Structures are examples of BIM tools [4].

Code Checking

Buildings usually follow legislation, which varies according to building type. Regulations and legislation are written by humans and, for a long time, were also read and interpreted only by humans. For this reason, at times they are incomplete, disregard specific conditions, and are contradictory. Standards- and regulations-checking, traditionally, are also done manually (even when there's machine help). This paper aims to demonstrate the benefits of automating checking processes.

Code checking is a computer-aided process of revision and validation that does not change a project's design. In

general, it is focused on principles and specifications for comfort, security, accessibility and performance [10].

Eastman [3] divides code checking into four phases: 1) interpretation and logical structuring of codes to be applied; 2) preparation of a construction model in which the information to be checked is prepared; 3) execution of code checking; 4) reporting results.

Code interpretation utilizes human language, typically texts, tables and equations to be translated into programmable code.

In this paper, in addition to the phases established by Eastman [3], a checking system will be developed using Excel.

A variety of programmable languages has been proposed since the mid-20th century [10]. Their benefits are that, beyond the portability principle (they can be used by different tools), if they are well developed they can match human languages with no restrictions, covering every aspect of the regulation.

However, none of the proposed languages have presented software compatibility or proper human language representation [10]. Recent improvements in the BIM platform can lead to key solutions, since BIM models contain data at all levels of detail, including complex information. This information can contribute to the checking process of the model as a whole. Correlating the properties and functions of the BIM model and translating the regulations into a programmable language makes the checking process much easier and more direct.

According to Tan [19], automated checking systems must consider that: 1) objects not following the standards should be identified by the system; 2) regulations must meet specific situations ; 3) checking systems must adapt to regulations and code changes; 4) regulations must be considered according to region or country; 5) there must be adequate interaction between standardization writers and users, to avoid systems errors.

Railway Infrastructure

The railway infrastructure is composed of earthwork located below the earthmoving grade. The top surface is the railroad platform [2].

The railroad superstructure is composed of the permanent way, which is divided into ballast, sub-ballast, ties and rails [2]. The superstructure is arranged to receive 20 to 30 tons per axle load [6].

GEOMETRY

The geometric project of a railway structure is the correlation of physical elements with the operational, braking, security and comfort characteristics of the track. It is guided by theoretical calculations and empirical results. It includes the plan, transverse and longitudinal layout and features a design that defines the speed according to the main geometric characteristics of the track [12].

There are some important elements to be checked:

- Minimum Radius of the horizontal curve:

Railroads have requirements for the minimum track radius related to the wheel-track solidarity, vehicle adherence on ramps, and parallelism of the axes of the same bogies [13].

The radius must be calculated according to the total gap between the wheel and the rail to ensure the free, intermediary and normal inscription of the vehicle. This calculation is made using formulas proposed by Brina (1960). The maximum calculated value is taken as the minimum radius value [2].

For passenger trains, the minimum radius is 120 meters. For loaded freight trains, the minimum radius is 90 meters [16].

According to PTSOM's Code of Practice, the minimum radius for main lines is 200 meters [15].

- Superelevation:

A train, as well as any object, traveling a curved trajectory experiences a force pushing it to the external part of the line, known as centripetal force. To combat the damaging effect of centrifugal force, a superelevation to the railway curves is adopted.

The superelevation is calculated according to Security and Comfort criteria and is a function of the resultant eccentricity. The maximum calculated value (using formulas proposed by Brina) is then adopted for the specific curve [2].

According to Brazilian Railway Standards [2], the superelevation in millimeters can, at most, achieve the value of 125 times the gauge expressed in meters.

- Maximum speed in the curves

To find the speed limit, it is necessary to establish values of maximum superelevation (hmax), determining the limit speeds in the curves according to security and comfort criteria [2].

- Minimum speed in the curves

Also, operating lines that share the traffic of both passengers and freight need to establish a minimum speed to prevent the loaded train from tipping to the internal part of the track (if there is insufficient centrifugal force) [2].

- Gauge Increase

In the curves, the gauge increases its width slightly. The formula to calculate it is proposed by Brina (1960). In practice, this increase varies within an interval of 1 to 2 centimeters [2].

Guardrails

Guardrails are put in the internal part of the line, together with the rail, especially in bridges and level crossings. Guardlines intended to prevent derailment require a specific distance from the rail, calculated using an expression proposed by Brina [2].

Forces Acting on the Route

The railroad is subjected to a series of vertical, transversal, and longitudinal loads. Knowledge thereof is important, not only to dimension the line but also to maintain it.

It is important to consider a dynamic coefficient in order to calculate bending moments in the track that are due to the different load effects coming from the movement of vehicles.

Although there is uncertainty related to the dynamic coefficient to be adopted, due to the conditions of rolling stock and the permanent way in which coefficient experiments are performed, this work will use a more modern expression that is used by AREA (American Railway Engineering Association) [2].

Bending Moment Calculations

The Zimmermann method will be applied to calculate the bending moment, t. This method is more realistic since it considers the crossties as elastic supports and provides results 10% above the results obtained using so-called “exact” methods. For that reason, it is considered conservative. It considers two fundamental hypotheses: one assumes the load influence of only a few gaps; the other considers loads in each crosstie proportional to the hold pressure.

The moments are calculated using both loading hypotheses, and the maximum calculated value is adopted.

The maximum permissible moment corresponds to the result of multiplying the Resistance module of the rail profile by the allowable tension, set at 1500 kg/cm² [2].

For heavily loaded trains, besides verifying the rail resistance to bending, the tension (σ) in the wheel-rail contact should also be checked. According to AREA (American Railway Engineering Association) recommendations, this must not exceed 50000 psi for new wheels and 67500 psi for used wheels [2].

III. CODE CHECKING SYSTEM

Code checking was developed based on to standards for rail projects in order to analyze parameters and standardizations according to approval or disapproval criteria. In other words, to determine whether the value meets or does not meet the specifications listed in the previous item.

The checking system, inserted into the BIM environment, ensures the success of the project from conceptual design to the end of its life cycle, since it can be entirely simulated and analyzed in the early stages. Thus, it can prevent incompatibility problems which would otherwise be detected only in the construction and operational phases. The costs of the project increase significantly when it is badly managed. The developed system enables, even in a restricted way, a series of modification studies and modification studies, including existing and new railroad projects.

The developed system requests input data such as radius, curve and tangent extension. These data are first analyzed and then extracted from the software used to make the design. Next, they are transferred manually to Excel. For this reason, the checking process is considered semiautomatic.

However, according to BIM principles, it would be ideal if the code checking system was inserted into a Civil3D (or other design software) package; or, at least, if it had a format compatible with the design software. In this way, all verifications and analysis would occur in a fully automatic way, either by checking codes concomitantly with the design creation or by importing data from one application to another.

Spreadsheet assembly:

The spreadsheet was created with two input sections, one including geometric data regarding curves (radius and length), tangents (extensions) and train stations (extensions and number of users getting on and off), shown in the following image:

Event	Input data						
	Speed	Curve		Tangent	Station		
		Radius (m)	Extension (m)	Extension (m)	Extension (m)	Ppl Entry	
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Figure 1: Input Section 1

The other input section includes specific data, shown in the figure below:

Speed of Project	-
Gauge (m)	-
Rail profile	-
Locomotive	-
Wheel Radius	-
Wheel-Rail Gap	-
Height of friezes (m)	-
Thickness of friezes (e)	-
Rigid Base of Vehicle (m)	-
Rail Module of Elasticity (KN/cm ²)	-
stationary wheel/axle load (Kgf)	-

Figure 2: Input Section 2

From those parameters, it is possible to calculate and check the geometry compliance with the regulations of the entire line.

The section projected right beside the geometric input section is the output section, which includes the code checking for the parameters of curve, tangent and station. Each row of the table corresponds to a specific event (curve, tangent or station), so only the data for that specific event will be inserted in each row of this table. Subsequently, outputs for the specific event will be generated.

The system shows an interesting approach since it can detect direction and specific nonconformities; in other words, it is possible to locate exactly the nonconforming

curve and make the necessary adjustments. This allows the designer to decide whether a discrepancy is acceptable or not; if not, to simulate a series of design changes, giving flexibility to the design of the project. The designer is able to go through all the errors and nonconformities in a quick and intuitive way, as the program indicates exactly where the problems are. These nonconformities are established according to maximum allowable values, discussed in the previous section.

IV. TEST OF THE SYSTEM DEVELOPED

The created system correlates existing geometric data in order to check all project parameters.

The regional train from Itapecuru Mirim (MA) to São Luís (MA), in the project developed by the Federal University of Minas Gerais (UFMG), was chosen to exemplify the operation of the system.

Each event of the project was recognized (if it is a curve, tangent or station), geometric data were extracted and conformities were checked. Also, the frequency with which the cars go through each station was analyzed according to the studied demand. Train speed through curves and tangents in between stations, meeting all station demands and without the risk of accidents, was determined. Therefore, all standards should be met.

The system enables changing speed rapidly in each section of the line, increasing it when possible and decreasing it in case of noncompliance with a specified parameter. At the same time, it enables meeting the requested demand. All codes are checked instantly, making it possible, in terms of time and cost, to simulate different speeds in each section, or to change inputs such as radius or speed until there is alignment of the necessary conditions.

Itapecuru Mirim (MA) - São Luís (MA) Regional Train Analysis

Nucletrans – The Transportation Center in the Transportation and Geotechnical Engineering Department of the UFMG Engineering School – conducted a study to evaluate technical and economic revitalization of the idle Itapecuru Mirim - São Luís (MA) extension for use in passenger transportation.

Demand

In this study, the main focus is not on the demand, but on the geometric means. For practical purposes, a maximum demand of 5000 users is adopted and divided equally among the stations.

Design Guidelines

The railway stretch studied has been operated by Transnordestina Logística S.A. The intention is to share the existing freight transportation with passenger transportation. For that, it is necessary to make verifications to meet both freight and passenger infrastructure. In this paper, passenger verification exclusively will be analyzed.

The line that goes from São Luís to Itapecuru Mirim has an approximately 115 km single way extension, containing seven stations.

The main permanent way characteristics are listed below:

- Gauge 1,000 mm
- Rail profile TR-57, with dimensions in centimeters, specified in the following figure:

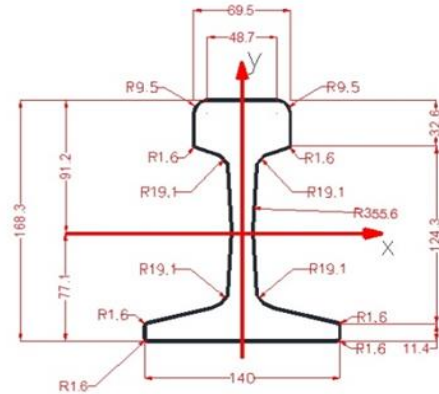


Figure 3: Rail Profile Source: [5]

- Distance from center to center of rails 1.07 meters;
- Mobile Model, produced by Bom Sinal:
 - Wheel diameter (new/used): 838.2/750 mm;
 - Thickness of friezes (mm): 30 mm;
 - Height of friezes (mm): 25mm;
 - Rigid Base of Vehicle (m): 2.86 m;

The trainload was not specified, so the maximum value stipulated by Greco [6], 30 tons per axle, will be considered for security.

The following table lists the events of the geometric layout (the table shows a sample of the events) in order of occurrence, regarding curves, tangents and stations. They are characterized according to municipality, arc extension, radius and length of the tangents of each section. For the stations, the input and output demands will be considered as equal, as previously discussed. They are presented in the table, below:

CITY	EVENT	ARC EXTENSION (m)	R (m)	T (m)
São Luís	Tirirical Station	-	-	-
São Luís	Curve 15	382.02	242.56	-
São Luís	Tangent 15	-	-	1156
São Luís	Curve 16	301.61	283.6	-
São Luís	Tangent 16	-	-	241

Figure 5: Events of the geometric layout [5]

Test of Spreadsheet

The checking process was done in order to consider different scenarios: 60, 80, 100 and 120 km/h. All input data were extracted from the project report made by ETG [5] in 2014.

V. ANALYSIS OF THE RESULTS

In the scenarios tested, nonconformities were detected in the radius, superelevation, maximum speed on curves, minimum speed (referring to freight trains, so that they won't be analyzed) and bending moment in the tangent.

Tables with comparable results of complete events are shown below:

Event	Curve		Rminimum			
	R (m)	Ext (m)	60 km/h	80 km/h	100 km/h	120 km/h
Curve 15	382.02	242.56	345.125	345.125	345.125	345.125
Curve 16	301.61	283.6	306.7778	306.7778	306.7778	306.7778
Curve 17	229.26	261.25	258.8438	258.8438	258.8438	258.8438
Curve 18	202.3	408.85	258.8438	258.8438	258.8438	258.8438

Figure 4: Comparable Minimum Radius

In the analyzed patch, despite compliance with the Railway Group Standard [16] specification of a minimum radius of 120 meters and the PTSOM Code of Practice (2008) specification of a minimum radius of 200 meters [15], some values calculated using the formulas proposed to Brina [2] are less than the measured existing values. Therefore, curves 16, 17, 18, 19, 25, 26, 27 and 31 must be modified.

Event	Adopted Superelevation			
	60 km/h	80 km/h	100 km/h	120 km/h
Curve 15	0.027709	0.089409	0.168738	0.265696
Curve 16	0.048858	0.127008	0.227486	0.350293
Curve 17	0.080567	0.183379	0.315566	0.477128
Curve 18	0.098184	0.214697	0.3645	0.547593

Figure 5: Comparable Superelevation

According to the Brazilian Technical Rules for Railroads [2], the superelevation of the curves must meet a limit, in meters, of 125 times the gauge extension (in millimeters). In the analyzed patch, the value was exceeded in some curves for the speeds of 80, 100 and 120 km/h.

Event	Adopted Maximum speed (km/h)			
	60 km/h	80 km/h	100 km/h	120 km/h
Curve 15	68.44765	68.44765	68.44765	68.44765
Curve 16	60.81887	60.81887	60.81887	60.81887
Curve 17	53.02487	53.02487	53.02487	53.02487
Curve 18	49.80964	49.80964	49.80964	49.80964

Figure 6: Comparable Maximum Speed

The speeds of the tested scenarios exceeded the maximum speeds stipulated by the formulas proposed by Brina [2]. In this way, the train can, at most, achieve the

maximum calculated speed. To minimize the time spent traveling from one station to another, the train can accelerate and gain speed (above curve limits) in the stretches of tangent.

Event	Adopted Mmax - tangents			
	60 km/h	80 km/h	100 km/h	120 km/h
Tangent 15	350616.1	388525.6	437266.3	496838.4
Tangent 16	350616.1	388525.6	437266.3	496838.4
Tangent 17	350616.1	388525.6	437266.3	496838.4
Tangent 18	350616.1	388525.6	437266.3	496838.4

Figure 7: Comparable Bending Moments

The maximum bending moments in tangents are below the limit of 442500 KN.m (according to Brina [2] $\sigma = M/W \leq \sigma_{adm} = 1500 \text{ kg/cm}^2$) for the 60, 80 and 100 km/h speeds. The values exceed this limit for the 120 km/h speed.

The time spent traveling between Tirirical Station and Pirraça Station, assuming constant speeds all the way, is shown for these scenarios in the table below:

Speed	Time Spent (seconds)
60 km/h	1020.1002
80 km/h	765.07515
100 km/h	612.06012
120 km/h	510.0501

Figure 8: Time Spent traveling between Stations

To meet the demand for time reduction, to a maximum of 900 seconds, it is possible to simulate speed changes in some sections, thereby ensuring compliance with all parameters.

The modifications made are shown in the following table (only for the sample events):

The radius that were smaller than the minimum required radius were modified to the calculated limit (Figure 4). The speeds in the tangent section is the maximum speed meeting the maximum bending moment (Figure 7). The speeds in the curves were adjusted according to the maximum calculated speed (Figure 6). After making these adjustments, those curves in which the superelevations still exceeded the limits had their speeds reduced.

The total time spent traveling to the Pirraça Station was 685 seconds. Considering that there are speed reductions in some curves, speed must be decreased in the previous tangents and increased in the following tangents (up to 100 km/h). In practice, the time spent will be greater than 685 seconds.

Event	Input Data		Output Data			
	Curve		Curves			Tangent
	Speed	Radius (m)	Rmin(m)	Superelevation	MaxSpeed (km/h)	Mmax(kgf.cm)
Tirirical Station	80	-	-	-	-	-
Curve 15	80	382.02	345.125	0.0894	68.44	-
Tangent 15	100	-	-	-	-	437266.34
Curve 16	80	306.78	306.78	0.1239	61.33	-
Tangent 16	100	-	-	-	-	437266.34
Curve 17	55	375	375	0.04675	56.34	-
Tangent 17	100	-	-	-	-	437266.34
Curve 18	70	258.84	258.84	0.1077	56.34	-
Tangent 18	100	-	-	-	-	437266.34

Figure 9: Modified Table

For practical purposes, this difference will not be calculated. To meet the required 900 seconds, there will be a 30% time increase, which is considered sufficient. In this way, the alterations made will meet the required demand without compromising the technical conditions of the layout geometry.

VI. CONCLUSION

Specification compliance is not only important for project approval. Poor technical conditions of the geometric layout (translated by non-compliance with specifications) result in high construction and operating costs, noncompliance with design requirements (such as demand) and even fatal accidents (the deviation from regulations of minimum radius, maximum speed, minimum superelevation, among other parameters).

Inserted into the BIM context, the standardization checking system discussed in this paper can extract information directly from the model. It can avoid mistakes and omissions and facilitate the project's validation. Automatic licensing becomes a reality, using the BIM implementation.

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