STANDARDIZATION OF TECHNICAL INFORMATION ON RAILWAY PROJECTS TO OBTAIN PERFORMANCE INDICATORS

NORMALIZAÇÃO DA INFORMAÇÃO TÉCNICA DE PROJETOS DE INFRAESTRUTURAS FERROVIÁRIAS PARA OBTENÇÃO DE INDICADORES DE DESEMPENHO

10.29073/rae.v2i1.865

RECEÇÃO: 14 de julho de 2023.
APROVAÇÃO: 15 de dezembro de 2023.
PUBLICAÇÃO: 6 de fevereiro de 2024.

AUTOR/A 1: Filipa Salvado, LNEC, Portugal, asalvado@lnec.pt.
AUTOR/A 2: Maria Falcão, LNEC, Portugal, mjoaofalcao@lnec.pt.
AUTOR/A 3: Paula Couto, LNEC, Portugal, pcouto@lnec.pt.
AUTOR/A 4: Simona Fontul, LNEC, Portugal, simona@lnec.pt.

ABSTRACT

During the last decades, there has been a significant evolution of rail transport. The need to standardize technical and economic information is emphasized to guarantee the optimization of construction and operation activities, as well as the challenge of developing databases with robust and reliable information that can be transferred and used throughout the whole life cycle of constructed assets. ProNIC (Portuguese abbreviation for Protocol for the Standardization of Construction Technical Information) is a research project that developed a methodology (into a computer tool) to standardize information for the lifecycle of constructed assets, while enabling the benchmarking of similar types of construction projects. This methodology has already been implemented in the building subsector. The present paper shows the results of the implementation of ProNIC methodology in railway infrastructures. Based on the analysis of different real projects, a normalized work breakdown structure (WBS) for railway works is developed, leading to the updating of the characterization of railway infrastructures in ProNIC. All documentation produced is implemented in ProNIC. To validate this method, a case study (section of a ballast railway with 29 km) is used to conceptualize the WBS proposed and the created technical contents and specifications. These developments, provided the conception of standard elements capable of being adapted to any case of railway works, based on the Portuguese and European legal standards and frameworks. A national referential, to be used in all types of public railway infrastructure projects, is defined.

KEYWORDS: Performance Indicators; ProNIC; Railway Projects; Standardized Information.

RESUMO

Durante as últimas décadas, houve uma evolução significativa do transporte ferroviário. Enfatiza-se a necessidade de normaliização da informação técnica e económica para garantir a otimização das atividades de construção e operação, bem como o desafio de desenvolver bases de dados com informação robusta e fiável. O ProNIC (Protocolo de Normalização da Informação Técnica da Construção) é um projecto de investigação que desenvolveu uma metodologia (numa ferramenta informática) de normalização da informação, já implementada no subsetor dos edifícios, e que permite análises comparativas de projetos com base em indicadores de desempenho. O presente artigo apresenta os resultados da implementação da metodologia ProNIC no subsetor de infraestruturas ferroviárias. Com base na análise de diferentes projetos reais, é desenvolvida uma estrutura analítica de projeto (*work breakdown* *structure, WBS*) normalizada para obras ferroviárias que conduziu à caracterização da infraestrutura ferroviária no ProNIC. Toda a documentação produzida é implementada no ProNIC. Para validar este método, é utilizado um caso de estudo (trecho de uma ferrovia com 29 km) para conceituar a WBS proposta e os conteúdos técnicos e especificações desenvolvidas. Estes desenvolvimentos proporcionaram a conceção de elementos normalizados adaptáveis a qualquer caso de obra ferroviária, com base nas normas e enquadramentos legais portugueses e europeus. É também definido um referencial nacional, a utilizar em todos os tipos de projetos de infraestruturas ferroviárias públicas.

PALAVRAS-CHAVE: Indicadores de Desempenho; Normalização da Informação; Projetos de Infraestruturas Ferroviárias; ProNIC.

1. INTRODUCTION

A significant evolution in rail transport, over the last decades, is noted, especially in passenger transport with high-speed trains. Such development has occurred due to the increase of the fossil fuel cost, the concern with the environmental impact of road and aeronautical transport and the fact that rail transport intends to become more competitive [1].

As in other subsectors of AECO (Architecture, Engineering, Construction and Operation) sector, in railway infrastructures subsector, there is an increasing concern with the normalization and uniformization of processes in order to guarantee the quality and sustainability of their activities (e.g., design, construction, maintenance, operation, rehabilitation, deconstruction), the choice of suitable materials and processes and the control of life-cycle costs. The interest of extending these standards to railway infrastructures is relevant [2].

Following audits carried out on public railway projects, it appears that there are weaknesses that have discredited Portuguese construction (e.g., deadlines for the works execution, exceeded budgets, deficient safety and lack of technical quality and information) [3]. The need to develop a database supported by real projects statistics (technical and economic performance indicators) is highlighted, in order to allow benchmarking similar projects [4]. It is also emphasized that the standardization of technical and economic information in AECO sector should be carry out, namely the development of the ProNIC (Portuguese abbreviation for Protocol for the Standardization of Construction Technical Information) methodology [5] to railway infrastructures.

The increase of the project's complexity, the related information and the high number of stakeholders involved, conduct to a high production of information in AECO sector [6,7]. It empathizes the need to develop new forms of efficient communication during all the process [4]. In the current context, the technical documentation that is produced in the several types of works, comes in different formats and with very different contents, thus creating weaknesses throughout the process. ProNIC represents a way to overcome this challenge [5].

Using a statistical process with the information available in ProNIC database, it is possible to obtain performance indicators (according to options, type of construction, work relevance, work region, among others). It is also possible to obtain strategic performance indicators for work groups, chapters, design specialties and construction entities [5].

It should be noted that, according to the Portuguese Strategic Plan for Transport and Infrastructure, an investment about 2.6 million euros in public railway infrastructures are planned for the next years [8].

The purpose of this paper is to develop a systematic and integrated set of credible and standardized information (technical and economic), supported by ProNIC methodology, with the aim of constituting a reference for the entire Portuguese AECO sector specifically for the railway infrastructure subsector.

2. METHOD

To achieve the objective of the present research study the method used is divided in the following four steps:

- STEP 1 — Gather background knowledge about railway infrastructure works (see section 3).
- STEP 2 — Gather the background knowledge about ProNIC methodology and related computer tool (see section 4).
- STEP 3 — Selection the contents of information available in ProNIC, to develop a systematic and integrated set of standardized information related to railway infrastructure (see Section 5.1).
- STEP 4 — Selection of a case study to apply the contents developed in STEP 3 (section 5.2).

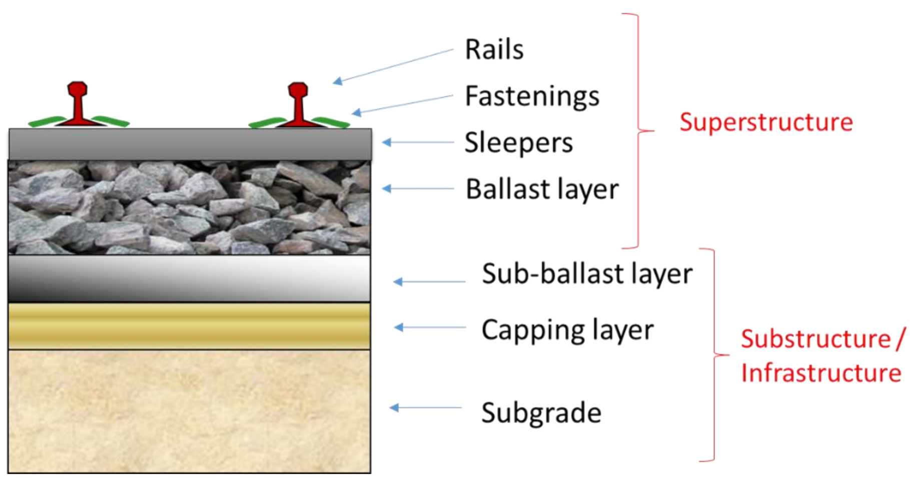
3. RAILWAY INFRASTRUCTURE

3.1. RAILWAY CHARACTRISTICS

Three types of railways are highlighted: ballasted, non-ballasted and mixed support. The ballast track, in addition to being the oldest solution, is also the most used on railway lines. The adoption of a ballasted track solution presents several advantages [9–12]: i) extensive experience regarding the applied materials, life-cycle costs, and duration; ii) rapid construction, maintenance, and rehabilitation; iii) relatively low construction costs; iv) good conditions for dissipating noise and vibrations; v) easy correction of the track geometry; vi) inspection methodologies to detect track defects and causes.

The structure of the ballasted railway (see Figure 1) is divided into superstructure (rails, fastening system, sleepers, and ballast layer) and substructure or infrastructure (subballast layer, capping layer, and subgrade) [9,11]:

FIGURE 1: Ballasted railway structure adapted from [11].



Rails are steel profiles, being considered one of the most important elements of the railway and having the highest cost. Its main functions are [11–14]: i) support and transfer the wheels —train loads to the sleepers, without excessive bending; ii) guide train wheels; and iii) conduct the electricity of the traction or signaling systems.

The fastening system aims to fix the sleepers to the rails, transmit the forces applied on the rails and dampen the vibrations and impacts caused by the train wheels [9,11]. Metallic supports are used on wooden sleepers. Resilient elements are placed on concrete sleepers to dampen vibrations caused by the wheels, to reduce the friction between the rail and the sleepers and to promote the electrical insulation of the track circuits [15].

Sleepers are elements placed between the rails and the ballast, usually spaced on 0.6 m. Its main functions are [9]: i) receive the loads from the rails and distribute them to the ballast layer with acceptable stress levels; ii) support the rail fastening system; iii) prevent vertical, lateral, and longitudinal displacements of the rails; iv) preserve the track gauge and slope; and v) ensure electrical isolation between the two rails. The sleepers can be made of wood, metal or concrete, being concrete sleepers the most used ones [9,11,14].

Ballast layer forms the intermediate layer between the sleepers and the subballast layer and consists of granular material resulting from stone crushing, with high resistance to wear and to fragmentation [10]. The characteristics required for the ballast are defined in the European standard EN 13450 [16] and are defined by type of ballast, namely ballast type I (for rail systems with speed above 250 km/h) and ballast type II (for the conventional network of lower speed). The ballast layer behavior is one of the main concerns of railway administrations, due to its high importance in guaranteeing the proper functioning of the infrastructure in terms of safety and comfort [11].

Subballast layer is the layer on which the ballast is laid, built with the objective of ensuring the good behavior of the track, regarding its geometry maintaining. This layer contributes to the correct distribution of loads and vibrations transmitted in depth, and to water drainage at its surface, preventing ballast fouling (migration of soil particles into the ballast layer) and the erosion of the natural ground [15,17].

Capping layer is built when it is necessary to improve the bearing capacity of the railway track. It consists of limestone unbound granular material or soil treated with different materials (e.g., cement, lime, bitumen) [10].

Subgrade consists of the natural soil on which the capping, subballast or ballast are placed. It is treated with different materials aiming to increase its bearing capacity if traffic loads are higher. It consists of local soils that has a lower quality than the material used in the capping and subballast layer. It serves as a support for the entire railway and transmits the loads from traffic to the terrain [18]. The international railway classification system, through the UIC 719R [19], classifies platforms according to their bearing capacity.

3.2. TRANSITION ZONES

Transition zones or technical blocks are structures to ensure the transition between landfills and bridges or viaducts, to reduce differential settlements, and to allow the progressive variation of the stiffness modulus, between these two track sections. Thus, the vertical stiffness of the transition zone should gradually increase until near to the structure, to make compatible vertical displacements, as close as possible, between the transition zone and the bridge [20].

However, along the life cycle, the differential settlement between landfill and adjacent structure increases [21,22].

This leads to increased maintenance costs, affects the availability of the track, and causes disruption to the railway operation. To mitigate this situation, the railway public administrations have been elaborating design specifications for the construction of these transition zones.

The adoption of transition zones (technical blocks) with well-defined dimensions, built with well-compacted layers of granular materials, subgrade treated with cement or binder, exhibiting high values of stiffness modulus and low permanent deformation, when compared with traditional landfill materials, has been a widely used solution [20,22].

4. PRONIC

ProNIC is a research project that develop a systematic and integrated set of credible technical and economic content, supported by a computer tool, to constitute a reference for the entire Portuguese construction sector. ProNIC is a standard work breakdown structure (WBS) for construction works, technical specifications, cost scenarios and software-based features to manage all the information and systematize the processes throughout the project, since design to the deconstruction (Construction Information System for Portugal). It gives a contribution to technical information standards and sustainability of the processes. Its fundamental aspects are the standardization of the construction processes and the collaborative work (cloud based). It allows the management and articulation of technical contents and the automatic generation of documents such as detailed measurements, technical specification, bill of quantities (BQ), budget estimates, which present technical information relating to guidelines, regulations, standards, and costs [3,20].

ProNIC presents potentialities that are integrated in the requirements of the recent Portuguese public procurement legislation and associated regulation. It presents in its structure a knowledge database in two major subsectors: buildings and road infrastructures [23,24].

Contrarily to what occurs in other systems, ProNIC WBS, being the basis of all information produced, has been the object of a structured and comprehensive development to achieve a higher degree of detail. The task of defining the structure desegregation has been one of the main works. The ProNIC work classification criterion presents a division by chapters, subchapters and articles assigned to a particular code (the same code is always assigned to the same construction work). An article presents the description of the construction work, which will be edited and integrated on the BQ and BE. Linked with the articles there are files with work and material technical specifications such as: work execution sheets (WES) and material sheets (MATS). These files are individual and seek the principle that each type of work has a description of how it is performed (a work specification file), and files with specifications for each different used material.

The concept of Construction Units (CU), introduced in the international standard ISO 12006-2 [25], defines a CU as an independent basic unit (e.g. physical division, constitution, construction organization, operation, maintenance, cost division). Its purpose is to identify the constituent parts of a project and break them into manageable items [26].

ProNIC comprehends the entire construction life cycle. From the above, it is verifiable that it serves first the designer and the work owner need, mainly during the construction design and procurement. However, its structure contains features that are transversal to all the constructive process, as the work contract process (designer and contractor/sub-contractors), construction (contractor and technical supervision) and use (maintenance and operation provisions). It is expected that, in Portugal, ProNIC will be mandatory for use in public works process [5].

5. RESULTS

5.1. CONTENTS FOR RAILWAY INFRASTRUCTURE

To acquire knowledge about the characteristics of railway infrastructure works, several case studies are analyzed in a global way [2,29,30].

One of the main objectives is to develop a WBS that is applicable to any type of railway work. The BQ and the WBS proposed by Campos [27], and the existing WBS in ProNIC are analyzed.

The first stage comprises the organization of the railway infrastructure works, analyzed according to construction models. Thus, the BQ works are organized according to construction units (CU) and to Design Specialties (DS). A comparison is also made between the BQ works of the railway works and the works already exist in ProNIC database. In addition, work descriptions and respective parameters should be developed to define WES and MATS.

The analysis carried out in the case study according to the model of the work organization (UC and SD) contributes to a better perception and interpretation of the information available.

After the definition of the standardized WBS for the railway work, articles, WES, MATS, CU and DE are formatted according to the assumptions established by ProNIC and implemented on the computer tool.

5.1.1. WORK BREAKDOWN STRUCTURE

After analyzing several case studies from different points of view, it was then possible to elaborate a new proposal for a complete standardized WBS that includes: i) the existing chapters in ProNIC; ii) the chapters proposed by Campos [27] and iii) the chapters proposed in the present work, that is, a new standardized WBS that is capable of being used in any railway work. Table 1 presents the results for the WBS developed.

5.1.2. ARTICLES

The articles correspond to the most detailed level of the WBS and consist of a generic work description, associated parameters (fill options) and units of measurement. In this study, articles related to i) technical blocks (TB), ii) capping layer, and iii) subballast layer are developed (see two examples in Table 2).

For the preparation of these articles, Portuguese regulations and normative documentation related to railway infrastructures are analyzed in order to obtain standardized descriptions and parameters [2].

5.1.3. WORKS EXECUTION SHEETS AND MATERIAL SHEETS

The set of all WES and MATS compile the construction specifications, which are automatically generated according to the articles selected in ProNIC.

In the present research study, three WES are developed for the execution of: i) technical blocks; ii) capping layer; and iii) subballast layer. Regarding MATS, two sheets are elaborated: i) aggregates for railway works and ii) aggregates for the subballast layer. In addition, the MATS for water and the FMAT for cement are reviewed (they are already in ProNIC database, but this review intends to incorporate the requirements of railway works) [2]. Table 3 shows the generic topics filled in all WES and MATS.

5.1.3. DESIGS SPECIALITIES

Organizing construction works according to the Design Specialities (DS) allows to separate the design diversity into specific areas [33]. In the present study the design specialties considered are: i) geotechnics and geology; ii) topography; iii) earth movements and containments; iv) demolitions; v) architecture; vi) drainage; vii) water and sewage facilities, equipment and systems; viii) stability; ix) electrical facilities, equipment and systems; x) HVAC facilities, equipment and systems; xi) railway; xii) catenary and traction energy; xiii) communications facilities, equipment and systems; xiv) signaling; xv) integrated security; xvi) environment; and xvii) acoustic conditioning.

5.1.4. CONSTRUCTION UNITS

The CU aims to identify the constituent parts of a DS and proceed to its division, which can be carried out considering factors such as: i) physical division; ii) constitution; iii) construction organization; iv) operation; v) maintenance and vi) cost sharing. Organizing construction works into CU provides a global point of view.

5.2. CASE STUDY CHARACTERIZATION

The case study under analysis is related to a new construction of a 29 km ballasted railway in Portugal [2,20,30].

This new constructed track section was designed with the objectives of 28: i) improve the railway transport conditions of passenger and products in terms of accessibility, safety, comfort, and speed, increasing its competitive capacity with road transport; ii) create a line of fast trains, in variant.

TABLE 1: WBS for railway infrastructure.

CHAPTER	WBS
1.Earthworks	1.1.Preparatory work; 1.1.1.Demolition and removal of railway infrastructure elements; 1.1.1.1.Track removal; 1.1.1.1.1.Rails; 1.1.1.1.2.Sleepers; 1.1.1.1.3.Ballast; 1.1.1.2. Railway switch removal; 1.1.1.3.Catenary removal; 1.1.2.Deforestation; 1.1.3.Elements demolition; 1.1.4.Wall demolition; 1.1.5.Stripping; 1.2.Excavation; 1.2.1.In line excavation; 1.2.2.Transportation of land — landfill; 1.2.3.Transportation of land — placement in a licensed landfill; 1.2.4.Excavation of soils to be discarded; 1.2.5.Regulation; 1.3. Landfill; 1.3.1. Landfill with soil from reuse; 1.3.2.Landfill with soil from a loan stain; 1.4. Complementary works; 1.4.1.Draining mask; 1.4.2. Draining spurs; 1.4.3. Sub horizontal land on slopes; 1.5. Technical Blocks; 1.5.1. Technical blocks type I; 1.5.2.Technical blocks type II; 1.6.Other works
2.Drainage	2.1.Works to guarantee the continuity of surface water drainage; 2.2.Hydraulic passages; 2.3.Hydraulic passages mouths; 2.4.Longitudinal drainage devices; 2.5.Complementary drainage devices; 2.6.Accessory work of drainage system; 2.7.Other works
3.Railway	3.1.Railway infrastructure; 3.1.1.Capping layer; 3.1.2.Subballast layer; 3.2.Railway superstructure; 3.2.1.Track ballast; 3.2.2.Track settlement; 3.2.3.Track equipment; 3.2.4.Rail connection; 3.2.5.Track tamping and levelling; 3.2.6.Grinding; 3.2.7.Track equipment installations
4.Fixed facilities for electric traction	4.1.Catenary; 4.2.Traction equipment
5.Accessory woks	5.1.Landscape integration and minimizing impacts; 5.2.Physical fences and parallel ways; 5.3.Containment works; 5.4.Installation/replacement of services; 5.5.Other works
6.Telecommunications	6.1.Telecommunications
7.Signaling and safety equipment's	7.1.Road signaling equipment; 7.2.Railway signaling equipment
8.Integrated passages	8.1.Top passages; 8.2.Lower passages
9.Special viaducts	9.1.Viaducts
10.Tunnels	10.1.Tunnels
11.Miscellaneous	11.1.Construction site

TABLE 2: Examples of articles for railway infrastructure.

ARTICLE DESCRIPTION	PARAMETERS (FILL OPTIONS)
Execution of the Technical Block next to small structures buried with a wedge-shape made up of a mixture of aggregate and $1 of cement, a height of $2 and a length of $3, and a wedge-shape consisting of layers of well graded crushed aggregate of $4 origin, with a $5 in length, including supply and transport of materials, loading, unloading and placement at the work site and all the necessary work for its execution based on the design drawings, according to the specified conditions.	$1 (cement percentage); $2 (wedges height); $3 (wedge length); $4 (aggregate source); $5 (length of aggregate wedge-shape)
Execution of the subballast layer of $1 [m] thickness, in $2 material and a capping layer with $3 [m] thickness, in $4 material, including supply and materials transport, loading, unloading, and placing at the application site and all the work necessary for its execution, according to the specified conditions.	$1 (0.05, 0.12, 0.15, 0.18; 0.25); $2 (granite, limestone, bituminous mixture); $3 (0.05, 0.12, 0.15, 0.25); $4 (granite, limestone, bituminous mixture)

TABLE 3: Topics filled in WES and MATS.

WORKS EXECUTION SHEETS (WES)	MATERIAL SHEETS (MATS)
1.Work definition	1.Material definition
2.Materials	2.Application field
3.Preparatory work	3.Composition
4.Process/Execution model	4.Features and properties
5.Control and acceptance	5.Application
6.Testing	6.Technical and regulatory references
7.Technical and regulatory references	7.Quality mark and certifications
8.Measurement criteria	8.Manufacturing process
9.Associated risks	9.Packaging, storage, and conservation
10.Other provisions	10.Risks and safety
11.Maintenance	11.Testing
	12.Restrictions and conditions of non-application
	13.Other provisions

The existing constructed track section is still kept in service for slow trains, electrified, thus increasing the exploration capacity of this section of the south line; iii) gain travel time of about 10 minutes in relation to the previous railway; iv) enable circulation at speeds between 190km/h and 220km/h over an extension of more than 100km; v) avoid impacts in terms of air and noise emissions, since the rolling stock is of electric traction; vi) execute works without interference with the existing railway in operation; and vii) reduce the maintenance costs during their life-cycle.

The present case study is chosen because it is based on the fact that is a recent work and encompasses the construction of several infrastructures, such as [28,29]: i) ballasted and electrified railway, with 60E1 rail, concrete monoblock sleepers multipurpose, spaced of 0.6m spacing, Vossloh type fixation and designed for a maximum axle load of 25ton; ii) Bridge consisting of three continuous sections, the metallic superstructure and the platform in reinforced concrete slab. The access viaducts are mixed, consisting of metal beams with a full core on which the reinforced concrete slab rests; iii) Pre-stressed reinforced concrete viaducts, where the superstructure is divided into several independent sections; iv) Uneven passages (upper and lower) in reinforced concrete and respective resettlement; v) Installation of signaling and communication systems; vi) Parallel path adjacent to the railway; and vii) Sealing the railway infrastructure to its full extent.

The study focuses on the part of the work related to the railway infrastructure, although a global analysis of the contract is carried out to organize its elements into construction models according to the perspective of the CU and DS [2,30,31].

6. DISCUSSION

In the present study, a new railway construction work was organized according to according to Construction Units (CU) and Design Specialties (DS). An analysis of the Bill of Quantities (BQ) of several railway infrastructure works was also carried out according to the work perspective to carry out a survey of which construction works are already in the ProNIC database. Then a WBS was created for the railway work, based on the chapters already existing in ProNIC. As for the remaining information elements, work descriptions and respective parameters, WES and MATS were developed. After the technical contents were created, they were implemented on the tool. Then it was possible to validate it using a case study. It is important to note that all the content developed was based on the rules and regulations in force at national and European level.

Briefly, the documents created in the present study were: i) WBS that is applicable to any type of railway work; ii) an article for the execution of type I technical blocks; iii) an article for the execution of technical blocks type II; iv) an article for the execution of the crowning layer; v) an article for the execution of the sub-ballast layer; vi) a WES to execute technical blocks type I; vii) a WES to execute the crowning layer; viii) WES to execute the sub-ballast layer; ix) a MATS for aggregates for railway works; x) a MATS for aggregates for sub-ballast; x) review of an MATS for cement; and xii) review of an MATS for water.

All the technical contents created were implemented on the PRoNIC tool. The BQ of the case study also was also included in ProNIC database.

It is expected that some of the gaps already existed in Portuguese AECO sector will be filled due to the fact that ProNIC has a transversal intervention in the entire process, covering the whole life cycle of constructed assets.

The study developed promotes the creation of standardized items that can be implemented in any case of railway works, based on Portuguese and European standards and legal frameworks in force. In this way, a national reference was created, for integration in an application, which is added to all types of public railway works.

It is worth highlighting the importance of providing the management and control of public works, with a view to creating greater accountability and skills for the stakeholders involved, and improve productivity and quality of the obtained results, allowing the monitorization and validation of the quality in the Portuguese AECO sector works, in particular railway infrastructures work.

7. CONCLUSION

Railway transport is used in Portugal not only for passengers' transport, but also for the transport of products around and seaports, contributing to the growth of the economy and exports.

The importance of the construction, maintenance and rehabilitation of railway infrastructures, the future investments foreseen in this subsector and the new requirements of the legal and regulatory framework, highlight the importance to use applications tools such as ProNIC.

The railway infrastructures were not yet included in the ProNIC tool. The use of ProNIC in railway works can lead to a standardized information between them, facilitating benchmarking, defining performance indicators and statistical values, and allowing the prediction of information for decision making processes and allowing improving management activities and project coherence, consequently providing optimization of time, resources, and costs.

REFERENCES

[1]. Moreira, A. Método de Dimensionamento de Vias-férreas, Mcs Thesis in Civil Engineering, Escola de Engenharia da Universidade do Minho, 2014.

[2]. Kanje, L. Aplicação da Metodologia ProNIC na Construção de Infraestruturas Ferroviárias. Mcs Thesis in Civil Engineering, Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa, 2016.

[3]. Tribunal de Contas. Auditoria a empreendimentos de obras públicas por gestão direta. 2009, pp. 1–63.

[4]. Åhrén, T.; Parida, A. Maintenance performance indicators (MPIs) for benchmarking the railway infrastructure: A case study. Benchmarking: An International Journal, Vol. 16:2, pp. 247–258. 2009.

[5]. ProNIC — Protocolo para a Normalização da Informação Técnica na Construção. https://www.inesctec.pt/

[6]. Sadeghia, J.; Motieyan-Najara, M.; Zakeri, J.; Yousefi, B.; Mollazadeh, M. Improvement of railway ballast maintenance approach, incorporating ballast geometry and fouling conditions. Journal of Applied Geophysics. Vol.151, pp. 263–273. 2018.

[7]. Zhai, W.; Wang, K.; Lin, J. Modelling, and experiment of railway ballast vibrations. Journal of sound and vibration, Vol. 270:4–5, pp. 673–683, 2004.

[8]. Pires de Lima, A.; Monteiro, S. Plano Estratégico dos Transportes e Infraestruturas. Horizonte 2014–2020, 2014.

[9]. Vale, C. Influência da qualidade dos sistemas ferroviários no comportamento dinâmico e no planeamento da manutenção preventiva de vias de alta velocidade. PhD thesis in Civil Engineering, Faculdade de Engenharia da Universidade do Porto, 2010.

[10]. Oliveira, A. Via Balastrada versus Via Não Balastrada, D Mcs Thesis in Civil Engineering, ISEL, 2012.

[11]. Fontul, S. Slides das aulas da disciplina infraestruturas ferroviárias e portuárias. Universidade Nova de Lisboa, Faculdade de Ciências e Tecnologia, 2015.

[12]. Solla, M.; Pérez-Gracia, V.; Fontul, S. A Review of GPR Application on Transport Infrastructures: Troubleshooting and Best Practices. Remote Sens. 2021, 13, 672. https://doi.org/10.3390/rs13040672

[13]. Indraratna, B.; Cholachat Rujikiatkamjorn, C; Vinod, J.; Hadi Khabbaz, H. A review of ballast characteristics, geosynthetics, confining pressures and native vegetation in rail track stabilization. University of Wollongong, Faculty of Engineering, and Information Sciences, 2009, pp. 25–35. https://ro.uow.edu.au/engpapers/848

[14]. Fernandes, J. Modelação do Comportamento Mecânico de Vias-férreas, Mcs Thesis in Civil Engineering, Universidade Nova de Lisboa, Faculdade de Ciências e Tecnologia, 2011.

[15]. Fortunato, E. Renovação de Plataformas Ferroviárias: estudos Relativos à Capacidade de Carga. PhD Thesis in Civil Engineering, Faculdade de Engenharia da Universidade do Porto, 2005.

[16]. EN 13450 — Aggregates for railway ballast. European Committee for Standardization (CEN), 2015.

[17]. REFER. Características técnicas do sub-balastro. Rede Ferroviária Nacional, EP. 2007.

[18]. Alves, J. Avaliação de Dimensionamento da Subestrutura Ferroviária de Linhas de Alta Velocidade., Mcs Thesis in Civil Engineering, Instituto Superior Técnico, 2010.

[19]. UIC 719R — Earthworks and track bed for railway lines, No. February. 2008.

[20]. Paixão, A., Fortunato, E., & Calçada, R. (2015). Design and construction of backfills for railway track transition zones. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 229(1), 58–70. doi:10.1177/0954409713499016

[21]. Coelho, L. Blocos técnicos em infraestruturas ferroviárias — Comportamento e práticas nacionais e internacionais em engenharia civil. Instituto Superior Técnico, 2008.

[22]. Paixão, A. Transition Zones in Railway Tracks. An Experimental and Numerical Study on the Structural Behaviour. PhD Thesis, Faculdade de Engenharia da Universidade do Porto, 2014.

[23]. ProNIC. Memorando Pronic. pp. 1–11, 2015.

[24]. Despacho n.º 578/2014, D.R. n.º 8 (Série II de 2014-01-13). Imprensa Nacional Casa da Moeda, Lisboa. vol. 2, pp. 2007–2008, 2014.

[25]. ISO 12006-2: 2015. Building construction — Organization of information about construction works. Part 2: Framework for classification. International Organization for Standardization. 2015.

[26]. Rodrigues, C. Aplicação da metodologia ProNIC a obras portuárias. Faculdade de Engenharia da Universidade do Porto, 2015.

[27]. Campos, R. Aplicação da metodologia ProNIC a obras ferroviárias — Princípios gerais e viaférrea. Mcs Thesis in Civil Engineering, Faculdade de Engenharia da Universidade do Porto, 2014.

[28]. Martins, F. Variante de Alcácer do Sal — Enquadramento, definição geral da obra e execução, Rede Ferroviária Nacional, EP. pp. 1–13, 2008.

[29]. Kanje, L., Couto, P., Fontul, S., Falcão Silva, M.J. Aplicação da Metodologia ProNIC na Construção de Infraestruturas Ferroviárias. 2.º Encontro Nacional da Qualidade e Inovação na Construção (QIC2016), LNEC, 2016.

[30]. Kanje, L., Couto, P., Fontul, S., Falcão Silva, M.J. Application of ProNIC methodology in railway infrastructures construction. 7th International Conference on Mechanics and Materials in Design (M2D), 2017.

[31]. Portaria 701-H/2008. Aprova o conteúdo obrigatório do programa e do projeto de execução, os procedimentos e normas a adotar na elaboração e faseamento de projetos de obras públicas e a classificação de obras por categorias. Diário da República n.º 145/2008, 1º Suplemento, Série I, 5106-(37) a 5106-(80), 29 de julho de 2008.

DECLARAÇÃO ÉTICA

CONFLITO DE INTERESSE: Nada a declarar. **FINANCIAMENTO:** Nada a declarar. **REVISÃO POR PARES:** Dupla revisão anónima por pares.