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An ontology-driven decision support system for high-performance and cost-optimized design of complex railway portal frames

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ABSTRACT

Electrification structures design for railway systems is a crucial and complex process, since it compounds plenty of infrastructure elements, design decisions, and calculation conditions. In this paper, an ontology-driven decision support system for designing complex railway portal frames is presented and developed. A knowledge-rules database has been also developed relying on experts knowledge and complying with railway standards. Our system outperforms the current portal frames design methods by decreasing construction time and costs. As a result, an intelligent computer-aided design tool is provided, thus facilitating the task of seeking for the optimal portal frame, which is geometrically and structurally feasible, and cost-effective.

1. Introduction

Railway companies and engineers have been trying to enhance and to regulate their design methods for electrification infrastructure for many years now (AENOR, 2009; AREMA, 1998, 2003; Brown, 1927; Bond & Harris, 2008; UIC, 1981). Computers have played an important role on this effort, as railway and engineering companies have developed several tools along the time to automate the design process. As some examples, in 1964, Andrews (1964) presented a tool to calculate the behavior of an overhead catenary system for railway electrification, and in 1969, West (1969) presented a program to make optimized structural calculus of railway. However, the traditional design systems are not enough to achieve the best-suited designs, as it depends on the knowledge of several expert engineers that must work closely together with the railway company experts to design good structural components that are at the same time compliant with the railway company regulation and the body of national and international standards. Trying to cope with the problems, expert systems (Bonissone, 1983; Chang, 1988; Domeshek & Kolodner, 1992; Fenves, Flemming, Hendrickson, Maher, & Schmitt, 1989) were developed and commercialized in 1980s as a research tool designed to diagnose and to solve technical problems in the railway area.

Expert systems rely on experts knowledge. Thus it is very important to organize and systematize the information to be able to include experts knowledge into the system. To achieve this goal, ontologies have been proposed as a way to systematize information in very different fields. An ontology seeks to provide a definitive and exhaustive classification of entities, including the types of relations by which entities are tied together. Gruber (1993) described the principles to design ontologies for knowledge sharing. Davies, Fensel, and van Harmelen (2001) shows several examples to manage knowledge based on ontologies. Abanda, Ng'ombe, Tah, and Keivani (2011) describes and ontology to solve the problem of land delivery in Zambia. Eden and Turner (2007) shows a possible ontology for computer programs and the problems for building such ontology. Ontologies of railways are not easy to find. A first attempt was presented in Bjorner (2004), where a proposal was made to create a Railway Domain to join experts and to create ontologies to classify railway objects, which was addressed as a grand challenge. Recently, Mohan and Arumugan (2011) has presented a railway ontology using Web ontology languages and Semantic Web Rule Language (SWRL) as a way to describe and share railway infrastructure information.

However, despite the efforts (Baden, 2000; Bailey & Smith, 1994), CAD tools used to design and calculate the railway overhead wire support structures still lack the vision of an integrated approach to the design problem. Thus, this process is usually divided in several steps (requirements, design, structural calculus, etc.), that may also involve several organizations, sometimes not well integrated. For example, designing with AUTOCAD or 3D CAD (Veerhoek, 2006) in one organization, and calculating with CYPE (CYPE, 2010) or CALPE (Benet, Cuartero, & Rojo, 2000) in another. This way of coping with the problem generates a catalogue of hurdles, including sometimes the exclusion of railway company experts from the process, which may lead to inadequate designs

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that are failure prone or difficult to maintain. Furthermore, it takes not less than 3 weeks of several engineers to have a design of a complex railway framework portal. Thus, it is important to have integrated CAD tools for railways, as proposed recently in other areas (Yang, Chang, Hu, & Zhang, 2010a), and one limited example for railway yard may be seen in Yang, Wangand, and Hehua (2010b).

Applying artificial intelligence to railway tools is a major trend in the XXI century (Meng, 2010; Sadeghi & Barati, 2010). There are examples for railway capacity planning (Yung-Cheng, Mei-Cheng, & Jyh-Cherng, 2010) and safety control systems (Yaroslavtsev & Levchenkov, 2011). However, AI has not been applied to the integral process of railway infrastructure design, and this is the major goal of our work. The global aim of the research shown in this paper is to provide an intelligent computer-aided design tool, named SIA, that helps railway infrastructure designers to design and calculate safer and more efficient complex structures for railway electrification systems, especially overhead wire support structures such as cantilevers and frame portals. The final goal of that tool is to help designers to build infrastructure for the electric railway transport that are compliant to the existing normative and safe from the circulation and structural point of view to avoid dangerous situations that arise currently due to mistakes in design. SIA follows a holistic approach to design, including facilities to automatically build from scratch detailed structures, including platforms, tracks, complex railway portals, catenaries, and electrification systems. Our tools provides an analysis of three-dimensional structures, detailed component calculations, election of minimum cost and minimum weight designs, and constructive plans adjusted to the millimeter of the optimal solution. The final result is the project documentation that can be provided to the building company.

The vital factors to achieve such a tool and to ensure its future are its acceptability to designers, its usability, and, of course, its correctness and flexibility to include expert knowledge in the field. As argued in West (1969), those factors depend upon the relationship fostered among the promoter and the designers, so that the railway engineering designers can trust the results of the system. Thus, it is very important to present the tools to the users and to have significant examples to show them the feasibility and utility of the tools. It is also very important to be able to demonstrate to the railway authorities that the final designs respect the regulation and the national and/or international standards, as they will be accepted only if they are compliant with the normative. To demonstrate SIA versatility and usability, we show in this paper the process of designing and calculating a railway portal from scratch.

The paper is organized as follows. Section 2 presents motivation and description of the railway portal design problem. In Section 3, the ontology used to represent knowledge in SIA is described. Section 4 shows the rule-based system that guides the design process itself depending on the ontology objects and their properties. Section 5 presents some results. And, finally, Section 6 shows the main conclusions of the paper.

2. The railway portal design problem

The design of complex railway portals is a very complex process that requires knowledge and experience to ensure that the designed superstructure will not only be economic and regulation compliant, but will also cater for all current load cases, cable routing and supports, etc. Usually, most companies have a small database of standardized portals that are used for all situations. Traditional Warren and Vierendeel designs are still the most cost effective solutions to long span portals design, thus most of the solutions are based in those structures.

However to automate the design process of a complex railway portal, we have to be able to fulfill all the steps from the catenary points specified by the railway electrification engineers (shown in Fig. 1) to the final structure (shown in Fig. 2) that is geometrically and structurally feasible, and cost-effective.

Fig. 3 shows all the steps for the design process and the actors (experts) involved in each step. As may be seen, four major actors participate in the design process:

- The user is the client that asks for the portal design. He must define the portal features and requierements, and also the location of the portal for ground features. The portal definition includes the number of platforms, geometry, and catenary points (as shown in Fig. 1). The output of the portal definition process is sent to the next actor: the design engineer.
- The design engineer must find a solution for the portal that complies with the railway company and the national authority regulations. The portal designed must be valid from the geometrical point of view, and it must include all the elements needed for the overhead contact wire support (foundations, poles, cantilevers, wires, etc.). CAD tools are used in this step and, usually, the design engineer provides a single solution, as it is complex and expensive to find more. However, ideally a set of valid solutions could be provided to check their legal and structural feasibility.
- The solution adopted must be sent to the Railway Company or national authority experts (third actor) to check whether the railway portal designed is compliant with the existing regulation. If it is not, the portal is rejected. If it is, it is sent back to the design engineer who must provide it as input data to the fourth actor: the structural engineer.
- The structural engineer checks for the structural feasibility of the portal using structural calculus tools and applies all the normative consulting with the railway authority. To check whether the portal is correct and regulation compliant, it must also cater for all regulated load cases (ice, snow, wind, etc.). If the structure is correct, it is sent back to the design engineer.
- Along the last step of the process, the design engineer must calculate economical costs consulting railway company databases for prices and tariffs. And check whether the portal fits the existing budget. If it does, then the portal is accepted and the construction plans are delivered to the user (client).

As may bee seen, there is a lot of expert knowledge involved in each step of the process, and the communication among the actors may be slow in many situations. Moreover, if a proposed portal is not valid, the process will have to be repeated again until finding a valid system or discarding all the possible solutions. The usual approach is having engineering companies providing a set of experts covering all the actors of the process. However, this approach has several weaknesses. First, it depends on the company expertise. Second, the regulation changes in every country, which makes difficult to have experts in the company, leading to subcontracts. Third, as it is expensive, only a single solution is provided and it is usually based on a limited casuistry. Fourth, the solution could be expensive, as it is not compared to other feasible solutions that could be more optimized.

SIA can overcome the former problems by applying the knowledge of several experts stored in an ontology and a powerful database for railway materials and infrastructure, and combining all the steps through a set of rules to define the process and the decisions to be taken for each step. Moreover, SIA allows to create the whole set of feasible railway portals for each step. This set of portals is filtered in each step of the process to get a refined set of options compliant with design, structural, and regulation constraints.