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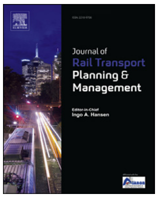

A stochastic model-based approach to analyse reliable energy-saving rail road switch heating systems

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ABSTRACT

Rail road switch heaters are used to avoid the formation of snow and ice on top of rail road switches during the cold season, in order to guarantee their correct functioning.

Effective management of the energy consumption of these devices is important to reduce the costs and minimise the environmental impact. While doing so, it is critical to guarantee the reliability of the system.

In this work we analyse reliability and energy consumption indicators for a system of (remotely controlled) rail road switch heaters by developing and solving a stochastic model-based approach based on the Stochastic Activity Networks (SAN) formalism. An on-off policy is considered for heating the switches, with parametric thresholds of activation/deactivation of the heaters and considering different classes of priority.

A case study has been developed inspired by a real rail road station, to practically demonstrate the application of the proposed approach to understand the impact of different thresholds and priorities on the indicators under analysis (probability of failure and energy consumption).

1. Introduction

Nowadays, there is a great attention towards cautious usage of energy sources to be employed in disparate application domains, including the transportation sector, to save both in economical terms and in environmental impact (Ghasemieh et al., 2015; Zhu et al., 2004; Qiu et al., 1999; Čaušević et al., 2014). Therefore, studies devoted to analyse and predict energy consumption are more and more gaining importance, especially in combination with other non functional properties, such as reliability, safety and availability. The (electric) energy consumption of a system is the amount of power consumed by a system in a unit of time, that is measured in Watt per hours, while reliability is defined as the continuity of correct service, i.e. the ability of a system to avoid service failures that are more frequent or more severe than is acceptable (Avizienis et al., 2004). While several works devoted at analysing reliability of systems or their energy consumption are available in literature (Ghasemieh et al., 2015) (Qiu et al., 2000) (Di Giandomenico et al., 2013) (Čaušević et al., 2014), there is relatively less work concerning the interplay of these two measures. In this paper, we address reliability and energy consumption through stochastic model-based analysis considering a realistic case study, a *rail road switch heating system* (http://www.railsco.com/~electric_switch_heater_controls.htm; Brodowski and Komosa, 2013).

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A rail road switch is a mechanism enabling trains to be guided from one track to another. It works with a pair of linked tapering rails, known as points. These points can be moved laterally into different positions, in order to direct a train into the straight path or the diverging path. Such switches are therefore critical components in the railway domain, since reliability of the railway transportation system highly depends on their correct operation, in absence of which potentially catastrophic consequences may be generated.

Unfortunately, during winter, snow and ice can prevent the switches to work properly and the mechanisms which allow a train to be directed can be blocked by an excessive amount of snow or ice. To overcome this issue, the rail road switches need to be cleaned from possible snow or ice forming on top of it. In the past, the switches were kept clean manually by employees who were sweeping the snow away. Nowadays, heaters are used so that the temperature of the rail road switches can be kept above freezing. The heaters may be powered by gas or electricity (Brodowski and Komosa, 2013). A failure in those switches can lead to major malfunctions.

In case electricity is used to heat the switches it is important to optimise the energy consumption and at the same time to ensure reliability. Different policies may be adopted as for example to heat a selection of switches for a given amount of time. A different approach would be to heat all the switches together. Note that, by turning on all the heating systems at the same time, an overhead of energy consumption can lead to a blackout. Alternatively, an excessively parsimonious policy to save on energy can cause the failure of some rail road switch heaters (Basile et al., 2015).

In this paper, we adopt a stochastic model-based approach to analyse the behaviour of the rail road switch heating system under different circumstances. A modular and parametric approach is followed, to assure usability of the developed analysis framework in a variety of system configurations, as well as to promote extension and refinements of the model itself, to account for further involved aspects/phenomena and so enhance its adherence to sophisticated and realistic implementations with respect to the current version. In particular, we exploit *Stochastic Activity Network* (Sanders and Meyer, 2000) to model the heating system, and use the Möbius tool (Clark et al., 2001) to perform evaluations.

The proposed analysis contributes to gain insight on the interplay between energy consumption and reliability in order to select an appropriate policy for the heating of the switches, which guarantees a satisfactory trade-off. A prioritized approach has been considered, where the heaters are categorized according to their importance inside the analysed railway station. Note that a failure of the heating system is accounted for by other components of the railway system, namely interlocking mechanisms which guarantee safety; however we do not include them in our analysis. This paper extends a previous work (Basile et al., 2015) in different directions: we provide a major update of the model by introducing a first in, first out (FIFO) prioritized approach, the analysis results are improved with new measure of interests and we consider real world data for our evaluations. Finally, we show that the reliability of the system augments when a prioritized approach is considered.

Structure of the paper Stochastic model-based analysis is introduced in Section 2. In Section 3 we describe the considered rail road switch heating system and its behaviour. We present the models of the rail road switch heating system in Section 4, which are then instantiated to a real scenario in Section 5. The results of our experiments are discussed in Section 6, while related work and conclusions are in Sections 7 and Section 8.

2. Stochastic model-based analysis

Given the stochastic phenomena involved in our analysis, namely the failure occurrence and weather forecast, we have adopted a stochastic model-based approach (Bernardi et al., 2013; Diab and Zomaya, 2005). Stochastic model-based methods are useful to support the development of systems, in all the phases of their life cycle. In the early design phases they can be helpful for avoiding waste of time and resources in the development phase. This can be done by pointing out the properties and the requirements that the analysed system must satisfy, which can be non-functional properties such as dependability, performability and others. Then a model of the system under analysis is built, that represents its behaviour, in order to guarantee that the requirements are met. It is possible to compare different alternatives for the same system, and select the one that better suits the requirements. An early modelling phase is also useful to highlight problems in the design of the system.

When the design phase is completed, a model allows for predicting the overall behaviour of the system, fostering an analysis for the fulfilment of constraints in the design phase and the acceptance cases. For an already existing system, an a-posteriori analysis of properties such as dependability or performance is useful in order to improve the system in its future releases. Moreover, with a model-based analysis it is possible to predict future behaviours to plan the maintenance and the upgrading of the system (Karlin, 1994).

2.1. *Stochastic Activity Network*

Several stochastic modelling methods have been proposed in literature (Balbo, 2007; Sanders and Meyer, 2000; Alur and Dill, 1994; Bause and Kritzinger, 1998; David and Alla, 2001).

According to the underlying stochastic process, they are classified into *Markovian* and *non-Markovian* (Haverkort, 2002). Markovian models are those satisfying the *Markov property* (memoryless), that is the conditional probability distribution of future states (conditional on both past and present values) depends only upon the present state. Non-Markovian models do not satisfy the Markov property and thus allow for different probability distributions. Since our system is characterized by stochastic phenomena that cannot be accurately represented by the exponential distribution, (e.g. the time regulating

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