Available online at www.sciencedirect.com

ScienceDirect

IFAC-PapersOnLine 49-3 (2016) 459–464

Modular Fault Diagnosis in Fixed-Block Railway Signaling Systems

Mustafa S. Durmus*, İlker Ustoglu, Roman Y. Tsarev***, Michael Schwarz******

**Electrical and Electronics Engineering Department, Pamukkale University, Denizli, TURKEY (e-mail: msdurmus@pau.edu.tr).*
***Control and Automation Engineering Department, Yildiz Technical University, Istanbul, TURKEY (e-mail: ustoglu@yildiz.edu.tr) ***
****Institute of Space and Information Technology, Siberian Federal University, Krasnoyarsk, RUSSIA (e-mail: tsarev.sfu@mail.ru)*
*****Computer Architecture and System Programming, Kassel University, Kassel, GERMANY (e-mail: m.schwarz@uni-kassel.de)*

Abstract: The diagnosis of possible faults in railway signaling systems is an important issue to provide safe travel and transportation in railways. Signaling system designers have to consider the possible faults which may occur in railway field components both on the requirements preparation phase and on the development phase of the signaling system software or namely, the interlocking system. Although the diagnosis of different unobservable faults is relatively hard, especially for large scale railway fields, this complexity can be overcome by using the Discrete Event System (DES) based modular diagnosis approach which is explained in this paper. The main advantage of using such modular approach for fault diagnosis in fixed-block signaling systems is the inspection of the diagnosability of the whole system with respect to its subsystems (railway field components). In this study, the diagnosability of the railway field equipment and the whole system is also explained with a case study.

Keywords: Discrete Event Systems, Modular Fault Diagnosis, Fixed-Block Railway Signaling Systems.

1. INTRODUCTION

The use of railway transportation among different alternatives (e.g. road and air transportation) brings many profits such as less carbon dioxide emission and energy consumption. Although the infrastructure and the signaling costs of railways are high, they provide more environmental friendly and affordable solutions.

Railway signaling systems are divided into two main categories named as fixed-block (conventional) and moving-block signaling systems. Train movements are rely on route reservation procedure in fixed-block signaling systems. The requirements of each route including the railway field equipment are pre-defined in the interlocking table. Railway lines are divided into fixed-length rail blocks. Each railway block consists of an entrance signal and an exit signal. These signals inform the train driver about the situation of the next railway block. Although the use of the fixed-block signaling systems decreases the efficient use of the existing railway lines, it has been in use since mid-1800s in all over the world.

As with all other safety-critical applications, standards are defined to combine different safety requirements and concepts for railways. Software development process for fixed-block signaling systems including the choice of hardware and the communication protocols are defined by the EN 50126, EN 50128 and EN 50129 standards. In addition to the requirements and recommendations of railway related functional safety standards, signaling system engineers should take fault diagnosis into account while developing the signaling system software, or in other words, the interlocking system. (IEC 61508-7) describes fault diagnosis as the process of determining if a system is in a faulty state or not and it should be performed at the smallest subsystem level because smaller subsystems allow a more detailed diagnosis of faults.

Detecting faults in railway signaling systems, especially the faults which may occur in field components (e.g. points, signals) is a vital issue due to its harsh results. Therefore, fault diagnosis and condition monitoring studies on railway point mechanisms can be found in the literature (Rouvray et al. 1998; Roberts et al. 2002; Garcia Marquez et al. 2003; Zattoni 2006). However, these studies are addressed the fault diagnosis problem from a different perspective.

Due to having DES-like features in their structure (Cassandras and Lafortune 2008), and the recommendation of railway related safety standards such as (IEC 61508-3) and (EN 50128), fixed-block signaling systems can be regarded as discrete event systems (DESs) and the DES based modeling and fault diagnosis methods are applicable to fixed-block signaling systems.

However, diagnosability is described by (Sampath et al. 1995) as the detection with a finite delay occurrence of failures of any type using the record of observable events. The diagnoser is obtained by using the system model itself and it observes online the behavior of the system (Sampath et al. 1996). The studies of (Sampath et al. 1995) and (Sampath et al. 1996) defined the basics of DES based fault diagnosis and these basics further developed by many workgroups and

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.07.077

studied as online (Ramirez-Trevino et al. 2007), centralized (Ushio et al. 1998; Chung 2005), decentralized (Debouk et al. 2000; Cabasino et al. 2013) and so on. As an application of DES based fault diagnosis to fixed-block railway signaling systems, (Durmuş et al. 2014) considers diagnosability analysis as an intermediate step between modeling the system and testing the developed software which enables signaling system designers to preliminary check their models. On the other hand, for large and complex systems, diagnosis of faults becomes a critical and stringent task. As pointed in (Giua and Seatzu 2014), due to the state explosion problem in DESs, the use of theoretical results while dealing with the real-world applications becomes complicated and sometimes inapplicable.

Therefore, instead of constructing a diagnoser for the whole system and checking its diagnosability, similar to (Debouk 2003) and (Contant et al. 2006), we will study the system model with respect to its subsystems and check the diagnosability of each subsystem (diagnosability of the modules) to show the overall diagnosability. The reader is referred to (Zaytoon and Lafortune 2013; Takai 2008; Zhou et al. 2008), for the overview of DES based fault diagnosis methods and for detailed explanation on modular fault diagnosis.

2. PRELIMINARIES

2.1 Fixed-Block Signaling System Components

The traffic control center is responsible for all railway traffic by providing an interface between the interlocking system and the dispatchers. Dispatchers (responsible officer) may send several requests to the interlocking system for evaluation such as route reservation request, point machine position request or field component blocking requests. Another main responsibility of the traffic control center is to log and monitor the train movements.

The interlocking system receives the requests of the traffic control center, and evaluates these requests for a final decision. The requests of the dispatchers can be accepted or rejected according to the safety restrictions. The design, development and the testing process of the interlocking system should be carefully handled and realized with respect to the related functional safety requirements (Durmuş et al. 2013, Durmuş et al. 2015a).

Railway blocks (RBs) are the subsections of the railway lines with fixed-length. The entrance and exit of a *RB* is equipped with signals to inform train drivers. The location of the trains are detecting by using simple electrical circuits know as track circuits or devices known as axle counters.

Signals (SLs) are used to inform the train drivers about the situation of their way. Even different colours and their combinations are in use and differ from country to country, the red colour and the green colour have similar meanings. Turkish State Railways use the red colour to denote the next two *RBs* are occupied whereas the green colour denotes the next two *RBs* are free. The yellow colour denotes the next *RB* is unoccupied but not the *RB* after the next. Depending on the topology of the railway field, an additional yellow colour is also used by Turkish State Railway to denote the line change. Generally, this additional yellow colour is placed at the bottom of the signal before entering point machine regions.

Point machines (PMs) are devices which enable trains to pass from one railway line to another. A *PM* can be operated either by a route reservation request or manually via traffic control center. The position of a *PM* can be also adjusted from the railway feld by the responsible officers (shunter) by using a lever.

General representation of a fixed-block signaling system is illustrated in Fig. 1. More detailed definitions of the components of fixed-block railway signaling systems can be found in (Hall 2001).

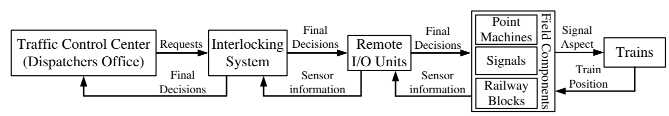

Fig. 1. General representation of a fixed-block signaling system.

2.2 Petri nets

A Petri net is defined by Murata (1989) as

$$PN = (P, T, F, W, M_0), \tag{1}$$

where

- $P = \{p_1, p_2, ..., p_k\}$ is the finite set of places,
- $T = \{t_1, t_2, ..., t_z\}$ is the finite set of transitions,
- $F \subseteq (P \times T) \cup (T \times P)$ is the set of arcs,
- $W : F \to \{1, 2, 3, ...\}$ is the weight function,
- $M_0 : P \to \{0, 1, 2, 3, ...\}$ is the initial marking,
- $P \cap T = \varnothing$ and $P \cup T \neq \varnothing$.

We use $I(t_j)$ and $O(t_j)$ to represent the sets of input places and output places of transition t_j, respectively, as

$$I(t_j) = \{p_i \in P : (p_i, t_j) \in F\}, \tag{2}$$

$$O(t_j) = \{p_i \in P : (t_j, p_i) \in F\}. \tag{3}$$

For a marking $M : P \to \{0, 1, 2, 3, ...\}$, $M(p_i) = n$ means that the ith place has n tokens (Murata 1989). A marking M can also be represented by a vector with k elements where k is the total number of places.

Definition 2.2.1 (Cassandras and Lafortune 2008): A transition t_j is said to be enabled at a marking M if each input place p_i of t_j has at least $W(p_i, t_j)$ tokens, where $W(p_i, t_j)$ is the weight of the arc from place p_i to transition t_j, that is, $M(p_i) \geq W(p_i, t_j)$ for all $p_i \in I(t_j)$.