Journal of KONBiN 4(24)2012
ISSN 1895-8281

RELIABILITY ANALYSIS OF HIGHWAY EMERGENCY RESPONSE SYSTEMS

ANALIZA NIEZAWODNOŚCIOWA AUTOSTRADOWYCH SYSTEMÓW ŁĄCZNOŚCI ALARMOWEJ

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***Abstract**: Transport telematic systems related issues are discussed in the paper. Most focused on were highway emergency response systems. Their structure and operational characterisation were described. Methods of assessing their reliability were also presented.*

Keywords: *transport telematics, highway emergency response systems, reliability*

Streszczenie: *W publikacji przedstawiono zagadnienia związane z systemami telematyki transportu. Zwrócono szczególna uwagę na autostradowe systemy łączności alarmowej. Opisano ich budowę oraz funkcjonowanie. Zaprezentowano także ogólną metodykę oceny ich niezawodności.*

Słowa kluczowe: *telematyka transportu, autostradowe systemy łączności alarmowej, niezawodność*

1. Introduction

Transport telematics is defined as a field of knowledge and technical activity integrating IT with telecommunications, intended to support transport systems. The assistance comes in form of integrated sensor, telecommunications, IT and information systems complemented by telematics-enabled apps (services) [16, 19].
The core functionality at the heart of telematic systems is handling information which entails collecting, processing, distributing via transmission and deploying data at decisional processes. The processes are carried out in a pre-determined fashion (e.g. automatic control) and/or as incident-induced processes (decisions of dispatchers, administrators, independent infrastructure users).
As of late, highway telematic systems have been subject of multiple papers [3, 6]. There are multiple reasons behind that. It has been widely acknowledged that development of road transport, especially Polish highway network is a top priority. Traffic density on trunk roads has reached volumes so high that without high efforts aimed at building and expanding the highway network, the country could potentially face a transport paralysis. No wonder than, highway transport issues should be close to hearts of researchers.
Secondly, a highway without adequate telematics-enabled equipment addressing needs determined by existing and expected traffic parameters i.e. traffic hotspots, potential hazards and many other factors, does not cater for highway users' needs. As a result, such solutions do not offer sufficient safety and are economically inefficient.

2. Highway telematics

Telematics-enabled physical infrastructure – called intelligent systems – can vary in function and dimensions [10, 15]. However, not only the range and number of elements constitute the size of a telematic system. First and foremost the quantity and diversity of information fed through and processed in the system matters, followed by the number of entire system's domains of activity.
As mentioned before, the fundamental feature of telematics-based applications is the capability to disseminate and process vast amounts of information adequate to a given function, adapted to consumer needs – users of that information, specific for right place and time. Information can be communicated either automatically or interactively, upon user request. An important feature of telematics-based applications is their ability to effectively integrate different subsystems and cause them to operate in a coordinated fashion [18].
A highway telematic system comprises many subsystems [11], dedicated for particular operational functions. Tasks delivered by individual subsystems make up a whole which represents a fully-fledged system for traffic surveillance, traffic control, hazard warning, road accident management, road maintenance and other functionalities useful for correct highway maintenance.
Highway telematics combines different information and communication technologies used in highway installations to increase travel and cargo safety

whilst decreasing at the same time environmental impact, increasing efficiency of transport processes through managing traffic flows, better use of available road infrastructure and improving profitability of highway operators.
Part of highway telematics are transport control centres managing flow of passengers, vehicles, drivers, goods. It also makes vehicles (cars, coaches etc.) part of computer network, GPS cellular network by equipping vehicles and cargo with sensors. Intelligent Transport System, subsystems managing roads, vehicles, drivers and transport service based on real time telecommunications create a logical sequence capable of managing moving people, vehicles and cargo under changing environmental conditions.

3. Highway emergency response system architecture

Highway emergency response system enables users to report from their current position any breakdowns, collisions etc. to the highway control center managing that road section.
Roadside infrastructure enables bidirectional communication (speaking and listening) and unidirectional communication (hazard reporting by pressing the help button). By pressing the help button, the user sends a message to the Control Center. That message contains address unique to the alarm indicator column. Hence the location of the accident site and local network geometry is known instantaneously. The operator identifies the number and location of column sending the signal, thus is able to quickly notify relevant services and remotely activates flashing light fitted to the column. In case of bidirectional communication, the operator dials the alarm signalling column and speaks to the user.
The STOER system (*Systeme de Transmission Optique pour Equippements de la Route*) is an emergency response solution using for transmission purposes a fiber optic cable laid underground beneath the highway. That way, the system is resilient to electromagnetic interference and assures high-speed connectivity. The system was designed not only to facilitate emergency communication but also to provide data transfer capacity (4800 bauds) for road-side equipment purposes. Overview of emergency response network architecture is displayed in fig. 2.
Introducing a solution based on fiber optics creates substantial cost economies, especially as far as roadworks are concerned arranged for laying and joining the cables.
Fiber optics emergency response system consists of the following elements:

- Central control station (CCS) managing user notifications, handling multiple calls, automatic PSTN number dialling.
- optoelectronic interface i.e. so-called central access point (CAP) which enables two-way transmission over fiber optic cable.
- network of passive photocouplers connected to optical fiber for emergency response system. They allow connecting together all alarm indicator columns located in particular part of the network using only one fiber.

- optoelectronic interface i.e. field optical box (FOB) assign to each alarm indicator column and to the master column. FOBs and the master column are connected using a short multi-couple cable, thus facilitating maintenance and repairs/replacement in case of any damage caused by on-going traffic.
- alarm indicator columns (master and secondary), located road-side along the highway thus creating branches leading to the Control Center. Master alarm indicator columns use electronic setup (audio frequency amplifier, input socket, acoustical system with microprocessor, modem and interface), microphone, speaker, emergency button.

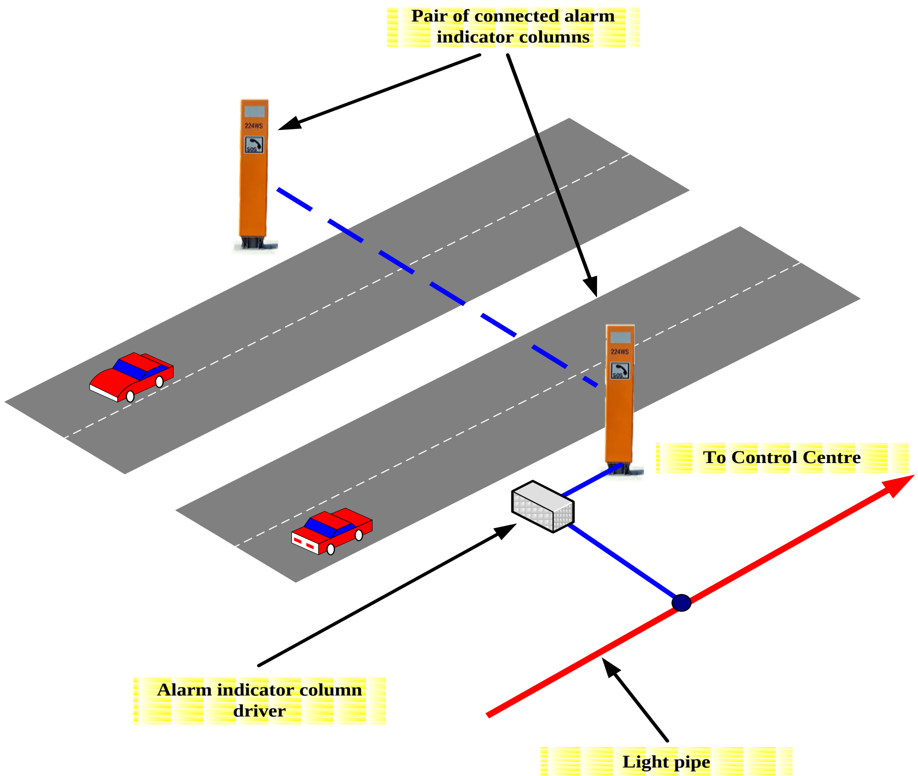

Fig. 1. Architecture of emergency response network

4. Reliability assessment of highway emergency response systems

In telecommunications network (including emergency response networks) readiness [12,13,14,17] i.e. the network's capability to establish and maintain connection between active users over given time under specific operating conditions, is determined by readiness of its constituting elements and the network's reliability structure.

Readiness of emergency response network could be measured using different indicators [2,4] which depend mainly on:

- failure process of telecommunications and transmission equipment part of the emergency response network,
- notification handling process i.e. how the Control Center supports reporting by alarm indicator columns and computer equipment [7],
- maintenance service process.

According to PN 93/N-50191 [8] the quality of service is defined as a number of service parameters which determine how well user needs are addressed. In case of highway emergency response system the quality of service is influenced by:

- reliability of the network,
- correctness of emergency message transmission.

Overview of emergency response network structure is displayed in fig. 2. It consists of the Control Center, light pipe and individual parts of alarm indicator columns (their total number is m).

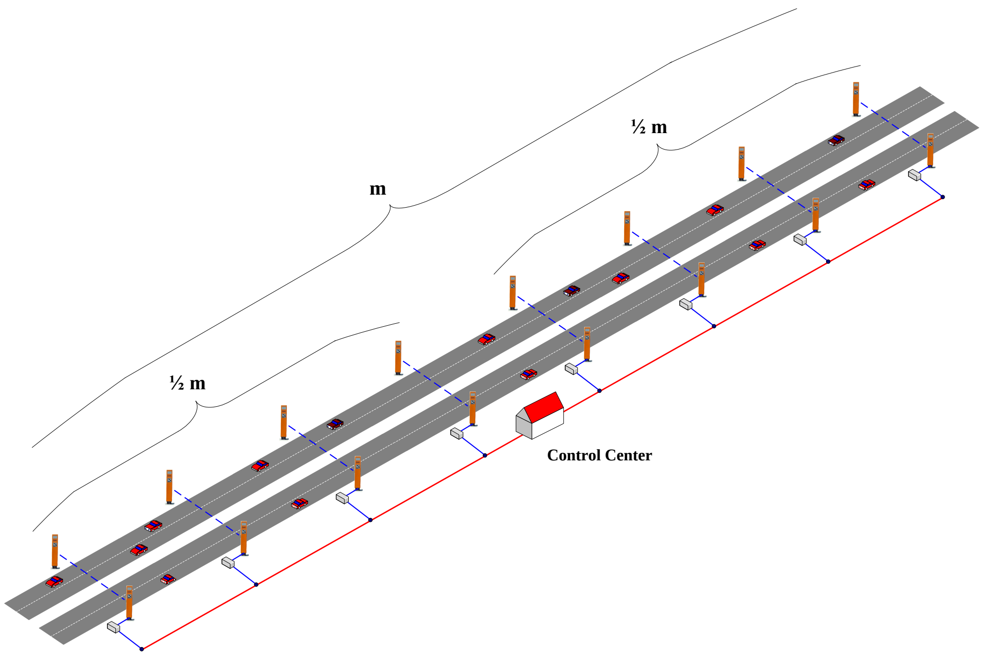

Fig. 2. Highway emergency response system

Relationships between structure elements, from reliability perspective, were determined by analysing the highway emergency response system operation and presented in fig. 3. Failure of any element of the serial structure switches the system from the state of full operational capability S_{PZ} into the state of failing security S_B.

Failure of any element of the parallel structure switches the system from the state of full operational capability S_{PZ} into the state of security threat S_{ZB} [1,5.9].

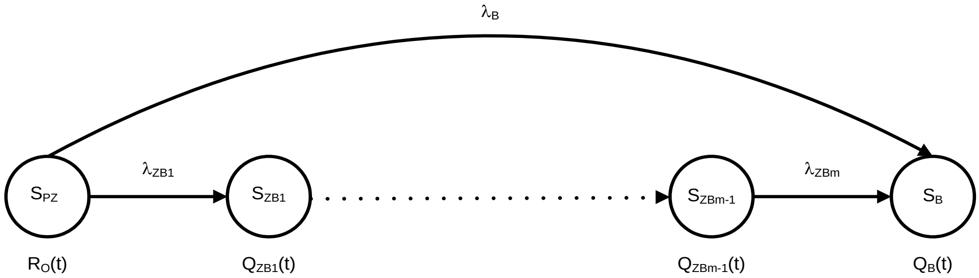

Fig. 3. Relationships within the highway emergency response system, where:

- $R_O(t)$ *– the likelihood function of system in state of full operational capability* S_{PZ}*,*
- $Q_{ZB}(t)$ *– the likelihood function of system in state of security threat* S_{ZB}*,*
- $Q_{ZB}(t)$ *– the likelihood function of system in state of security breach* S_B*,*
- λ_B *– change rate of the management centre,*
- λ_{ZB} *– transition rate for individual alarm indicator columns*

Proposed relationship graph (fig. 3) for highway emergency response system does not allow two or more alarm indicator columns to fail at the same time. Such situation could be potentially caused by light pipe failure. In that case, the equipment from failure point to the last set of alarm indicator columns would have been deactivated. Hence, relationships between structure elements, from reliability perspective, could be determined by analysing the highway emergency response system operation as presented in fig. 4.

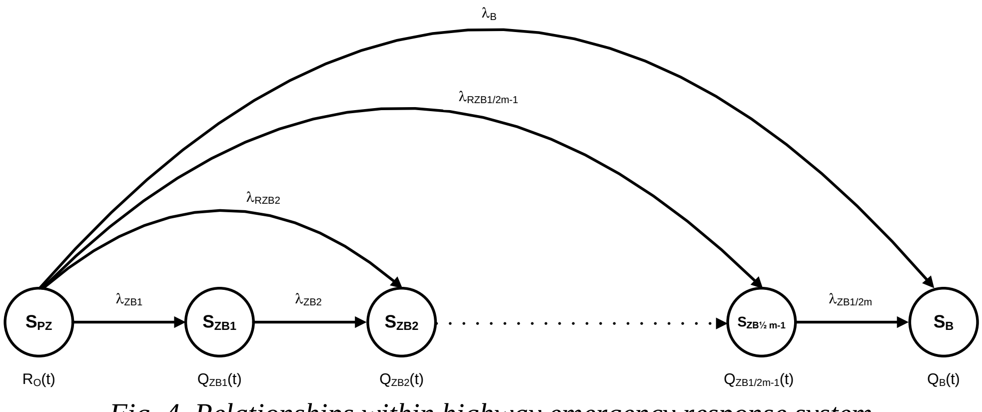

Fig. 4. Relationships within highway emergency response system in case of two of more alarm indicator column failure, where: λ_{RZB} *– transition rate of two or more alarm indicator columns*

Proposed relationship graph (fig. 4) for highway emergency response system does not allow two or more alarm indicator columns to fail at the same time in case where such situation has taken place. Hence, relationships between structure elements, from reliability perspective, could be determined by analysing the highway emergency response system operation as presented in fig. 5.

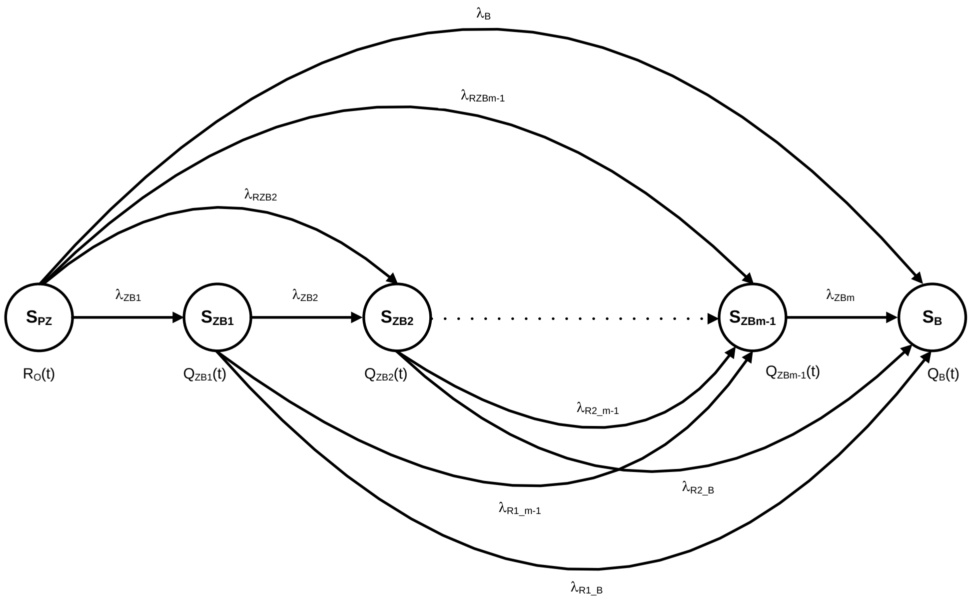

Fig. 5. Relationships within highway emergency response system taking into account different failure alternatives

Relationships for determining system state probability can be determined through mathematical analysis (based on relationship graphs displayed in fig. 3,4,5).

5. Summary

In order to determine the availability rate of emergency response network, transition rate between defined system states has to be known. Numerical values of those parameters could be estimated based on reliability prediction methods. This is justified for newly built systems. Operational tests or empirical data from system elements testing can be the other way to obtain those numerical values. This pertains to estimating parameters of fiber optic telecommunications networks.
Given relationships show that requirements important for networks transmitting telematics-based information are high reliability of single nodes (alarm indicator columns, dispatch terminal units) and network structure assuring lowest possible impact of element failure on the system.

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