Reliability Engineering and System Safety 141 (2015) 10–21

Contents lists available at ScienceDirect

Reliability Engineering and System Safety

journal homepage: www.elsevier.com/locate/ress

Modelling Vessel Traffic Service to understand resilience in everyday operations

Gesa Praetorius [a,*], Erik Hollnagel [b], Joakim Dahlman [c]

[a] World Maritime University, Maritime Risk and System Safety, P.O. Box 500, SE 201 24 Malmö, Sweden
[b] University of Southern Denmark, Center for Kvalitet, P.V. Tuxensvej 5, DK 5500 Middelfart, Denmark
[c] Chalmers University of Technology, Department of Shipping and Marine Technology, Maritime Human Factors, SE 412 96 Gothenburg, Sweden

ARTICLE INFO

Available online 26 March 2015

Keywords:
Vessel Traffic Service (VTS)
Functional Resonance Analysis Method (FRAM)
Resilience engineering
System design

ABSTRACT

Vessel Traffic Service (VTS) is a service to promote traffic fluency and safety in the entrance to ports. This article's purpose has been to explore everyday operations of the VTS system to gain insights in how it contributes to safe and efficient traffic movements. Interviews, focus groups and an observation have been conducted to collect data about everyday operations, as well as to grasp how the VTS system adapts to changing operational conditions. The results show that work within the VTS domain is highly complex and that the two systems modelled realise their services vastly differently, which in turn affects the systems' ability to monitor, respond and anticipate. This is of great importance to consider whenever changes are planned and implemented within the VTS domain. Only if everyday operations are properly analysed and understood, it can be estimated how alterations to technology and organisation will affect the overall system performance.

1. Introduction

Shipping has been one of the major means of transportation more than the past 5000 years. From local trading along rivers, shipping has developed into transportation global business [38] demanding efficient and safe operations. As in other domains, demands are normally responded to through changes both in technology and organisation. Examples of such change within the maritime domain include, but are not limited to, the increase of the volume and size of vessels through the past decade [41], the introduction and integration of decision support tools such as the AIS and electronic chart displays, into one standardised system [27], and the introduction of safety management systems [29,40]. However, although these improvements are often introduced to increase the safety within the maritime transport system, they have generally been used to increase the overall productivity, counteracting their initial safety effect with the consequence of inducing incidents and accidents rather than preventing them completely [32]. This paper will consider one of the most recent examples fora maritime safety measures, the so-called Vessel Traffic Service (VTS), a service implemented to promote safe, efficient and environmental-friendly marine traffic [22].

VTS is a shore-side service within a country's territorial waters. VTS Operators (VTSOs) monitor the traffic, assist in navigational matters, and provide information to all vessels in a designated area, normally port areas or areas that pose navigational difficulties. VTS can be delivered on three different service levels: Information Service (INS), Traffic Organisation Service (TOS), and Navigational Assistance Service (NAS). Information Service (INS) means broadcasting information to all participating vessel within the VTS area on a specific VTS channel. INS contains information relevant for the safe passage of the area, and can consist of reports on position, identity and intentions of other traffic, or information concerning the meteorological and geographical state of the area. Traffic Organisation Service (TOS) is an operational management of traffic movements within the determined VTS area conducted through VHF broadcasts. It aims to prevent the upcoming of dangerous situations as well as to avoid congestions within the area. Navigational Assistance Service (NAS) is the highest service level a VTS can exercise and is often only provided upon request of a vessel. NAS is an intervention in the decision making on board with the aim to assist the traffic to a safe and expedient passage by providing information on the VHF. However, the decision making power remains with the Master on board the vessel and is not transferred to the VTS ashore. Therefore, ships are offered instructions only when safety is at risk or upon their request. As the

* Corresponding author. Tel.: + 46 40 128 442.
E-mail addresses: gp@wmu.se (G. Praetorius), erik.hollnagel@rsyd.dk (E. Hollnagel), joakim.dahlman@chalmers.se (J. Dahlman).

http://dx.doi.org/10.1016/j.ress.2015.03.020
0951-8320/

international framework identifies VTS as an assistance service, the VTSOs are not supposed to take part in traffic management tasks such as voyage optimisation, route planning, or the planning of traffic density in the area. That constrains the possibilities of the VTS to actively work for safe and efficient traffic movements.

While VTS has often been studied with either focus on technology (i.e. [6,24,44]), information needs (i.e. [5]), communication [4,9,10,25], or interface design [42], there is only a limited amount of research focusing on the VTS as sociotechnical system, and the challenges that VTSOs face within the settings of their daily work. As Nuutinen, Savioja, and Sonninen [30] note, the VTS system is currently undergoing changes. Developments both within the VTS system (e.g. such as chain planning) and the maritime domain as such, will pose challenges for how traffic management is conducted currently. Therefore this article focuses on how the VTS contributes to safe and efficient traffic movements within the VTS area. The Functional Resonance Analysis Method (FRAM) is used to describe everyday operations of two VTS systems. The VTS is a socio-technical system under change and it is essential to understand how the system maintains control through adapting to the uncertain and dynamic environment that the maritime traffic constitutes. Furthermore, the resilience engineering abilities (respond, monitor, anticipate and learn) are used to identify and discuss the systems' ability to resilience and ways in which one may strengthen the systems' possibilities to sustain required functioning during many different operating conditions.

2. Background

Large sociotechnical systems, such as the VTS, comprise processes distributed over people, technology and organisations, which are becoming increasingly complex and therefore hard to control. Control is important for sociotechnical systems as these systems must adapt to the context to be able to operate in a large variety of operational conditions and match challenges that may arise through the dynamic character of the environment. Control here is not meant in an absolute way, but rather wants to emphasise the pressure on today's system to produce stable output over time – e.g. efficient and safe traffic movements – based on a dynamic input [20].

Resilience engineering (RE) is a relatively young body of research that emerged at the beginning of the 2000s. Resilience, which has its origin as a concept within ecology in the early 1970s, defines an ecological system's ability to arrive at an equilibrium, or stable state, over time in a dynamic and changing environment [15]. In the context of socio-technical systems, resilience is the ability to sustain required functioning and achieve system goals under a variety of operational conditions.

In resilience engineering, systems are analysed with the aid of four cornerstones, monitoring, response, anticipation, and learning, which characterise the features a system should have to be able to maintain its functioning before, during and after anticipated and unanticipated events have occurred. Furthermore, RE emphasises examples of the positive, meaning that it is concerned with how systems succeed by adapting their performance to the demands within the environment [21]. When adaption is successful, safety emerges as a property, as the system balances goals and demands in the current context [49], e.g. safe and efficient traffic movement within a port approach.

In the core of the RE framework, there are four abilities (learn, monitor, anticipate and respond) that can help to understand a system's performance and provide insights in how resilience manifests itself in everyday operation. These four abilities are essential for a system to be able to recognise challenging conditions, respond to them, evaluate the response and prepare for future events. The four abilities are mutually dependent, and each represents one facet of a system's functioning. By analysing everyday operations with the aid of the abilities, one is able to identify ways in which the system's capacity for knowing what to do (respond), what to look for (monitor), what to expect (anticipate) and what has occurred (learn) can be strengthened [16]. Furthermore, informing design activities with the help of findings in relation to the four cornerstones can help to make a system more bumpable [51] in the sense that it will be able to operate under a variety of conditions without major performance drops.

2.1. Functional Resonance Analysis Method (FRAM)

The FRAM is a method to analyse and model complex sociotechnical systems. The method focuses on the concept of performance variability and ways in which systems manage and monitor potential and actual variability. FRAM is based on four basic principles; the principle of equivalence of successes and failures, principle of approximate adjustments, principle of emergence and the principle of functional resonance (e.g. [14,18]). The *principle of equivalence of successes and failures* expresses that the only difference in between these two is the judgement of the outcome. While an action is deemed as success if it has the desired outcome, the same action can be identified as a failure when negative and unforeseen consequences occur. How these consequences can arise is accounted by the *principle of approximate adjustments*. Sociotechnical systems are complex systems acting in an uncertain and dynamic environment. Functions are distributed over people, technology and organisation that adjust their performance to be able to meet the demands the system is facing in the current situation. As this adjustment is based on the availability of resources (e.g. time, manpower) it will always be approximate. Consequently, everyday performance is and needs to be variable to help the system to successfully adapt its functioning to the current operational conditions. While variability within one function possibly can be managed or monitored, the *principle of emergence* emphasises that variability in multiple functions may combine in unanticipated ways and cause disproportional and non-linear effects. Although performance variability can lead to negative outcomes, it is first and foremost necessary for a system's resilience, for the ability to function under beneficial and harmful conditions alike. The last principle, *the principle of functional resonance*, highlights the potential of the variability in multiple functions to resonate, and therefore reinforce and even amplify itself, so that the outcome of a function might carry an unusually high amount of variability, which the system is not able to manage given the current condition. As a result, accidents might occur.

FRAM consists of four steps which are used to model the system based on functions and to identify sources of performance variability as well as measures to manage, dampen or monitor it. In *Step 1* all necessary system functions are defined. The aim is to afford a consistent description as a basis of the analysis. All functions are described in form of their six aspects (Input, Output, Time, Control, Precondition, and Resources/Executing conditions, Table 1). These aspects describe the basic characteristic of an activity and help to understand relations among functional units within a system.

The functions that are the focus of the analysis are called foreground functions. Functions that are required by the foreground functions, but which do not themselves contribute to the variability being investigated, are called background functions [17]. Background functions represent the context and while they do not vary during the time frame specific for the analysis, they shape the performance and affect how events progress [19].

Step 2 helps to identify the variability of the functions in the FRAM model. The functions performance can vary in various ways.