Archives of Transport System Telematics

Volume 2

Issue 3

September 2009

Reliability structure of the vessel traffic services in the Gulf of Gdansk

T. BUDNY
Faculty of Navigation, Gdynia Maritime University, Al. Jana Pawła II 3, 81-345 Gdynia, Poland
EMAIL: astymo@wp.pl

ABSTRACT
In the paper reliability structure of the Vessel Traffic Services Gulf of Gdansk system is described. Four different functional subsystems are distinguished. Some definitions of the different kinds of structures are also presented

KEYWORDS: traffic monitoring systems, systems reliability, vessel traffic services at sea, reliability structure

1. Introduction

Growing traffic at the sea, particularly in the vicinity of large ports caused necessity to organize this traffic. International Maritime Organization (IMO) in 1997 adopted a new regulation to International Convention on Safety of Life at Sea (SOLAS). Resolution No A.857 (20) introduced principles and general operational provisions for the operation of a Vessel Traffic Service (VTS) and vessels participating in it [4]. The purpose of vessel traffic services is to improve the safety and efficiency of navigation, safety of life at sea and the protection of the marine environment and/or the adjacent shore area, from possible adverse effects of maritime traffic. According to the resolution mentioned above the Vessel Traffic Services "VTS Gulf of Gdansk" has been established on May 1, 2003, providing for participating vessels a range of services and maintaining control on maritime safety within VTS Area of responsibility. To fulfill its tasks and ensure surveillance of whole VTS Area few different devices are used. There are 5 shore based maritime radars, 3 Automatic Identification System (AIS) devices and additionally 2 radio direction finders (RDF). Essential data processing is done by set of servers in the VTS Center in Port of Gdynia. All data are eventually visualized and presented on three operators' consoles. Because of its functions the system should be very reliable. In order to calculate reliability of the system we have to determine its reliability structure. In the paper there is proposed possible approach to determine and calculate VTS Gulf of Gdansk system's reliability.

2. Systems' definitions

We assume that [1,2]

$$E_i,\ i = 1,2,\ldots,n,\ n \in N, \quad (1)$$

are two-state components of the system having reliability functions

$$R_i(t) = P(T_i > t),\ \ t \in (-\infty,\infty),\ i = 1,2,\ldots n, \quad (2)$$

where T_i, i = 1,2,...,n, are independent random variables representing the lifetimes of components E_i with distribution functions

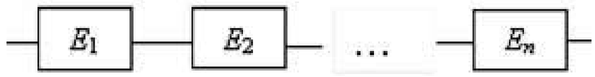

Fig.1.The scheme of a series system

$$F_i(t) = P(T_i \le t),\ t \in (-\infty, \infty),\ i = 1,2,\dots,n. \quad (3)$$

Definition 1. A two-state system is called series if its lifetime T is given by

$$T = \min_{1 \le i \le n}\{T_i\} \quad (4)$$

The above definition means that the series system is not failed if and only if all its components are not failed, and therefore its reliability function is given by

$$q_i > 0,\ \sum_{i=1}^{a} q_i = 1 \quad (5)$$

Definition 2. A two-state series system is called non-homogeneous if it is composed of a, 1 ≤ a ≤ n, different types of components and the fraction of the ith type component in the system is equal to q_i, where $q_i > 0,\ \sum_{i=1}^{a} q_i = 1$ Moreover

$$R^{(i)}(t) = 1 - F^{(i)}(t),\ t \in (-\infty, \infty),\ \mathrm{i} = 1,2,\dots,\mathrm{a}, \quad (6)$$

is the reliability function of the i-th type component.

The scheme of a non-homogeneous series system is given in Figure 2.

It is easy to show that the reliability function of the non-homogeneous two-state series system is given by

$$\overline{\mathbf{R}}'_{k_n l_n}(t) = \prod_{i=1}^{a} (R^{(i)}(t))^{q_i n},\ t \in (-\infty, \infty) \quad (7)$$

A two-state system is called an "m out of n" system if its lifetime T is given by

m = 1,2,...,n,

where, is the mth maximal order statistic in the sequence of component lifetimes ,,...,.

The above definition means that the two-state "m out of n" system is not failed if and only if at least m out of its n components are not failed. The two-state "m out of n" system becomes a parallel system if m = 1, whereas it becomes a series system if m = n. The reliability function of the two-state "m out of n" system is given either by

$$\mathbf{R}_n^{(m)}(t) = 1 - \sum_{\substack{r_1, r_2, \dots, r_n = 0 \\ r_1 + r_2 + \dots + r_n \le m-1}}^{1} \prod_{i=1}^{n} [R_i(t)]^{r_i} [F_i(t)]^{1-r_i},\ t \in (-\infty, \infty) \quad (4)$$

or by

$$\overline{\mathbf{R}}_n^{(\bar{m})}(t) = \sum_{\substack{r_1, r_2, \dots, r_n = 0 \\ r_1 + r_2 + \dots + r_n \le \bar{m}}}^{1} \prod_{i=1}^{n} [F_i(t)]^{r_i} [R_i(t)]^{1-r_i},\ t \in (-\infty, \infty),\ \bar{m} = n - m \quad (5)$$

Definition 3. A two-state "m out of n" system is called non-homogeneous if it is composed of a, 1 ≤ a ≤ n, different types of components and the fraction of the ith type component in the system is equal to qi, where $q_i > 0,\ \sum_{i=1}^{a} q_i = 1$ Moreover

$$R^{(i)}(t) = 1 - F^{(i)}(t),\ t \in (-\infty, \infty),\ \mathrm{i} = 1,2,\dots,\mathrm{a}, \quad (6)$$

The scheme of a non-homogeneous "m out of n" system is given in Figure 3, where $i_1, i_2, \dots, i_n \in \{1,2,\dots,n\}$ and $i_j \ne i_k$ for $j \ne k$

The reliability function of the non-homogeneous two-state "m out of n" system is given either by

$$\overline{\mathbf{R}}_n^{(m)}(t) = 1 - \sum_{\substack{0 \le r_i \le q_i n \\ r_1 + r_2 + \dots + r_a \le m-1}} \prod_{i=1}^{a} \binom{q_i n}{r_i} [R^{(i)}(t)]^{r_i} [F^{(i)}(t)]^{q_i n - r_i},\ t \in (-\infty, \infty) \quad (7)$$

or by

$$\overline{\mathbf{R}}_n^{(\bar{m})}(t) = \sum_{\substack{0 \le r_i \le q_i n \\ r_1 + r_2 + \dots + r_a \le \bar{m}}} \prod_{i=1}^{a} \binom{q_i n}{r_i} [F^{(i)}(t)]^{r_i} [R^{(i)}(t)]^{q_i n - r_i},\ t \in (-\infty, \infty) \quad (8)$$

where $\bar{m} = n - m$

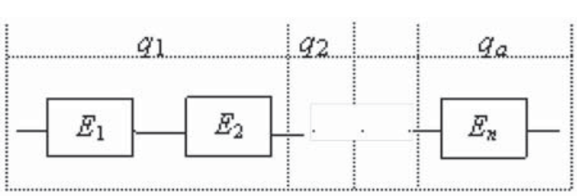

Fig.2.The scheme of a non-homogeneous series system

3. Reliability structure of the VTS subsystems

VTS Gulf of Gdansk system can be divided into few separate subsystems which allow for surveillance and data

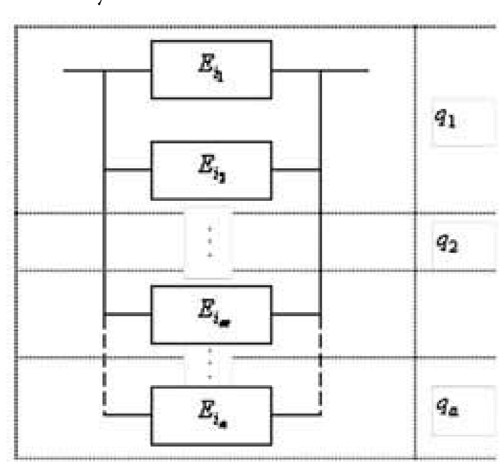

Fig.3.The scheme of non-homogenous "m out of n" system

processing. We can distinguish radars subsystem, AIS subsystem, auxiliary (supporting) RDF subsystem and data processing and visualization subsystem. Reliability structures of those subsystems can be described separately.

3.1. Radars subsystem

Radars subsystem is composed of five shore- based maritime radars which are positioned around Gulf of Gdansk coastline (fig. 4) [3]. Two of the radars are established on the Harbor Masters buildings in Gdynia and Gdansk. Three others are on the Lighthouse Hel, Lighthouse Krynica Morska and on radar tower Górki Zachodnie. Radars have similar structure, but to assure data transfer from three latter radars they are equipped additionally with microwave radio data transmitter. Considering shape of Gulf of Gdansk and also concentration of ships traffic we assuming that Hel radar is extremely important. It is the only one which allow for observation of the area north to the Hel Peninsula which is crossed by predominate number of the ships sailing to and from ports of Gdynia and Gdansk. Other four radars assure very good simultaneous coverage in the approaches to ports and on the Traffic Separations Schemes areas. Because of radars ranges three of those four provide coverage good enough for the proper work of the system. Taking into account above facts reliability structure of the radars subsystem can be describe as combination of non-homogenous "3 out of 4" system and a series system (fig. 5). Using equation (7) and than equation (3) we can calculate reliability of the radars subsystem [1].

3.2. AIS subsystem

Automatic Identification System (AIS) is a broadcast communications system, operating in the VHF maritime band, that is capable of sending ship information, such as identification, position, course, speed, ship dimensions, draught, ship type, and cargo information, to other ships and to shore. AIS is a mandatory equipment for most ships [SOLAS] and is used by Vessel Traffic Services to monitor movement of ships in the Gulf of Gdansk. There are three land based AIS devices (receivers) positioned on the lighthouses in Rozewie, Hel and Krynica Morska. Information from AIS receivers are transmitted to the VTS center by using of radio microwave links or by light fiber (from Rozewie) which are series connected with the receivers. Each two receivers guarantee receiving of information from ships in the VTS area. Thank to that we can define reliability structure of the AIS subsystem as a "2 out of 3" system (fig. 6) and calculate its reliability according to equation (7) or (8).

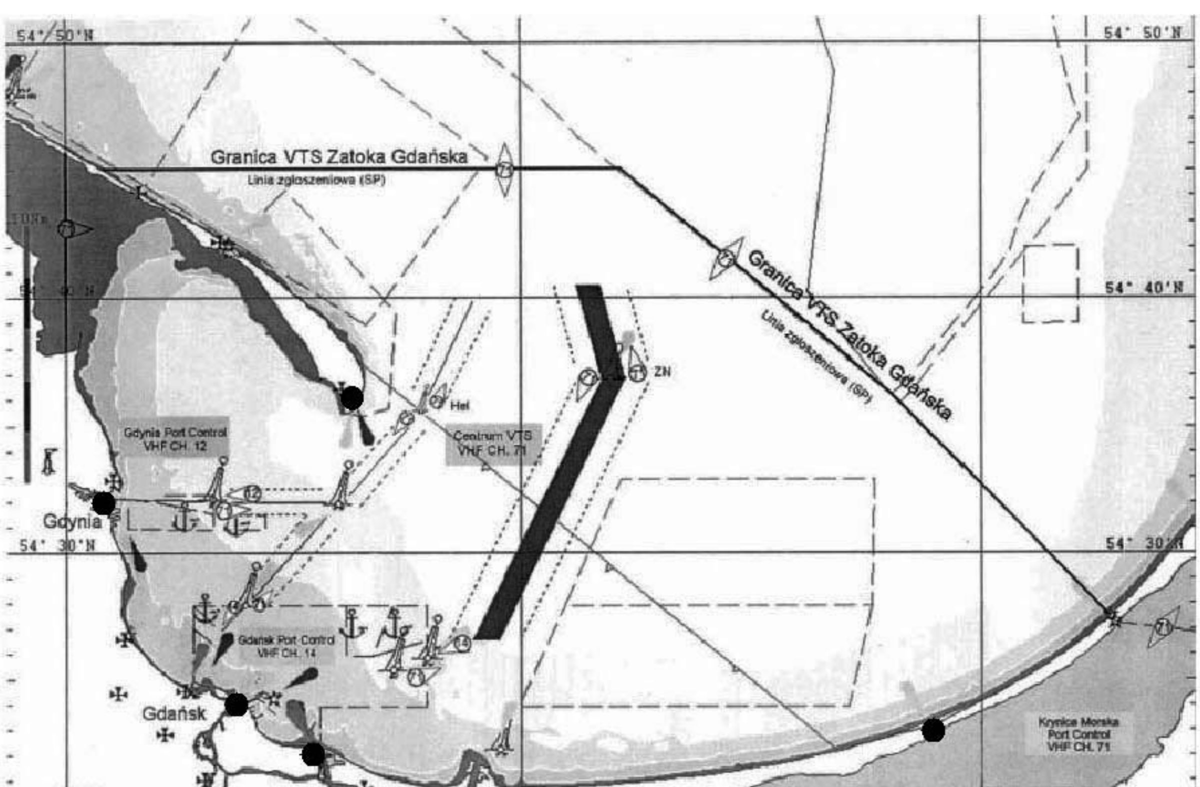

Fig.4. Position of radars on the coast of Gulf of Gdansk

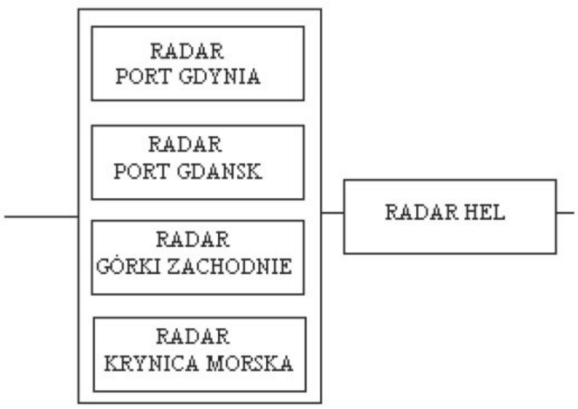

Fig.5.Reliability structure of radars subsystem

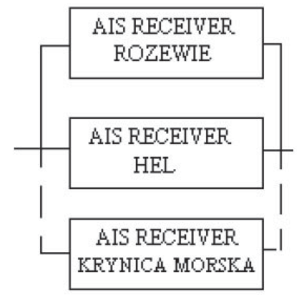

Fig.6.Scheme of AIS subsystem reliability structure

3.3. Radio direction finders subsystem

Radio Direction Finder (RDF) is a radio receiver and directional antenna system used to determine the direction of the source of a signal. In order to obtain position of a ship at least two RDF devices are necessary. RDF is used in VTS systems as a auxiliary component which allows for confirmation of ships' position.

VTS Gulf of Gdansk system uses 2 RDF devices. They are positioned on the lighthouses in Hel and Krynica Morska. It means that subsystem is working if and only if both of the RDFs are working properly. Data from RDFs are transmitted via microwave links. From the reliability point of view subsystem has a series structure (fig. 7) and its reliability can be calculated by using equation (3).

3.4. Data processing and visualization subsystem

Information Processing System (IPS) consist several computer servers which collect data coming from observation subsystems and prepare them to visualization on operators' consoles. There are three such consoles in the VTS centre in Gdynia. At least one of them should work to assure good and continuous work of the whole VTS system. It means that they form a "1 out of 3" reliability structure and they are series connected with Information Processing System (fig. 8). Reliability of that subsystem can be calculated by using equations (7) and (3).

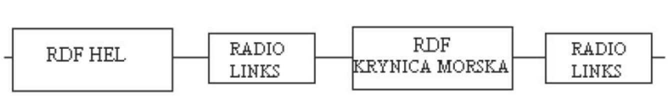

Fig.7.Reliability structure of RDFs subsystem

4. VTS GULF of Gdansk reliability structure

After calculating of reliability of each subsystem separately next we will be able to calculate reliability of the VTS system, but only if we describe its reliability structure. In order to assure proper work of the system three of its four subsystems have to be operational i.e. radars, AIS and data processing subsystems must not be out of service. If one of them fail whole system should be consider as inoperative. It means that VTS system has series reliability structure. Radio Direction Finders subsystem as an auxiliary part of the VTS doesn't have to be built-in the reliability scheme and can be treat independently (fig. 9).

According to equation (3) we obtain

$$R_{VTS} = R_R \cdot R_A \cdot R_I \tag{9}$$

where

R_R – reliability of radar subsystem,

R_A – reliability of AIS subsystem,

R_I – reliability of the information processing and visualization subsystem.

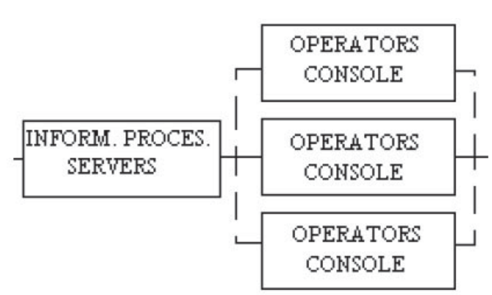

Fig.8.Reliability structure of data processing and visualization subsystem

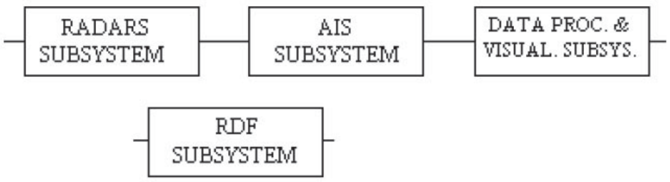

Fig.9.Proposed reliability structure of the VTS System

5. Conclusions

VTS Gulf of Gdansk system, because of its important purposes should be very reliable. Attempt of describing its reliability structure undertaken it the paper is a crucial step to further research on reliability and what is even more important availability of the system. Mathematical tools presented in paper allow us for calculating reliability of the system. For further research collecting of real data regarding VTS system is necessary. In order to calculate or estimate its availability more advanced tools such as markov or semi-markov processes are needed.

Bibliography

[1] BUDNY T., VTS Zatoka Radar System Reliability and Availability Analysis, International Journal of Reliability, Quality and Safety Enginnering, Vol.14, No 6, 2007.

[2] KOŁOWROCKI K. et al., Asymptotic approach to complex systems reliability analysis, Two-state non-renewal systems. Gdynia Maritime University Publishing House, Gdynia, 2005.

[3] STUPAK T., et al., Research on availability of VTS Zatoka radars. Maritime Office, Gdynia, 2003.

[4] International Convention on Safety of Life at Sea, SOLAS (consolidated edition), International Maritime Organization, London, 2004.