MODELLING OF PARTIAL CAPABILITY STATES AND ESTIMATION OF THE LEVEL OF OPERATIONAL READINESS FOR INTEGRATED AVIONICS SYSTEMS

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Abstract:

Maintaining continuity of use is extremely important in the modern world and in particular in the armed forces. Analysis of the system exploitation course allows obtaining information about the time in which the system was in a state of total or partial capability or in a state of inability to use. Based on information about the amount of time spent in a given state, user of the system or device can plan the operation of the device in the context of the future. On the basis of operating data, operational readiness can also be calculated, which information can be found in the article. The fallowing paper presents the possibilities and conditions of forming operating readiness for full and partial capability states of a ZSŁ (Integrated Communications Systems) with its selected components current serviced at AFIT (Air Force Institute of Technology). A probabilistic approach to the analysis of the issues associated with the determination and prediction of reliability and capability of integrated communications systems was discussed, with the use of the theory of operating states and Markov chains. The assumptions to the adopted method of modelling operating states for electronically integrated ZSŁ type communications systems were presented. Conditions for the determination of operational readiness and the possibility of forming it on the basis of an IT system were presented based on the obtained results of analytical studies. The article also presents the test stand for the integrated communication system. Information on capability of individual system components is also included, an example is based on the SK1 communication server. It's presented graph of transitions between it's individual partial capability states. The server can be in five operating states. By modelling individual components of the system in this way, you can estimate how the system will behave during operation. At the end of the article there is information about the actual and estimated operational readiness of the system.

Keywords: communications, systems, avionics, military

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1. Introduction

The basic on-board system of a modern aircraft is the communications system, which developed from an analogue phase to a digital one (Lewitowicz, 2006; Lewitowicz and Kustroń, 2003). Electronically integrated communications systems are one of the most advanced technical solutions in application as, et al., main components of avionics systems, developed for military aircraft and helicopters (Pazur and Szelmanowski, 2014). In order to ensure open and coded communication, these systems utilize, et al., digital on-board radio-stations and specialized computer systems (so-called communications servers), supporting the function of a system's cooperation with the crew and its management via communication control panels. Nowadays, one of the main issues present in the operating process of air communications systems, used, et al., on-board aircraft with analogue avionics, is the problem of ensuring required reliability and readiness (Barlow and Proschan, 1975; Kececioglu, 1995).

The task of ensuring the required reliability and readiness of communications systems installed on-board aeroplanes and helicopters used by the Polish Armed Forces, is one of the essential elements, enabling their efficient operation. The main issue attempted to be solved at AFIT (Air Force Institute of Technology) was the development of systems increasing the reliability and functionality of air communications systems (Pazur A., 2015). The Figure 1 and Figure 2 An example of technologically advanced communications systems is the ZSŁ (Integrated Communications Systems), an integrated communications system, developed and constructed at AFIT (Pazur, 2015). This system was electronically integrated, based on an SK1 (communications server), which enables increasing the reliability and capability levels of the entire system, through the use of components with improved operational parameters in the scope of, et al., mean time to failure and serviceability. Currently, it is being operated in helicopters from the Mi8/Mi17/Mi24 and W3PL series (Pazur, 2010; Pazur, 2015; Pazur, 2012). The task of ensuring the required reliability and readiness of communications systems installed on-board aircraft and helicopters used by the Polish Armed Forces, is one of the essential elements, enabling their efficient operation. The main issue attempted to be solved at AFIT, was the development of systems increasing the reliability and functionality of air communications systems and functionality of air communications systems.

The architecture of a ZSŁ integrated communications system, depending on the type of the executed task and on-board equipment, utilizes various types of analogue and digital radio-stations. In order to improve the situational awareness of the crews, the system provides them with a minimum set of air and tactical radio-stations, necessary to fulfil the task. They are supposed to provide the crew with communication on-board an aircraft, throughout the entire flight (Pazur, 2010, Pazur et al., 2016, Pazur, 2012).

Fig. 1. View of an Mi17 cabin with installed communications control panels PSŁ1 (Pazur et al., 2019)

Fig. 2. View of an W3PL cabin with installed MW1 multi-functional screens (Pazur et al., 2019)

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The state of use of individual on-board radio-stations is presented on PSŁ1 (communication control panels) and MW1 (multi-functional screens). A ZSŁ system, just like modern Western solutions of a computer system operating on a digital data exchange bus according to an adopted standard, et al., MIL-1553B (MIL-STD-1553 is a military standard published by the United States Department of Defense that defines the mechanical, electrical, and functional characteristics of a serial data bus. It was originally designed for use with military avionics, but has also become commonly used in aircraft on-board. The "brain" of such an integrated communications systems, is based on IT technologies and is an analog system is an SK1 communications server), which executes the integration of ZSŁ components. The ZSŁ system ensures communication between helicopters, the on-ground systems and the air space control service. It allows the crew to select any subscriber radio station within the internal and external communication, and to listen to special signals (navigational and warning). A communications system on-board a helicopter secures open and coded communication via coding frequencies, so-called TRANSEC (Transmission security) and encrypting speech and data, so-called COMSEC (Communications security) over a frequency band range of 1.6÷400 MHz. In Figure 3 the frequency band range was adapted to the needs of the sponsor and the types of radio-stations selected, which were subject to integration on-board a military helicopter. SK1 communications server provides supervision and management of an on-board communications network, manages and control the internal

and external communication system via PSŁ1 control panels (on-board Mi8/Mi17/Mi24 helicopters) or MW1 multi-functional screens (on-board W3PL helicopters).

Depending on the purpose of a military aircraft and the degree of complexity of the on-board integrated communications system, parameters from individual on-board radio-stations and data from the radio-navigation system are transmitted to an SK1 communications server (Pazur, 2012). Figure 4 an SK1 communications server consists of several major modules, which include a CP (processor card) data processing module, a CPIO I/O signal module and a CPP power supply module (Pazur, 2015; Pazur, 2012).

Fig. 3. View of the external structure of an SK1 communications server (Pazur et al., 2019)

Fig. 4. View of the internal structure of an SK1 communications server (Pazur et al., 2019)

In Figure 5 and Figure 6 the testing of an AFIT - developed software integrating individual air and tactical radio-stations utilizes a test-measurement station, with its task being the optimization of developed communications systems in the scope of their architecture, organization and detailed management of their individual operating modes.

Optimization of a communications system is executed due to the adopted quality criteria, et al., reliability, readiness, cost and profit. Thanks to the optimization, a ZSŁ system secures further operation of Polish military helicopters of the Mi8/Mi17/Mi24 family, until modern aircraft are introduced. However, the possibility of standardizing on-board equipment of these helicopters and their further modernization requires adapting their on-board systems to the ever-changing user needs. One of the main requirements is to ensure a high level of their operating readiness (Pazur A., 2015; Pazur A., 2012). In Section 6, there is a conclusion for the reliability based design optimization for Planar-type VCM and future work.

2. Operating readiness of air transport systems

Each user, a military user in particular, should aim for optimizing the operational process of on-board systems, in the scope of, et al., maintaining a set capability. However, it requires appropriate methods and tools, including modelling techniques, with the use of data accumulated in IT systems. For this purpose, the Department of Avionics at AFIT constructed and maintains a local IT system, which systematically gathers data characterizing the operating process of a ZSŁ integrated communications system Michalak S., (Pazur et al. 2014; Pazur and Szelmanowski, 2014; Pazur et al., 2016).

The data contained within this system were used to verify the presented model in the scope of determining and forming operating readiness of a ZSŁ system, using the theory of operating states and semi-Markov chains. Constructing the model required taking many elements into account, including operating properties and specific features, characteristic for air transport systems (Lewitowicz, 2006; Lewitowicz and Kustroń, 2003; Zieja et al., 2015).

2.1. Distinctive features of air transport systems

Air transport is the safest and most effective manner of transporting people, animals and goods, compared to other transport types. The distinctive features of air transport systems are availability and readiness to execute tasks both in civil, as well as military aviation. These features particularly concern air communications systems, which represent a specific pilot's operating environment on-board an aircraft (Pazur, 2010; Szelmanowski, 2004).

The integrated communications systems currently implemented on-boards Polish aircraft, thanks to optimization in the scope of selecting tasks and functions, provide an option to depict flight parameters and state functions, necessary for its execution (Pazur, 2010).

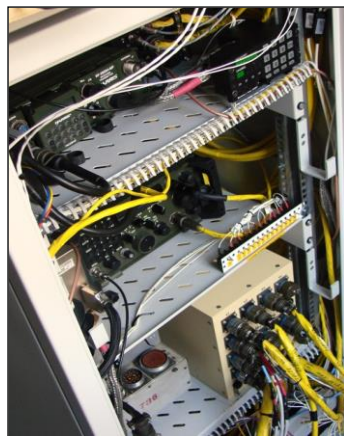Fig. 5. View of the integration site ZSŁ systems (Pazur et al., 2019)

Fig. 6. View of an SK1 chassis (Pazur et al., 2019)

Their main task is to support a pilot in the scope of executing basic flight elements, such as: basic pilotage, start-up, take-off, lift, flight and landing in different weather conditions. In the scope of extended pilotage, integrated communications systems provide a pilot with the possibility to manage the flight using control panels and screens managing the operation of an integrated communications system. The main advantage of integrated communication is the direct support of the pilot through radio-navigation systems, et al., VOR/ILS, TACAN, ARK (Pazur, 2010). Capability is one of the main types of readiness of a technical facility and constitutes its ability to execute a task within a set time. In relation to an SK1 communications server it means a probability of total appearance of events determining its functional and task readiness. A classic approach to the manner of determining functional readiness of an SK1 server, as the main element of a ZSŁ integrated communications server, requires the knowledge of the times of the server staying in the states of worthiness and unworthiness, derived from the record of operational documentation, kept by units operating military helicopters.

In relation to ZSŁ integrated communications systems, the determination of capability requires knowledge in terms of data regarding the time of its selected elements staying in defined operating states. However, data available to AFIT enable the determination of only the number of fly-outs, duties, executed repairs and service maintenance. Hence, determining capability required the use of an adequate method based on the number of transitions between individual operating states, and a mean time of staying in a given state, estimated on the basis of operational data (Pazur, 2010; Szelmanowski, 2004).

2.2. Basic Mathematical Relationships Characterizing Operating Readiness

According to (Lewitowicz, 2006) capability of an SK1 server may be generally defined as a probability of the server staying in a state of functional worthiness, at a selected moment and its ability to execute a task within an anticipated time interval, which can be presented in the following form:

$$P_0(t, \tau) = P_F(t) \cdot P_Z(\tau) \tag{1}$$

Where $P_F(t)$ a probability of an SK1 server staying in a state of functional worthiness at a selected point

in time t prior to commencing a task $P_z(\tau)$ is probability of an SK1 server staying in a state of task worthiness, within a period of time of not shorter than T necessary for task execution.

In order to describe capability of an SK1 communications server, we can use general relationships, which enable presenting it in the following form:

$$G_O(t, \tau) = G_F(t) \cdot G_Z(\tau) \tag{2}$$

Where functional readiness of an SK1 server, described by probability of an SK1 server staying in a state of functional worthiness, task readiness of an SK1 server, described by probability of an SK1 server staying in a state of task worthiness.

In the classic approach (Barlow et al., 1995), functional readiness of an SK1 communications server can be determined from a relationship defining its functional readiness coefficient:

$$G_F(t) = K_G(t) = \frac{E(T_Z)}{E(T_Z) + E(T_N)} \tag{3}$$

Where $E(T_z)$ is expected value of an SK1 server worthiness time random variable $E(T_N)$ is expected value of an SK1 server unworthiness time random variable.

Within the same approach, task readiness of an SK1 communications server may be determined from a relationship defining its unworthiness function:

$$G_Z(\tau) = R_Z(\tau) = \frac{N - M(\tau)}{N} \tag{4}$$

Where $R_z(\tau)$ is reliability function of an SK1 server N the total number of transitions of an SK1 server between operating states $M(\tau)$ the number of transitions of an SK1 server to states of unworthiness (maintenance, repair, service).

Because the data owned by AFIT do not cover the entirety of the times of an SK1 server staying in individual operating states, the use of that data requires a different approach than the one presented above. In order to determine the coefficients characterising capability of an SK1 server, a probabilistic model with operating states described with a semi-Markov chain was used, which characterises the frequency of transitions between the states and allows determine probabilities of transitions between the states (Lewitowicz and Kustroń, 2003).

3. Mathematical model for determining operating readiness for full capability of an ZSŁ system

The information accumulated in the IT system of the Department of Avionics at AFIT were used to determine the data included in the relationships describing the capability of an SK1 communications server (Pazur, 2010; Szelmanowski, 2004). Input data for modelling, introduced into mathematical relationships (3) and (4), describing capability of the server, were determined on the basis of archived information regarding the dates of commencing and completing services and repairs, as well as the type of damage and repair method.

3.1. Assumptions for the Modelling of Operating Readiness of a ZSŁ system

In order to complete the model, the operating states of an SK1 communication system, which is part of a ZSŁ system, as well as the probabilities of staying in these states, were described. Due to the specifics of SK1 server's operation, which is installed on-board a military aircraft, the description included 5 selected, basic operating states (Lewitowicz and Kustroń, 2003).

The following operating states of an SK1 communications server were distinguished:

− S1 – in-flight use (from this state, the SK1 server may switch only to the S4 maintenance and S5 service states);
− S2 – on-ground duty (from this state, an SK1 server may switch only to the S1 use or S4 maintenance states);
− S3 – repair in AFIT conditions (from this state, an SK1 server may switch only to the S4 maintenance state);
− S4 – maintenance in JW (military unit) conditions (from this state, an SK1 server may switch only to the S1 use, S2 duty or S3 repair states);
− S5 – servicing in AFIT conditions (from this state, an SK1 server may switch only to the S4 maintenance state).

It should be emphasized that currently, AFIT uses a 6-state model with a separate diagnosing process executed at a JW, not presented in this paper due to a field associated with the State's defense capabilities. The Figure 7 in order to illustrate the scheme of transitions of an SK1 communications server between operating states, they were presented in the form of a transition graph.
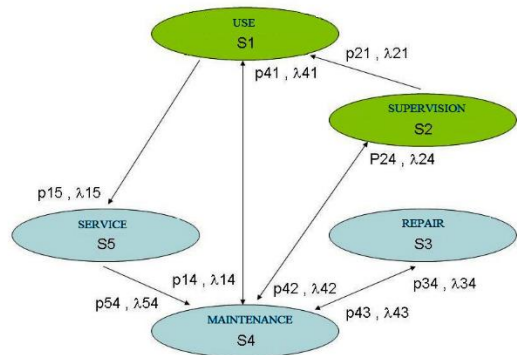

Fig. 7. Graph of transitions of an SK1 server between individual operating states (Pazur et al., 2019)

Modelling according to the method of Markov chains (with expansion onto semi Markov chains for process characterized by times of the server staying in individual operating states, with a distribution other than exponential) were selected for the analysis of an SK1 communications server, as the main element of a ZSŁ system. Such an approach made it possible to obtained moderately simple relationships defining the transition probabilities and limit probabilities of staying in individual operating states, necessary to determine the coefficients defining the task readiness (Knopik and Migawa, 2018; Knopik et al., 2016; Lewitowicz and Kustroń, 2003; Lewitowicz and Kustroń, 2003).

3.2. Formulas Describing a Model of Shaping for Full Capability of a ZSŁ System

The formulas describing the determination of the capability for a ZSŁ system were presented on the basis of a solution to the matrix equations of semi-Markov chains (Kececioglu, 1995; Restel, 2015) for an SK1 communications server, which is the main functional element of this system. Probability values for transitions (marked as p_{ij}) between selected states were determined for individual operating states of an SK1 server.

The transition probabilities p_{ij} may be presented in the following form:

$$p_{ij}(t) = P\langle X(t) = S_j | \{X(0) = S_i\rangle, \quad i,j = 1,2,3,4,5, i \neq j \tag{5}$$

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Which in practice may be determined, using the relationship:

$$p_{ij}(t) = \frac{n_{ij}(t)}{n_i(t)} \qquad (6)$$

Where:

$n_{ij}(t)$ is the number of transitions from an initial state S_i to state S_j within a studied period of time,

$n_i(t)$ the total number of transitions from the initial state S_i within a studied period of time.

A probability matrix of transitions between individual operating states, using a transition graph, may be presented in the form:

$$[p_{ij}(t)] = \begin{bmatrix} 0 & 0 & 0 & p_{14}(t) & p_{15}(t) \\ p_{21}(t) & 0 & 0 & p_{24}(t) & 0 \\ 0 & 0 & 0 & p_{34}(t) & 0 \\ p_{41}(t) & p_{42}(t) & p_{43}(t) & 0 & 0 \\ 0 & 0 & 0 & p_{54}(t) & 0 \end{bmatrix} \qquad (7)$$

The formulas describing the shaping of capability of an SK1 communications server were based on a solution of a general equation concerning the predictions of the probabilities of the server staying in selected operating states:

$$\begin{bmatrix} 0 & p_{21}(t) & 0 & p_{41}(t) & 0 \\ 0 & 0 & 0 & p_{42}(t) & 0 \\ 0 & 0 & 0 & p_{43}(t) & 0 \\ p_{14}(t) & p_{24}(t) & p_{34}(t) & 0 & p_{54}(t) \\ p_{15}(t) & 0 & 0 & 0 & 0 \end{bmatrix} x \begin{bmatrix} p_1(t) \\ p_2(t) \\ p_3(t) \\ p_4(t) \\ p_5(t) \end{bmatrix} =$$
$$= \begin{bmatrix} p_1(t) \\ p_2(t) \\ p_3(t) \\ p_4(t) \\ p_5(t) \end{bmatrix} \qquad (8)$$

The determination of individual limit probabilities (marked as p_j) was performed with the use of an additional normalization condition, in the form of:

$$\sum_j p_j(t) = 1 \qquad (9)$$

The limit probabilities determined from the above equation enable defining the functional readiness indicator, which includes the probabilities of an SK1 communications server staying

in the states of worthiness, namely, in-flight use (state S1) and on-ground duty (state S2). An instantaneous value of functional readiness for an SK1

communications server may be determined from a following relationship:

$$K_G(t) = \frac{p_1(t) + p_2(t)}{\sum_{j=1}^{j=5} p_j(t)} \qquad (10)$$

Where a probability of an SK1 server staying in the S1 usability state, a probability of an SK1 server staying in the duty state.

An instantaneous value of task readiness for an SK1 communications server may be determined with the use of a reliability function, from a following relationship:

$$G_Z(\tau) = R_Z(\tau) = exp\left[-\int_{t=t_0}^{t=t_0+\tau} \lambda(t)dt \right] \qquad (11)$$

Where $R_Z(\tau)$ is reliability function of an SK1 server over a time interval of τ not shorter than the time needed for task $\lambda(t)$ execution the value of damage intensity of an SK1 server.

On this basis, it is possible to determine an instantaneous capability value for an SK1 communication server, with the use of the relationship (2).

An important element of verification of the developed model for the determination and shaping capability is checking its stability in the case of selected manners of defining the number of transitions of times of staying in individual operating states.

It should be noted that for a time approaching infinity, it is possible to determine a limit value of a function (10) describing the capability coefficient, in the form of:

$$K_G = \frac{ET}{ET + EU} \qquad (12)$$

Sample testing data for a ZSŁ system with an assumed distribution of malfunction and

a determined SK1 communications server damage intensity determined on the basis of operation, were used for initial testing of the developed model (Pazur, 2010; Szelmanowski, 2004).

4. Mathematical model for determining operating readiness for partial capability of an ZSŁ system

The integrated communication system may have different states of capability - complete and partial operational capability (Kececioglu 1995; Knopik and

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Migawa, 2018; Zieja et al., 2019). This solution is necessary for maintain the operational readiness of the system, and thus associated with the entire aircraft.

4.1. Assumptions for the Modelling of Partial Operating Readiness of a ZSŁ system

Depending on the missions taken by the aircraft, there are other needs for system capability. In the case of SAR (Search And Rescue) missions, the system should have at least two VHF (Very High Frequency) and UHF (Ultra High Frequency) radio stations. Hoverer, when performing CSAR (Combat Search And Rescue) operations, it should have secret and tactical communication which is associated with the need to use a different set of radio stations. The system does not have full operational capability to accomplish the mission. Figure 8 shows the diagram of the integrated communication system. It can

be seen that the whole system contains of many different radio stations and information display systems (control panels). "The heart" of the system is the communication server SK1, but the system has been designed to keeping the connection from main radio stations even when server doesn't work (Pazur, 2010; Pazur, 2015).

4.2. Formulas Describing a Model of Shaping for Partial Capability of a ZSŁ System

A new approach was uset to describe mathematical relationships (Zieja et al., 2019). The system can operate in many different states of capability (Michalak, S. et al., 2014; Pazur, A., 2015). The whole system can be described as a set of elements in various capability states (Knopik and Migawa, K., 2018; Pazur, 2010; Pazur, 2015). Operational readiness can be described as the probability or time being in a given state. The fallowing relationships describe this case.
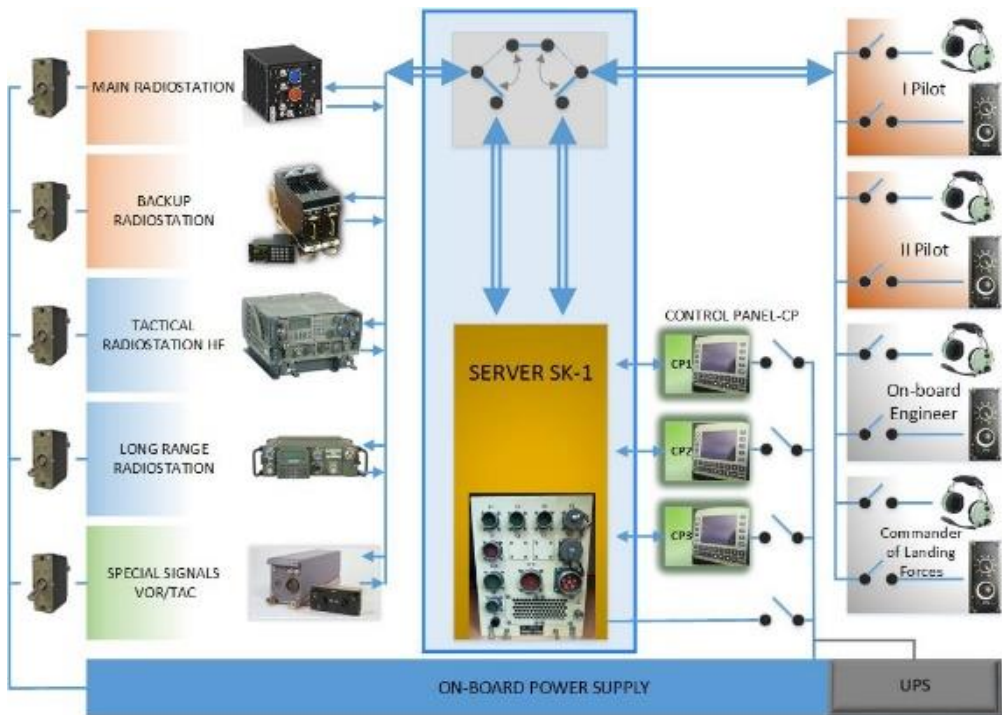

Fig. 8. The operation organisation of the integrated communication system (Pazur et al., 2019)

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Below there is formula specifying the individual probability of the system being in a state of full capability and partial capability.

$$K_g(t) = \frac{p_{Z1}(t) + p_{Z2}(t) + \ldots + p_{ZM}(t)}{\sum_{i=1}^{i=M} p_Z(t) + \sum_{i=1}^{i=M} p_N(t)} \qquad (13)$$

Where:
$p_{z1}(t)$ – probability of the system staying in the 1st state of usability (complete usability)
$p_{z2}(t)$ – probability of the system staying in the 2nd state of usability (reduced usability)
$p_{zM}(t)$ – probability of the system staying in the M state of usability (reduced usability),
which can be then written as separate components of the sum in the following form:

$$K_g(t) = \frac{p_{Z1}(t)}{\sum_{i=1}^{i=M} p_Z(t) + \sum_{i=1}^{i=M} p_N(t)} + \\ + \frac{p_{Z2}(t)}{\sum_{i=1}^{i=M} p_Z(t) + \sum_{i=1}^{i=M} p_N(t)} + \cdots + \\ + \frac{p_{ZM}(t)}{\sum_{i=1}^{i=M} p_Z(t) + \sum_{i=1}^{i=M} p_N(t)} \qquad (14)$$

Based on the analysis of this relationship, it can be seen that the system's operational readiness can be presented as the sum of the coefficients of individual components.

$$K_g(t) = K_{g1}(t) + K_{g2}(t) + \ldots + K_{gM}(t) \qquad (15)$$

Where:
$K_{g1}(t)$ – readiness coefficient of the system staying in the 1st state of usability (complete usability)
$K_{g2}(t)$ – readiness coefficient of the system staying in the 2nd state of usability (reduced usability)
$K_{gM}(t)$ – readiness coefficient of the system staying in the M state of usability
(reduced usability).

$$K_g(t) = \sum_{i=1}^{i=M} K_{gi}(t) \qquad (16)$$

Operational readiness can also be presented as a value depending on the weight of individual partial readiness.

$$K_g^*(t) = W_1 \cdot K_{g1}(t) + \\ + W_2 \cdot K_{g2}(t) + \cdots + \\ + W_M \cdot K_{gM}(t) \qquad (17)$$

Where:
W_1 – weight of the readiness coefficient of the system staying in the 1st state of usability (complete usability)
W_2 – weight of the readiness coefficient of the system staying in the 2nd state of usability (reduced usability)
W_M – weight of the readiness coefficient of the system staying in the M state of usability (reduced usability) this relationship can be written in the following form:

$$K_g^*(t) = \sum_{i=1}^{i=M} W_i \cdot K_{gi}(t) \qquad (18)$$

In a modified version it can be written as above: for the weight $W_1=1$ and other weights $W_2 \div W_M= 0$
A system with partial capability can be described in matrix form.

$$\begin{bmatrix} K_{g1}^*(t) \\ K_{g2}^*(t) \\ \ldots \\ K_{gM}^*(t) \end{bmatrix} = \\ = \begin{bmatrix} K_{g1}(t) & 0 & \ldots & 0 \\ 0 & K_{g2}(t) & \ldots & 0 \\ \ldots & \ldots & \ldots & \ldots \\ 0 & 0 & \ldots & K_{gM}(t) \end{bmatrix} x \begin{bmatrix} W_1 \\ W_2 \\ \ldots \\ W_M \end{bmatrix} \qquad (19)$$

Finally the operational readiness can be presented in matrix form.

$$\begin{bmatrix} G_{11}(t,\tau) \\ G_{12}(t,\tau) \\ \ldots \\ G_{1M}(t,\tau) \end{bmatrix} = \\ = \begin{bmatrix} K_{g1}(t) & 0 & \ldots & 0 \\ K_{g1}(t) & K_{g2}(t) & \ldots & 0 \\ \ldots & \ldots & \ldots & \ldots \\ K_{g1}(t) & K_{g2}(t) & \ldots & K_{gM}(t) \end{bmatrix} x \begin{bmatrix} R_{11}(\tau) \\ R_{12}(\tau) \\ \ldots \\ R_{1M}(\tau) \end{bmatrix} \qquad (20)$$

Based on the above relationships, the requirements for the operational readiness of the entire system can be determined. It should be remembered that the condition of reversibility of the operational readiness matrix is maintained.

$$
\begin{bmatrix} R_{11}(\tau) \\ R_{12}(\tau) \\ \dots \\ R_{1M}(\tau) \end{bmatrix} =
$$

$$
= \begin{bmatrix} K_{g1}(t) & 0 & \dots & 0 \\ K_{g1}(t) & K_{g2}(t) & \dots & 0 \\ \dots & \dots & \dots & \dots \\ K_{g1}(t) & K_{g2}(t) & \dots & K_{gM}(t) \end{bmatrix}^{-1} x \begin{bmatrix} G_{11}(t,\tau) \\ G_{12}(t,\tau) \\ \dots \\ G_{1M}(t,\tau) \end{bmatrix} \quad (21)
$$

Determining the level of reliability of individual components allows to ensure the intended efficiency of the system and to analyze which elements need to be replaced or improved.

Based on the data collected in the IT system at the avionics plant, the following data was obtained, the readiness coefficient in the state of total system capability is $K_g = K_{g1} = 0.900$ respectively system readiness coefficient in the case of partial capability is $K_{g2} = 0.050$; $K_{g3} = 0.030$; $K_{g4} = 0.010$. Reliability of the system in the case of full system capability is $R(\tau) = R_{11}(\tau) = 0.729$, $R_{12}(\tau) = 0.810$; $R_{13}(\tau) = 0.810$; $R_{14}(\tau) = 0.900$. Therefore, operational readiness can be calculated:

$$
G(t,\tau) = K_g(t) \cdot R(\tau) = 0,900 \cdot 0,729 = 0,656 \quad (22)
$$

The operational readiness of the ZSŁ system can be presented in matrix form with various states of capability:

$$
\begin{bmatrix} G_{11}(t,\tau) \\ G_{12}(t,\tau) \\ G_{13}(t,\tau) \\ G_{14}(t,\tau) \end{bmatrix} =
$$

$$
= \begin{bmatrix} K_{g1}(t) & 0 & 0 & 0 \\ K_{g1}(t) & K_{g2}(t) & 0 & 0 \\ K_{g1}(t) & K_{g2}(t) & K_{g3}(t) & 0 \\ K_{g1}(t) & K_{g2}(t) & K_{g3}(t) & K_{g4}(t) \end{bmatrix} x \begin{bmatrix} R_{11}(\tau) \\ R_{12}(\tau) \\ R_{13}(\tau) \\ R_{14}(\tau) \end{bmatrix} \quad (23)
$$

Where

$G_{11}(t, \tau)$ – operational readiness of the system staying in the state of complete usability (all elements are efficient)

$G_{12}(t, \tau)$ – operational readiness of the system staying in the state of reduced usability (inefficient SK1 server)

$G_{13}(t, \tau)$ – operational readiness of the system staying in the state of reduced usability (inefficient tactical radio)

$G_{14}(t, \tau)$ – operational readiness of the system staying in the state of reduced usability (inefficient SK1 server and tactical radio).

Substitute the numerical data in the formula to obtain the following matrix:

$$
\begin{bmatrix} G_{11}(t,\tau) \\ G_{12}(t,\tau) \\ G_{13}(t,\tau) \\ G_{14}(t,\tau) \end{bmatrix} = \begin{bmatrix} 0,656 \\ 0,697 \\ 0,721 \\ 0,730 \end{bmatrix} =
$$

$$
= \begin{bmatrix} 0,900 & 0 & 0 & 0 \\ 0,900 & 0,050 & 0 & 0 \\ 0,900 & 0,050 & 0,030 & 0 \\ 0,900 & 0,050 & 0,030 & 0,010 \end{bmatrix} x \begin{bmatrix} 0,729 \\ 0,810 \\ 0,810 \\ 0,900 \end{bmatrix} \quad (24)
$$

The method also allows reversing approach to the topic of reliability. The fallowing matrices represent a full capability of system on the system and the other one the partial capability of the system.

$$
\begin{bmatrix} R_{11}(\tau) \\ R_{12}(\tau) \\ R_{13}(\tau) \\ R_{14}(\tau) \end{bmatrix} = \begin{bmatrix} 0,778 \\ 0,900 \\ 0,900 \\ 0,900 \end{bmatrix} =
$$

$$
= \begin{bmatrix} 0,900 & 0 & 0 & 0 \\ 0,900 & 0,050 & 0 & 0 \\ 0,900 & 0,050 & 0,030 & 0 \\ 0,900 & 0,050 & 0,030 & 0,010 \end{bmatrix}^{-1} x \begin{bmatrix} 0,700 \\ 0,745 \\ 0,772 \\ 0,800 \end{bmatrix} \quad (25)
$$

$$
\begin{bmatrix} R_{11}(\tau) \\ R_{12}(\tau) \\ R_{13}(\tau) \\ R_{14}(\tau) \end{bmatrix} = \begin{bmatrix} 0,833 \\ 0,900 \\ 0,900 \\ 1,000 \end{bmatrix} =
$$

$$
= \begin{bmatrix} 0,900 & 0 & 0 & 0 \\ 0,900 & 0,050 & 0 & 0 \\ 0,900 & 0,050 & 0,030 & 0 \\ 0,900 & 0,050 & 0,030 & 0,010 \end{bmatrix}^{-1} x \begin{bmatrix} 0,750 \\ 0,795 \\ 0,822 \\ 0,850 \end{bmatrix} \quad (26)
$$

Based on the analysis it can be concluded that in order to obtain the operational readiness at the level of 75% (0,750) for the system in the state of complete capability and 85% (0,850) for the system in the state of partial capability should be completely efficient.

5. An example of the operating readiness determination for a ZSŁ system

In order to verify the developed module for determining and shaping capability of a integrated communication system, the information obtained from the IT system of the Department of Avionics at AFIT were used, with the system collecting actual data on the time parameters, et al., delivery dates of ZSŁ components to the warehouse, dates of their re-

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ceipt from the warehouse, dates and times of servicing, repair and validation at AFIT control stations. Based on operating data possessed by AFIT, selected factors were determined, which characterize the capability of a ZSŁ system, with the use of relationships (2), as well as (10) and (11). The stability of the model for actual data including the operating process of an SK1 communications server was verified.

A standard MS Excel calculation package was used to study the stability (Pazur, 2010; Szelmanowski, 2004; Zieja et al., 2016).

5.1. The Evaluation Results of the of Previous Operating Readiness of an ZSŁ System

In Figure 9 the capability waveform for an SK1 communications server, determined for the last 10 years of operation of a ZSŁ system.

A low value of the capability of an SK1 server determined in this manner results from taking into account the number of transitions between states only, without estimating the times of staying in these states.

Only the introduction of an additional parameter, taking into account the mean times of an SK1 server staying in individual operating states, made it possible to obtain an capability with a value applied in the Polish Armed Forces. The graph shows that capability varies from 0,998 to about 0,993.

5.2. Predicting capability for selected forming scenarios

Predicting capability based on analysis the probability of a ZSŁ system being and staying in a set operating state (et al., state of unworthiness), enables studying the capability waveform of the entire system or its selected components, for its different shaping scenarios (Pazur, 2015; Pazur, 2012). A detailed damage analysis of an SK1 communications server showed that damage to a CP module significantly impacted its capability (Pazur, 2010). This is why, work associated with replacing the faulty module with a new process solution using a power supply system less prone to damage, were performed at AFIT.

In Figure 10 the capability waveform for an SK1 communications server, determined for the next 10 years of operation of a ZSŁ system. The capability of an SK1 server determined within the prediction process, after replacing a CP module, indicates an increase of its mean value, which results from both

the improved functional (decreased number of repairs), as well task (decreased damage intensity) readiness.

The obtained results enable current evaluation of the operating process of a ZSŁ system and shaping the level of its capability according to the quality standards adopted at AFIT and priorities applicable in the Polish Armed Forces.

5.3. Practical implication of the research for ZSŁ system capability

Predicting capability based on analysis the probability of a ZSŁ system being and staying in a set operating state (i.a. state of unworthiness), enables studying the capability waveform of the entire system or its selected components, for its different shaping scenarios (Pazur, 2015; Pazur, 2012). A detailed damage analysis of an SK1 communications server showed that damage to a CP (processor card) module significantly impacted its capability (Pazur, 2010). This is why, work associated with replacing the faulty module with a new process solution using a power supply system less prone to damage, were performed at AFIT.
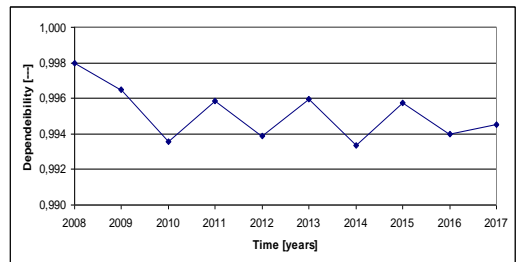

Fig. 9. The operating readiness waveform of an SK1 communications server in the years 2008-2017 (Zieja et al., 2018)
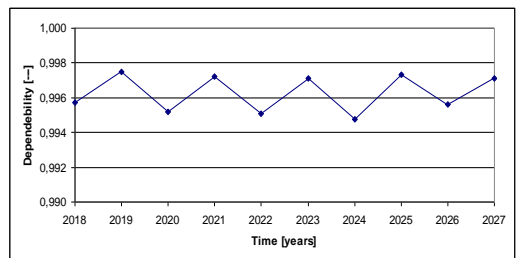

Fig. 10. The operating readiness waveform of an SK1 communications server in the years 2018-2027 (Zieja et al., 2018)

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Features of the station dedicated to service ZSŁ. The station's main tasks include testing of new system applications as well as optimization and unification of the integrated communication system (Pazur et al., 2016). Its main advantages include the possibility of testing a single radio (and diagnostics) and testing cooperation with the SK1 server, which is the main element of the system. The server is equipped with interfaces for cards of the MIL-1553B standard. The station also allows the user to upload software to individual radio stations and upload communication plans (Szelmanowski, 2004). The station operates on the Windows XP system.

6. Conclusions

Installing a modern communication system allows the user to extend the capabilities of an older generation aircraft. The challenge when designing the system was primarily to develop reliable and responsive software. The software must provide internal and external communication on the aircraft. AFIT took up this challenge and was the first company in Poland to integrate new radio-electronic equipment when modernizing the W3PL helicopters. The ZSŁ integrated communication system in the present is used on Mi8/Mi17/Mi24 helicopters and the abovementioned W3PL. The system was tested in combat conditions, primarily during the mission of the Polish Military Contingent. Ensuring high operational readiness is possible thanks to ongoing analysis of the reliability of individual system components. Data collection in the IT system developed in the Avionics Department allows for ongoing assessment of reliability. In addition, the data collected in the system allows predicting the time interval following system failures will occur. The developed model may be implemented in a local computer system functioning in the Department of Avionics at AFIT, and then included in professional IT systems SI SA-MANTA and TURAWA, in the scope of ongoing assessment and forming capability of selected equipment on-board military aircraft, including helicopters operated by the Polish Armed Forces.

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