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INFORMATION SYSTEMS AS A TOOL FOR SUPPORTING THE MANAGEMENT OF AIRCRAFT FLIGHT SAFETY

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Abstract: *The article discusses the issue of air traffic safety in the context of aircraft combat readiness. Implemented methodological approaches to ensure security of civil and military aviation depend on the achieved level of safety The article points out selected aspects of data analysis in the field of flight safety gathered in IT systems functioning in civil and military aviation supporting the management of flight safety. Selected aspects of data analysis with different tools influencing the safety of flights are presented.*
The article also points to the role of the inspection functions and supervision at the stage of execution of normative acts on safety and conduct of flights and the implementation of projects to ensure flight safety. The development of projects firstly preventing air accidents is mentioned as an important action to support flight safety. Increasing level of flight safety in civil and military aviation requires searching for methods to support decisions and actions. The main aim is to develop such methods to support decisions which minimize the risk of errors.

Key words: *database, safety, statistical analysis, forecast*

1. Introduction

Flight safety is interpreted as a complex on-board and ground-based set of activities aimed at ensuring the safe, economical and efficient movement of aircraft in all phases of flight. According to Jacyna-Gołda (2015) and Żak et al. (2014) fundamental importance for the effective functioning of the systems, especially in terms of safety and efficiency, is the human factor.

In the air system a primary role is played by the flight crew and air traffic controllers. The specific characteristics of the aircraft significantly affecting air traffic management include:
- the ability to achieve high speeds and flight altitude (but with a wide variation of performance of individual aircraft types);
- the limited scope of cruising speed changes;
- inability to stop the movement in the air;
- limited possibility of use in adverse weather conditions, especially during the occurrence of dangerous weather events (storms, fog, icing).

Authors Bolender (2000); Stolzer et al. (2008); Atkin et al. (2010); Wong and Brooks (2015) conclude that the flight safety management objective is to allow users of aircraft - both civilian and military - action in accordance with the scheduled time of arrivals and departures and to ensure their preferred flight profile, with possibly small limitations and non-reduced level of air operations safety. Air traffic management system according to Bahakt and Austin (2003) and Tyler et al. (2015) as well as the entire air transport system, is characterized by:
- complexity, resulting from the large number of items and relationships;
- inability to predict all phenomena occurring in the process of Air Traffic Management (a certain degree of probability of events);
- limited capacity for self-regulation, meaning that after the occurrence of irregularities in its actions is required human intervention to restore efficiency;
- dynamism and flexibility, resulting from human intervention in the functioning of the system at a given time and space and from the opportunity to adapt to the new conditions.

According to Foushee (1984), human errors implies 60-80% of accidents and disasters in aviation and in other complex systems. At the present stage of further enhancing safety in civil and military aviation achieved flight safety level determines the necessary level of scientific justification for decisions and activities made.

IT systems currently functioning in military aviation have been implemented by the conventional approach to IT project consisting in the development and implementation of technological solution according to the plan and within the allotted budget. The requirements for the information contained in the system and the technical specifications were determined at the beginning, at the solution design stage. When the system was implemented, the information collected been used to calculate and present in graphic form the basic safety indicators in accordance with the requirements of the applicable regulatory documents Safety Management Manual (ICAO, 2009). The basis for the analysis are historical data on the number of flight events and safety indicators presented in the form of suitable histograms. This way of carrying out the analysis does not require extensive analytical module with the appropriate tools. At the same time the above mentioned documents indicate that the analytical results should allow for the use of proactive operating methods reducing risk Zieja et al. (2015), Loaws and Ciarllo (2016).

Donald et al. (2013) claim that an important aspect of the research is way of using the generated by the system sets of data for proper decision making or to obtain deeper insight into key aspects of activity in the field of flight safety. This requires the installation of analytical tools, which is relatively easy. It is more difficult to determine for what they can be used because at the very beginning, no one knows what decisions these new tools will support and what questions they have to help answer. According to Klein (2006), Kulavskiy et al. (2011), Volynsky et al. (2012) data analysis is a discovering relationships and significant regularities in data sets, for example, factors causing certain effects or associated with them. Therefore, it is important to observe phenomena and search for answers to the following questions: what problem we want to solve? what are its root causes?, what factors most likely affect the existence of certain dangerous phenomena? what we need to do differently?

2. Statistical analysis of the collected data

Example of analysis of statistical data collected in IT systems for military aircraft using selected methods and tools is presented in work Zieja et al. (2015). A similar approach to the analysis of data from flight safety shows Krystek (2005) using data for the years 1996-2006 for civil aviation and methods and tools as: a graph of correlation and time series model to forecast safety indicators.

Figure 1 shows a graph of correlation between the number of air accidents, as a variable *X*, and the number of air incidents, as a variable *Y* in the above mentioned period. Correlation allows to assess the degree of relationship of these two variables and does not depend on units of measurement. Mathematical basis of this tool is the correlation coefficient - *r* expressed as a quotient:

$$r(X,Y) = \frac{E(XY) - E(X)E(Y)}{\sqrt{D^2(X)D^2(Y)}}$$

The properties of the correlation coefficient – r :

- if the random variables *X* and *Y* are independent then $r(X,Y) = 0$
- $|r(X,Y)| \le 1$
- if $Y = aX + b$ then $|r(X,Y)| = 1$

From the analysis of the graph shown in Figure 1 indicates that greater number of incidents corresponds to the lower number of accidents (negative correlation). We may, therefore hypothesize that the direction of pilots training and investing in a system to ensure the flights safety is correct, because with the increasing number of incidents less and less ends up with air accident.

Figure 2 shows the trend of the failure rate for general aviation for the next eight years - the basic rate of flight safety, recommended by the International Civil Aircrafft Organizasation - ICAO calculated from the relationship:

$$K_{wl}(t) = \frac{n_{wl}(t)}{T(t)} 10^5 \tag{1}$$

where:

$n_{wl_i}(t)$ - the number of air accidents;

t - considered time interval;

$T(t)$ - overall air raid.

As the graph shows, the trend of failure rate is increasing (negative). Comparing the results of the forecasts with the actual values of the indicator was

calculated forecast error which amounted for the first year of the forecast - 17%; for next year 0%.
For the prediction was used a simple model of the time series consisting of considering each observation consisting of a solid (*b*) and a random component (ε) expressed as dependency: $X_t = b + \varepsilon_t$.

Another proposal is to analyze selected indicators of operation process quality of aircraft in which it was assumed that statistical analysis of operational information will be that much effective how much will be identifying problems to solve and will allow the formulation of projects for technical operation process control.

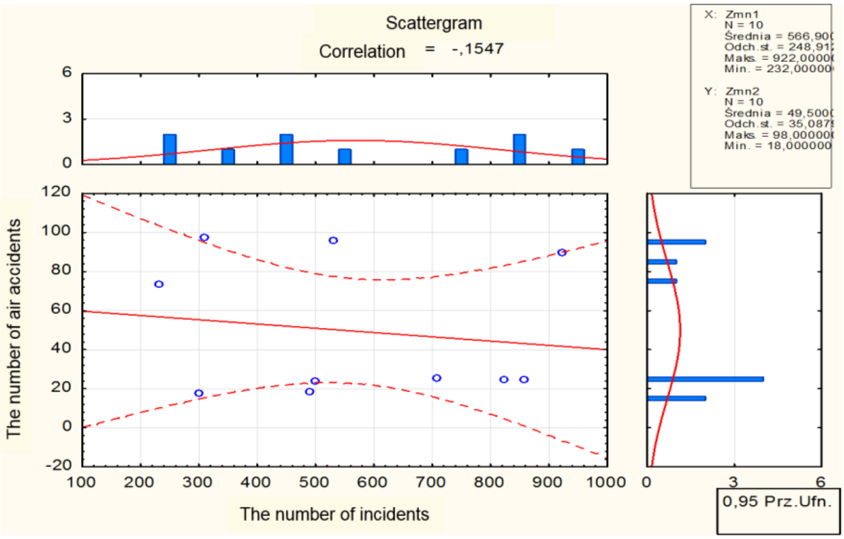

Fig. 1. Graph of correlation of number of air accidents and incidents

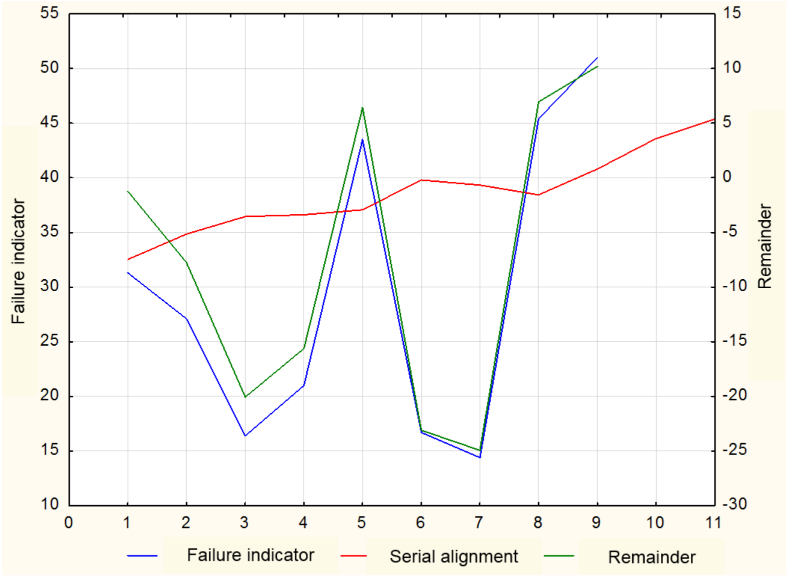

Fig. 2. Forecast of failure rate in subsequent years (item 10 and 11)

3. Quality assessment indicators of aircraft exploitation

The relative detection rate of damage by engineering and aviation personnel - W_{pil} was selected for analysis. Its value for a seven consecutive years, in one of the dominant states of the exploitation process (technical support), has a direct relationship with the indicator of disclosure any defects in the flight characterizing the state of the use of aircraft. Indicator is calculated from:

$$W_{pil} = \frac{N_{wpil}}{N} \tag{2}$$

where:

N_{wpil} – the number of detected defects by engineering and aviation personnel in technical services,

N – the total number of defects of aircraft detected in technical services and occurred in flight.

Trend analysis of damage detection indicator in technical services by engineering and aviation staff W_{pil} with the Shewart control card for the analyzed aircraft set is presented in Figure 3. For example, the use of control cards of average value and interval $(\overline{x} - R)$ is based on the assumption of normal distribution of random variable, eg. under the Central Limit Theorem. Conducting this, card requires the designation:

- average value $\overline{x}$

- GGK – upper control limit:

$$GGK = \overline{\overline{x}} + A_2\overline{R} \tag{3}$$

- GGO – upper warning limit:

$$GGO = \overline{\overline{x}} + A_2^{'}\overline{R} \tag{4}$$

- LC – center line:

$$LC = \overline{\overline{x}} = \frac{\sum_{i=1}^{n} \overline{x}_i}{n} \tag{5}$$

- DGO – lower warning limit:

$$DGO = \overline{\overline{x}} - A_2^{'}\overline{R} \tag{6}$$

- DGK – lower control limit:

$$DGK = \overline{\overline{x}} - A_2\overline{R} \tag{7}$$

where:

R – interval;

A_2, A'_2 – ratio for the control card, depending on the sample size.

An analysis of the graph (Fig. 3) shows that the indicator trend is decreasing - negative. The value of the indicator in the sixth time interval of analysis was close to the lower warning limit. In the next time interval the value has increased, but did not reach center line.

In the next step was determined the forecast of indicator W_{pil} for the analyzed set of aircraft using the exponential compensation (fig.4.).

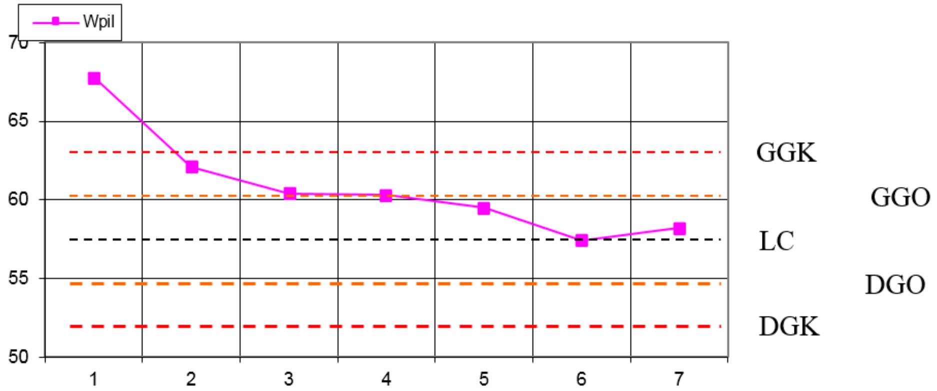

Fig. 3. Graph of Shewhart control card - the trend for the damage detection indicator by aviation and engineering staff - W_{pil} for analyzed set of aircraft

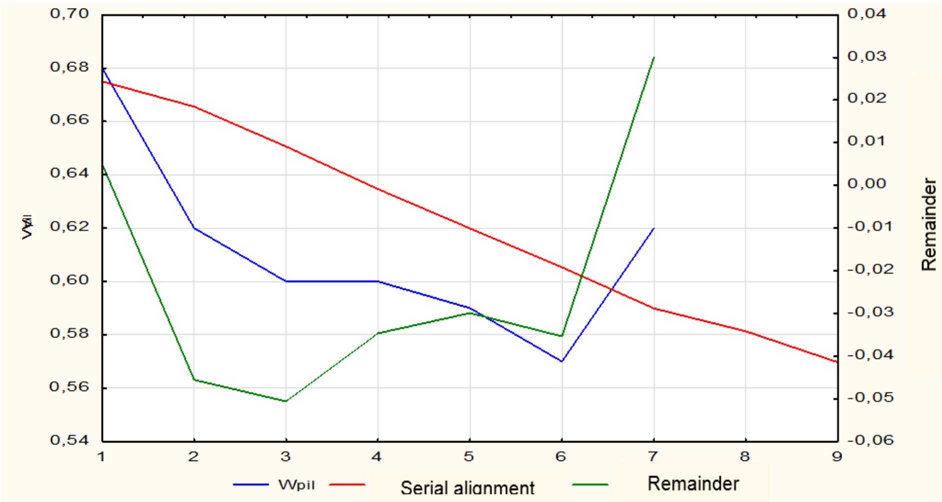

Fig. 4. Graph of the trend and forecast with exponential alignment of damage detection indicator by engineering and aviation staff - W_{pil} for analyzed set of aircraft

Graph (fig.4.) confirms the negative trend of indicator W_{pil} in the analyzed period, it means that fewer and fewer defects are detected by aviation and engineering staff in technical services in relation to the total number of detected (and occurred on the fly) damages. The forecasted value of the indicator for next time interval is $W_{pil} = 0{,}58$ and it is below the average value.

Efficacy studies for detection of damage done by aviation and engineering staff the following indicators in particular types of technical services were used: current services - W_{ob}, periodic services - W_o and other services - W_{in} in the analyzed period by regression..

$$W_{ob} = \frac{N_{ob}}{N} \tag{8}$$

Nob – the number of detected defects by engineering and aviation staff in current services

$$W_o = \frac{N_o}{N} \tag{9}$$

No – the number of detected defects by engineering and aviation staff in periodic services

$$W_{in} = \frac{N_{in}}{N} \tag{10}$$

Nin – the number of detected defects by engineering and aviation staff in other services.

The method allows studying relationship between multiple independent variables (explanatory, predictors) and the dependent variable (criterion, explanatory). The general computational problem is fitting a straight line to a set of points.

The straight line in two-dimensional space is defined by the equation $Y = a + b^* X$. It means that the value of variable Y may be calculated as the sum of constant value and the ratio of slope (*b**) by variable *x*. Occurring in the equation constant is called the intercept and the slope – the regression coefficient *b*.

In the multidimensional case, when we are dealing with more than one independent variable, the regression line cannot be so simply presented in two-dimensional space In general, a multiple regression equation takes the form:

$$Y = a + b_{1_1} x_1 + b_{2_2} x_2 + \ldots + b_n x_2$$

b^* – standardized regression coefficient,

b – ordinary regression coefficient.

A summary of the results of the regression is shown in table 1.

Regression results analysis shows that the regression indicators have negative values, which means that the greater detectability of defects in the technical services corresponds to the smaller disclosure of defects in flight. The lowest value reached regression indicator W_o. This means that detection of defects in periodic services is by far the smallest impact on the disclosure of damage in flight in relation to other types of service. One reason of such condition could be the level of applied diagnostics in periodic services. It is therefore necessary to examine the trend and the forecast of defects detectability indicator in periodic services *Wo*.

Table 1. Results of the regression

regression coefficient → indicator ↓	b*	b	p
Wob	-1,80469	-1,1046	0,046533
Wo	-0,53616	-0,9334	0,001012
Win	-1,04073	-1,1150	0,000801

p - significance level.

As shown in fig. 5, the trend of effectiveness of damage detection indicator by engineering and aviation staff in periodic services is decreasing. According to data the forecasted value of the indicator for the next period is W_o = 0,1285. Decreasing effectiveness of damage detection by aviation and engineering personnel in periodic services may be related to the increasing number of failures disclosing when carrying out the air tasks and reducing the level of efficiency of their execution.

Further analysis in this area should be carried out for individual types of aircraft and directed to investigate the causes of this phenomenon and develop appropriate control interactions in order to increase the damage detection by aviation and engineering staff in periodic services in analyzed aviation organization. In order to illustrate better the quantity, type and trend of operating exceedances PAFID program by PLL "LOT" S.A. was developed to create statistical reports based on analysis of flight parameters. This allows formulating conclusions on the effectiveness of actions of these training elements and air safety systems, which are responsible for proper training of crews but also enables the recognition of harmful trends dependent eg. on the season (fig.6) or training and simulator cycles.

Presented example of analysis of statistical indicators characteristics using information gathered in IT systems exploited in the aviation confirms the usefulness of statistical analysis in identifying existing problems to solve in the process of technical operation of aircraft.

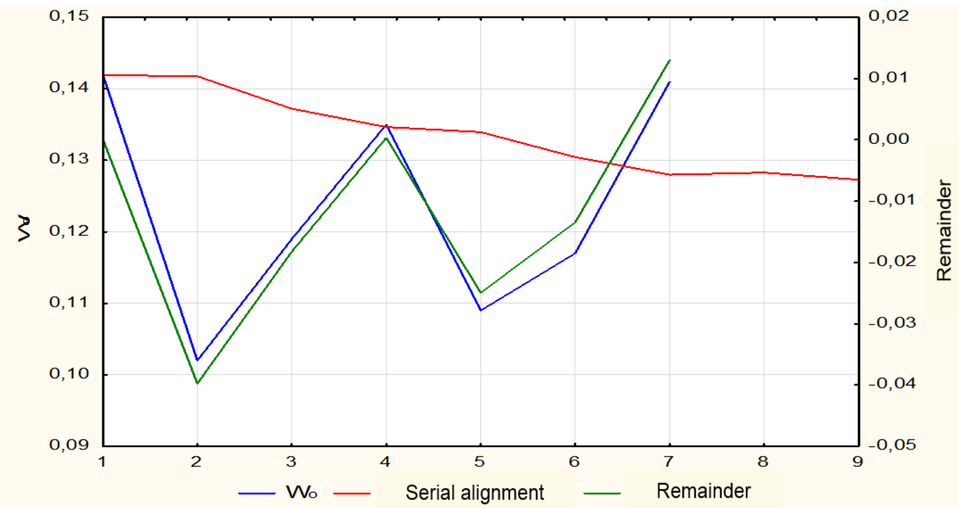

Fig. 5. Graph of the trend and forecast with exponential alignment of damage detection indicator in periodic services *Wo* for analyzed set of aircraft

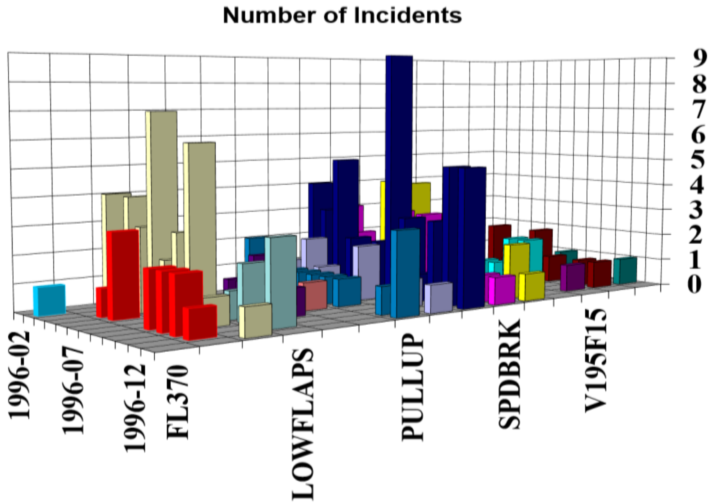

Fig. 6. Histogram showing the dependence on the number of incidents to the season

4. Big data sets analysis

Expansion of the implemented systems in military aviation with new modules: flight training, air traffic, risk, objective flight control, aviation simulators, diagnostics and others, will cause the increment of information, which will cause the orientation of systems listed above to the analysis of increasing data sets. Bowles and Wang (2005) say that the analysis of large data sets, involves, among other things, the formulation of questions to which answers will provide "worked" data and formulated hypotheses, which later are tested by repeated experiments to finally make the discovery which have major importance in ensuring flight safety.

Analysts data (information support teams) of a given area of activity should know in depth the decision making process and information needs and help employees for better access to data and improve their utilization. As they will learn to make better use of the new information, must wonder how to modify databases and improve their utilization - apply the principle of “if we think that something is true, or we know that it is so?”.

Decisions that are motivated data, produce better results. Using large datasets managers can make choices based on the evidence and not based on intuition. For this reason, these sets have the potential to revolutionize the management sphere. Challenges in management sphere are very specific. Higher level decision makers should assimilate the principle of making decisions based on evidence. Their companies should recruit researchers who are able to recognize the correctness among the data and translate them into useful information for the company.

The power which big data sets have does not eliminate the need to have a vision or be guided by intuition.

If we take into account air events occurred due to damage to aircraft, flight safety then we can associate with the characteristics of reliability, for example technical probability of events consisting on that the technique has been damaged and the crew opposed the occurrence of their effects with some probability, and we can write:

$$P_t = \prod_{i=1}^{n} P_i \left[1 + \sum_{i=1}^{n} \frac{q_i}{P_i} P_{pi} \left(\frac{BL}{q_i} \right) \right] \tag{11}$$

where:

P_t – technical probability of flight safety,

P_i – probability of failure-free operation of i–th SP system,

q_i – probability of damage of i-th SP system,

n – general (possible) the amount of such damage in flight.

The probability of damage and the probability of failure-free operation (proper operation) a certain *i*-th system on the fly (or at the relevant stage of flight) at time *t* is determined by the intensity of damage to the system (λ_i) according to data, which are calculated during the preparation, corrected during testing and specified in the process of exploitation.:

$$q_{.i} \approx \lambda_i \cdot t; \tag{12}$$

where:

λ_i – failure intensity,

$P_{pi}\left(\frac{BL}{q_i}\right)$ – the probability of prevention of emergency situations by the pilot caused by the *i*-th damage.

As a first approximation it can be assumed:

$$\beta_i = P_{pi}\left(\frac{BL}{q_i}\right)$$

or

$$\frac{\lambda_b}{\sum_{i=1}^{n}\lambda_i} = 1 - \frac{\sum_{i=1}^{n}\lambda_{i_i}\ \beta_i}{\sum_{i=1}^{n}\lambda_i} \tag{13}$$

Then the efficiency indicator (Jacyna-Gołda, 2015) of the flight safety assurance (FSA) system taking into account the damage to the technique is as follows:

$$W_{bt}^{ZBL} = 1 - \frac{\lambda_{bt}}{\sum_{i=1}^{n}\lambda_{itz}} = \frac{\sum_{i=1}^{n}\lambda_{itz}\ \beta_i}{\sum_{i=1}^{n}\lambda_{itz}} \tag{14}$$

where:

λ_{bt} – intensity of air accidents caused by damage to SP on the fly,

λ_{itz} – failure intensity of SP on the fly causes a threat to flight safety.

Efficiency indicator W_{bt}^{ZBL} shows what part of damages of technique on the fly leads to failure of the aircraft.

Efficiency indicator W_{bt}^{ZBL} can be extended to events arising from the mistakes of the crew or meteorological conditions encountered during the implementation of the air tasks and other threats, then the dependence (14) takes the form:

$$W_{io}^{ZBL} = 1 - \frac{\lambda_{bio}}{\sum_{i=1}^{n}\lambda_{ioz}} = \frac{\sum_{i=1}^{n}\lambda_{ioz}\ \beta_{io}}{\sum_{i=1}^{n}\lambda_{ioz}} \tag{15}$$

where:

λ_{ioz} – intensity of security threats of flights of *i*-th type,

λ_{bio} – intensity of air accidents caused by the *i*-th type of threats.

Efficiency indicator W_{io}^{ZBL} shows what part of the threats incurred during implementation of the air tasks leads to an emergency situation causing losses in the system.

The probability of counteracting by the pilot emergency situation caused by *i*-th risk factor and q_{io} - the probability of its inception, i.e. $\beta_{io} = P_{pio}\left(\frac{BL}{q_{io}}\right)$ can be assessed by experts or in analytical way if we have the relevant data.

With the occurrence of *i*-th risk factor, an emergency situation develops over time t_{aw} in order to achieve one of the defining coordinates x_i of acceptable limit x_{idop} (fig. 8). The pilot can prevent a failure if the response time to failure t_r will be lower than the maximum permissible time t_{dop}. Values t_{aw} , t_r , t_{dop} are the random values and are guided by rules of distribution $f(t_{aw})$, $f(t_r)$, $f(t_{dop})$.

Time t_r is determined by delay of information about the failure or identify failures and insufficiently fast pilot reaction in assessing the situation and taking action. The probability of counteracting by the pilot an accident or other emergency factor amounts:

$$P_{\beta i} = P(t_{ri} < t_{dopi}) = P(\Delta t_i \geq 0)$$

where: $\Delta t_i = t_{dopi} - t_{ri}$.

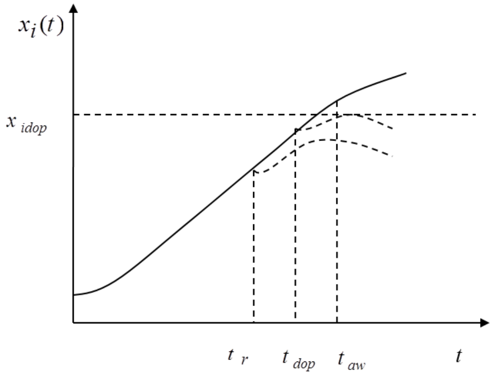

Fig.8. Ilustration of a function $x_i(t)$ of time of pilot reaction to the threat

If there are known the distribution $f_r(t)$ and $f_{dop}(t)$ rules at independent random values t_r and t_{dop}, then the probability can be calculated from the expression:

$$P_{\beta i} = P(\Delta t_i \geq 0) = \int_0^{\infty} f(\Delta t_i) dt_i \tag{16}$$

$$f(\Delta t_i) = \int_{-\infty}^{\infty} f_{ri}(t) f_{dopi}(t + \Delta t) dt \tag{17}$$

If the distributions t_r and t_{dop} are normal then their ratio also gives a normal distribution:

$$f(\Delta t_i) = \frac{1}{\sigma_{\Delta t_i}\sqrt{2\pi}} e^{-\frac{(\Delta t_i - \Delta \bar{t}_i)^2}{2\sigma_{\Delta ti}^2}} \tag{18}$$

where:

$\Delta \bar{t}_i$ – expected value $\Delta \bar{t}_i = \bar{t}_{dopi} - \bar{t}_{ri}$;

$\sigma_{\Delta ti}$ – standard deviation, $\sigma_{\Delta ti} = \sqrt{\sigma_{t_{ri}}^2 + \sigma_{t_{dopi}}^2}$.

and so the probability of counteracting failure by the pilot amounts to:

$$P_{\beta i} = 1 - \frac{1}{\sigma_{\Delta ti}\sqrt{2\pi}} \int_{-\infty}^{\infty} e^{-\frac{(\Delta t_i - \Delta \bar{t}_i)^2}{2\sigma_{\Delta ti}^2}} d\Delta t_i = \Phi * \left(\frac{\Delta \bar{t}_i}{\sigma_{\Delta ti}}\right) \tag{19}$$

Probability of counteracting failure from *i*-th risk factor is the higher, the greater the expected value $\Delta \bar{t}_i$ and the smaller the variance $\sigma_{\Delta t_i}^2$.

5. Conclusions

The big unknown is to answer the question of what decisions will be supported and what questions will be answered by new tools of analyses.

Data analysis is nothing but the discovering relationships and significant patterns in data sets, for example, factors causing certain effects or circumstances related to them. To improve activities of the organization in operational and strategic area, under the philosophy presented in this article, the priority of the manager is to make discoveries that will benefit the organization and seeking of unknowns that could threaten the organization. This is shown by presented examples of the analysis of characteristics of statistical indicators using information gathered in IT systems operated in aviation. These examples confirm suitability of statistical analysis to identify existing problems to solve in the technical operation process of aircraft.

Expanding opportunities for IT support for managing the process of the technical operation of aircraft requires the development of currently operated systems with the analytical module. In the analysis of large data sets usually begins with noticing a problem, then often proceeds to formulation of theories about occurrence of this phenomenon or the result obtained, formulating hypotheses, determine the necessary data and conducting an experiment and thus creates the possibility of discovering new facts and apply them in the management process. Summing up nowadays IT projects in a smaller extent, should concentrate on technology and more on the use of the information collected.

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