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RESEARCH OF HUMAN FACTOR PARTICIPATION IN AIR OCCURRENCE CAUSES USING THE NEW CONSTRUCTED CAUSE TAXONOMY

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Abstract

Article discussed participation of human factor in air occurrence causes. Human errors are causative factors in about 70% to 90% of air occurrences. Up to now, Polish Armed Forces aviation tools constructed to describe and clarify accidents causes has not considered a progress in flight safety theories and contribution of the human error as a causative factor of air accidents and incidents. That is the reason a method of modelling of air occurrences causes as a tool of human factor classification is constructed and presented. The new constructed taxonomy includes mod-ern flight safety theories as 5-M Model, James Reason Theory and HFACS – Human Factor Analysis and Classification System as a tool of classification of human factor in air accident causes. The survey of the taxonomy was based on cause analysis of air accidents investigated by State Aviation Air Accident Investigation Board (KBWL LP) from 2008 up to 2012. According to prepared algorithm a statistical code of three taxonomies was determined to the root cause of each accident (KBWL LP had determined its statistical code according to IBL2004 taxonomy during investigation of each occurrence). To compare results of the survey the new taxonomy, foregoing taxonomy used by Polish Armed Forces Aviation (IBL2004), Civilian Aviation Authority taxonomy (ULC) and Air Forces Flight Safety Committee Europe one (AFFSCE) were used. The final verification was made after qualitative parameters were exchanged for quantitative ones (human factors participation percentage) and compared them with analogical results in NATO and civilian aviation cited in the literature.

Keywords: *air accidents, human factor, flight safety, cause taxonomy*

1. Introduction

Aviation development together with technological improvements led to evolution of flight safety concept. New theories of flight safety were constructed and approach to the safety in aviation was modified.

The early days of aviation until the 1970s, can be characterized as the "technical era" where safety concerns were mostly related to technical factors. A gradual but steady reduction of technical hazards was instrumental in better reliability of aircraft. The early 1970s were associated with major technological advances. This was the beginning of the "human era", and the focus on safety of human performance and Human Factors. The early 1990s were time when aviation focused on operational contexts. This time was the beginning of the "organizational era" when safety started to be viewed from a systemic perspective [1]. The evolution of safety thinking is depicted in Fig. 1. It can reasonably be said that aviation safety has steadily improved over the last 60 years. Indeed, aviation has become one of the safest forms of transportation [2, 7].

Air accident and incidents causes are often called failure factors or causative ones [4]. Tendency of causative factors changes by years 1903-2013 is presented in Fig. 2 [1].

Human factor takes main role in majority of safety theories. According to accident, statistics cited in the literature human errors are causative factors in about 70% to 90% of both civil and military air occurrences. Up to now, the majority of research tools prepared to describe and clarify accidents have not considered a progress in understanding a contribution of the human error as a causative factor of air accidents and incidents. As a result, there are problems in an identification of deficiencies that would otherwise have gone undetected. This is a reason that appropriate remedial action associated with human factor causes cannot be implemented [3, 5, 7].

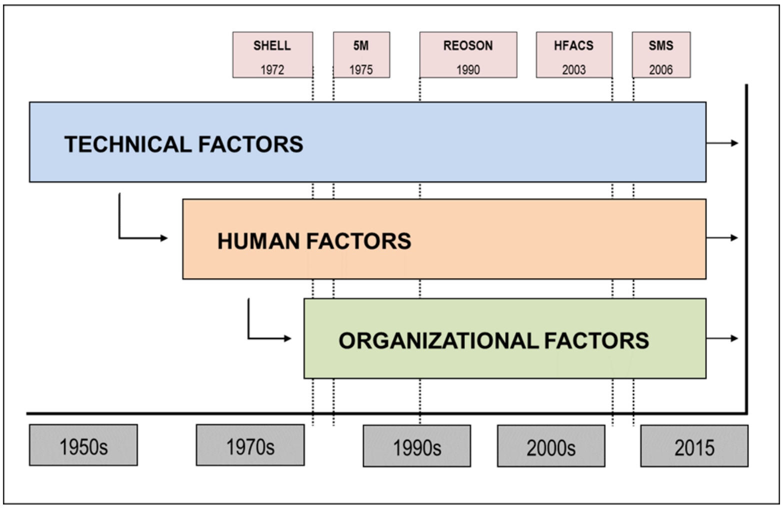

Fig. 1. The evolution of safety thinking

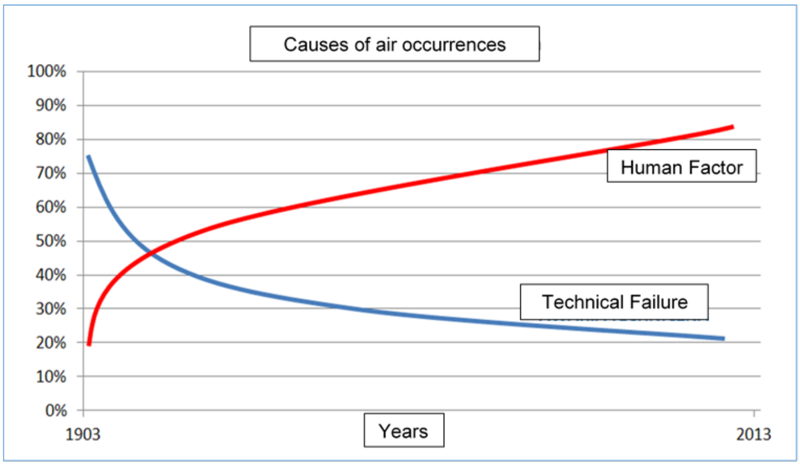

Fig. 2. Change of human factor participation percentage in air occurrences by year

2. Modern models of air occurrence cause taxonomies

Taxonomy is the science or technique of classification. This article discusses technique of air occurrence cause classification. Air occurrence is defined as "accident or incident". Generally, accidents and incidents differ only in the degree of injury sustained by persons involved or in damage sustained to the aircraft [5].

The article discuss two existing models of taxonomies used by military aviation (IBL2004 and AFFSCE) and one existing model of taxonomy used by civilian aviation (ULC) except the new constructed model [7].

2.1. Foregoing taxonomy used by Polish Armed Forces Aviation (IBL2004)

Polish Armed Forces has used this taxonomy from 2004 to 2015. The technique of classification was implemented in Flight Safety Manual of Polish Armed Forces Aviation in 2004 (WLOP 346/2004). It consisted of 19 codes without dividing them into any areas or categories. 10-codes were devoted to human factor. None of safety theories is involved in the taxonomy.

2.2. Taxonomy used by Air Forces Flight Safety Committee (Europe) (AFFSCE)

Air Forces Flight Safety Committee (Europe) – AFFSC(E) consists of 27 countries. The body was established by Royal Air Force (RAF) in order to exchange flight safety experience and information about air accidents and its prevention among the members. There was the need to prepare a common, simple taxonomy for using the same technique of air accident cause classification. It consists of 17 codes without dividing them into any areas or categories. 9-codes are devoted to human factor [3].

2.3. Taxonomy used by Polish Civilian Aviation Authority (ULC)

Civilian aviation has its own taxonomy that was set up in 2002 by Decree number 3 of Polish Civilian Aviation Authority Chairman. The taxonomy is attributable to 5-M Model. It consists of 39 codes. They are divided into 4 categories: technical factor, human factor, environmental factor and organisational one. 24-codes are devoted to human factor [7].

3. The new constructed cause taxonomy

Taking into account statistics associated with human factor participation percentage in air occurrences in Polish Armed Forces aviation (based on IBL2004) and comparing them to analogical results in NATO and civilian aviation and also data cited in the literature (two red horizontal lines in Fig. 3) we can notice a big disparity between these data (Fig. 3). Foregoing taxonomy used by Polish Armed Forces Aviation (IBL2004) does not include new safety trends and theories. The human factor aspects need to be enhanced and developed. It is on necessity to implement general model of assessment of human factors, which could serve for elaborating new tools of flight accidents analysis and aircraft accident investigations.

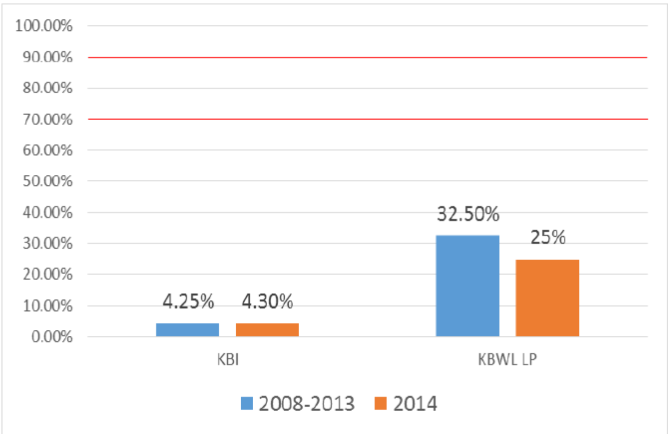

Fig. 3. Human factor participation percentage in air occurrences across years 2008 to 2013 and in the year of 2014 investigated by KBWL LP and KBI respectively

These facts have disposed authors to construct a new model of air occurrence cause taxonomy. It was assumed that the model should include more safety trends and according to objective reality should "calibrate" human factor participation in air occurrence causes.

The model employs modern flight safety theories as 5-M Model, "Swiss Cheese Model" of James Reason and Human Factor Analysis and Classification System - HFACS. Some codes from IBL2004 were also used in the model to classify causes not related to human factor.

The 5-M Model comprises Man, Machine, Media, Mission and Management. They are five core areas that failing factors of accident/incident may appeared in. The constructed taxonomy uses Mission area as a resultant of four other areas. For better identification of hazards associated with management, the area was divided into three parts (Man, Machine, Media). This model is one of the most common used method in aviation industry to examine in a systemic way areas of air occurrences.

The Human Factors Analysis and Classification System (HFACS) were developed by Dr Scott Shappell and Dr Doug Wiegmann. A broad human error framework was originally used by the US Air Force to investigate and analyse human factors aspects of aviation. HFACS is based on James Reason's "Swiss Cheese Model". The HFACS provides a tool to assist in the investigation process or analysis. Investigators are able systematically to identify active and latent failures within an organisation that results in an accident.

The HFACS framework describes human error at each of four levels of failure:

(a) unsafe acts of operators,
(b) preconditions for unsafe acts,
(c) unsafe supervision,
(d) organisational influences.

Within each level of HFACS, causative categories were developed that identify the active and latent failures that occur.

All of these modern safety trends and theories were used in the new constructed model to get more general conclusions of both immediate and systemic character of air occurrence causes. Architecture of the new model taxonomy and an algorithm of statistical code determination are depicted in Fig. 4.

Statistical code determination process consists of five steps.

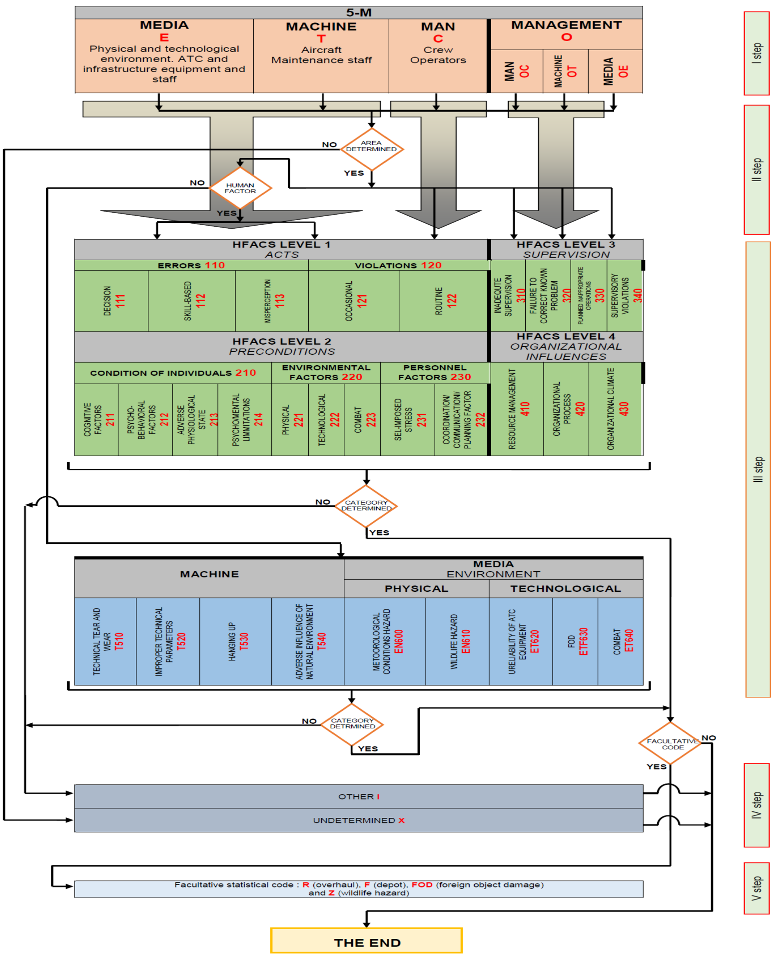

Fig. 4. The new constructed model of taxonomy

We just need to follow the algorithm. First step is associated with determination of one of four 5-M Model areas. During the second step, the answer weather the cause is connected with human factor is needed. If so in the third step, we determine one of HFACS categories. If not we determine one of not related to human factor categories. If we are not able to determine any of previous categories in the fourth step, we determine code “other” or “undetermined”.

The last step is facultative and it is opportunity to expand the statistical code with four categories: Foreign Object Damage (FOD), Depot level, Overhaul level and Wildlife hazard. Entire statistical code consists two parts. First is literal part and the second numerical one. For instance, C112 or ET620.

4. Survey of the new constructed model taxonomy

Descripted in previous paragraph model was a tool to analyse causes of air accidents (serious accidents, accidents, serious incidents and incidents) investigated by State Aviation Air Accident Investigation Board (KBWL LP) from 2008 up to 2012. Structure of investigated air occurrences is presented in Fig. 5.

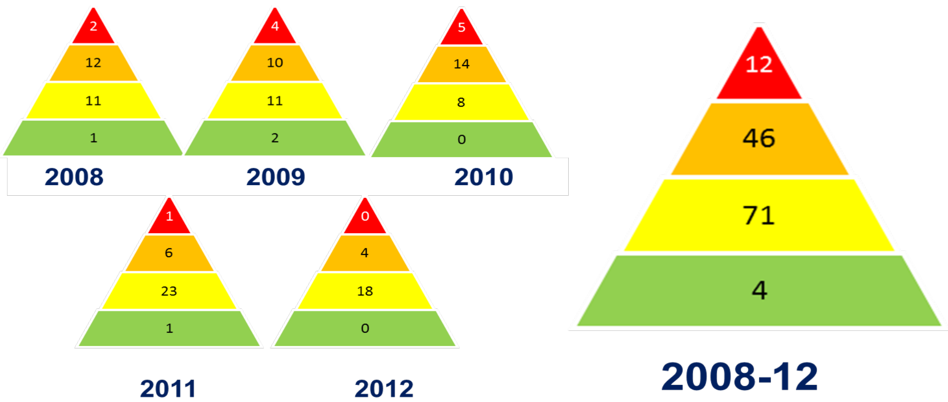

Fig. 5. Structure of investigated air occurrences

In Fig. 5, serious accidents are colour-coded red, accidents are colour-coded maroon, serious incidents are colour-coded yellow and incidents are colour-coded green.

Survey of the new constructed model of taxonomy was conducted according to the algorithm depicted in Fig. 6.

There was assumption that each investigated occurrence has one root cause for which it should be determined one statistical code according to the new model of taxonomy and also for comparison according to ULC and AFFSC(E) taxonomy. KBWL LP determined its statistical code according to IBL2004 taxonomy during investigation of each occurrence and put it in the final report.

5. Verification of the new constructed model taxonomy

5.1. Descriptive statistics

On the basis of conducted survey, we got results for the new taxonomy depicted in Fig. 7. Comparison to other results survey taxonomies are presented in Fig. 8.

As it is seen in Fig. 7 and 8, verification process succeeded. Using the new model taxonomy from the sample data of 133 air occurrence causes we got the mean equals 80.45% of human factor participation. It was the highest result among survey taxonomies and is precisely in the statistics range cited in the literature.

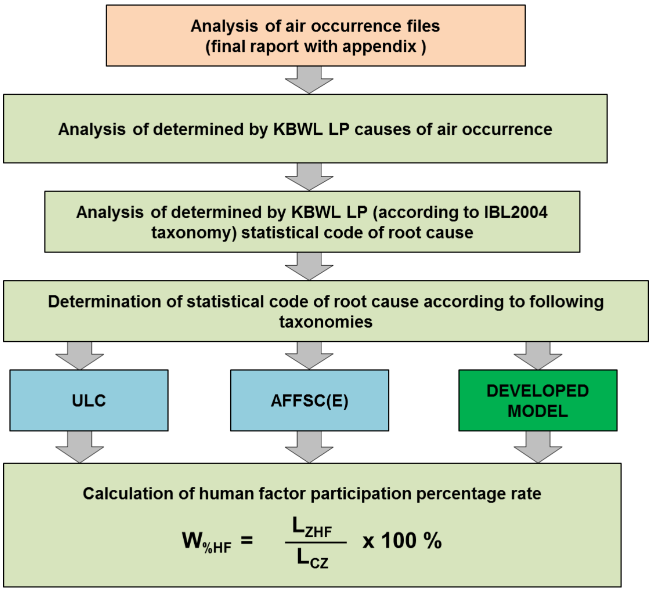

Fig. 6. Survey algorithm of causes of air accidents and incident investigated by State Aviation Air Accident Investigation Board (KBWL LP) from 2008 up to 2012 (LZHF – number of occurrences related to human factor and LCZ – total number of occurrences)

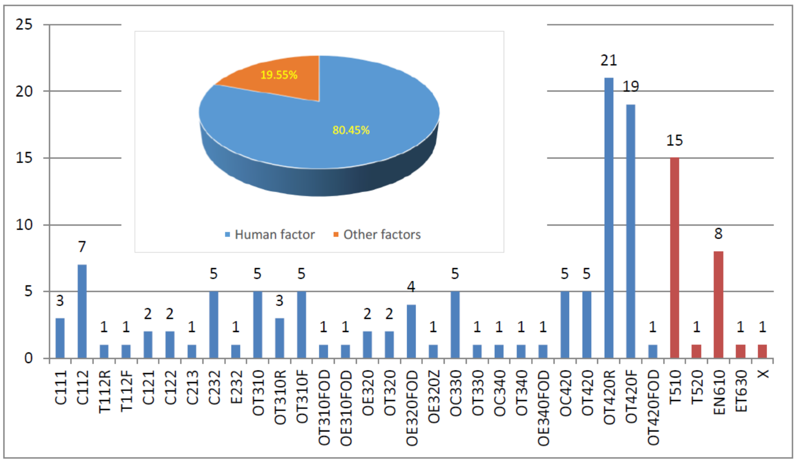

Fig. 7. Qualitative and quantitative parameters of human factor participation in air occurrence causes across years 2008 to 2012 using the new model taxonomy (Human factor parameters are coloured blue, other ones are coloured maroon)

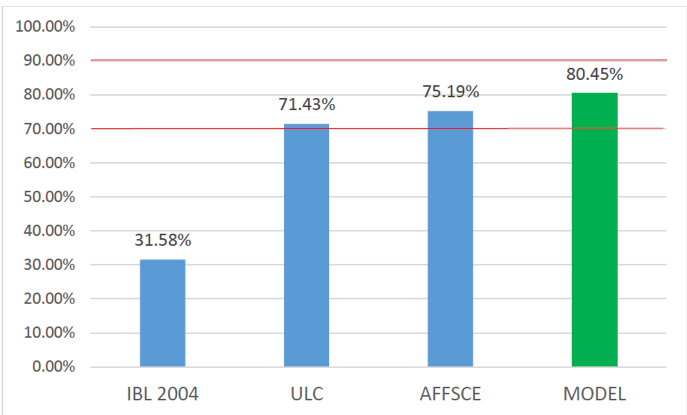

Fig. 8. Mean of human factor participation percentage in air occurrence causes across year from 2008 to 2012 using survey taxonomies

5.2. Mathematical statistics

In this paragraph it is described Inference. Inference is the process of deducing properties of the underlying distribution, by analysis of data. The mathematical statistics consists of:

1) calculation of human factor participation relative coefficients per 1000 causes in the sample of 133 causes according to survey taxonomies. It is given by the formula (1):

$$W_{HFT} = \frac{L_{ZHFT}}{L_{CZ}} \times \mathbf{1000} \,, \tag{1}$$

where: L_{ZHFT} – number of occurrences related to human factor according to taxonomy T (coefficient of: the new model – W_{HFM}, IBL2004 – W_{HFIBL}, ULC – W_{HFULC}, AFFSCE – W_{HFAF}) and L_{CZ} – total number of occurrences

Tab. 1. Human factor participation relative coefficients per 1000 causes across years 2008 to 2012 according to survey taxonomies

	W_{HFM}	W_{HFIBL}	W_{HFULC}	W_{HFAF}
2008	846.15	346.15	692.31	769.23
2009	851.85	333.33	777.78	814.81
2010	740.74	296.30	666.67	740.74
2011	709.68	290.32	645.16	645.16
2012	909.09	318.18	818.18	818.18
Mean	812.00	317.00	720.00	758.00
Standard deviation	83.26	23.76	74.48	70.72

2) estimation of human factor participation relative coefficients per 1000 causes across years 2008 to 2012 according to survey taxonomies

Normal distribution was chosen for calculation because of cited examples in the literature [3]. Parameters of random variable X are the distribution mean - m, and the standard deviation - σ. We can write X: N(m, σ), if the probability density of the normal distribution is given by the formula (2):

$$\Phi_{m,\sigma}(x) = \frac{1}{\sigma\sqrt{2\pi}} exp\left(\frac{-(x-m)^2}{2\sigma^2}\right), \text{ for: } -\infty < x < \infty, \sigma > 0 \,. \tag{2}$$

The data from Tab. 1 were estimated to indicate the value of an unknown quantity in a population.

For better comparison of the data, we calculate the standardization of a random variable. It is given by the formula (3) [4].

$$\widetilde{X} = \frac{X - m}{\sigma} \,. \tag{3}$$

Results of this calculation were depicted in Tab. 2.

Tab. 2. Human factor participation relative coefficients per 1000 causes across years 2008 to 2012 using standardization of a random variables

	W_{HFM}	W_{HFIBL}	W_{HFULC}	W_{HFAF}
2008	0.410207	1.227014	-0.371809	0.158806
2009	0.478643	0.687430	0.775749	0.803377
2010	-0.855864	-0.871368	-0.716076	-0.24405
2011	-1.228952	-1.122787	-1.004816	-1.59557
2012	1.166117	0.049740	1.318231	0.850987

Using data from Tab. 2 with Statistica software there were estimated standardised human factor participation relative coefficients per 1000 causes across years 2008 to 2012 according to survey taxonomies.

3) analysis of Pearson's correlation coefficient for human factor participation relative coefficients according to survey taxonomies

It is given by the formula (4).

$$r_{xy} = \frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)}{\sqrt{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}\sqrt{\sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2}}, \tag{4}$$

where: $\bar{x}$, $\bar{y}$ are proper means (5):

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \,, \quad \bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i . \tag{5}$$

Using Statistica software there were calculated in pair correlation of human factor participation relative coefficients per 1000 causes across years 2008 to 2012 according to survey taxonomies. Results are depicted in Tab. 3.

Tab. 3. Pearson's correlation coefficient for human factor participation relative coefficients according to survey taxonomies

Variable	Correlation (dysp_hf)			
	W_{HFM}	**W_{HFIBL}**	**W_{HFAF}**	**W_{HFULC}**
W_{HFM}	1.000000	0.753934	0.902914	0.900932
W_{HFIBL}	0.753934	1.000000	0.698321	0.473667
W_{HFAF}	0.902914	0.698321	1.000000	0.865970
W_{HFULC}	0.900932	0.473667	0.865970	1.000000

There are following conclusion of the calculation:

a) coefficients W_{HFM} and W_{HFAF} have positive linear correlation (strong relationship),
b) coefficients W_{HFM} and W_{HFULC} have positive linear correlation (strong relationship),
c) coefficients W_{HFAF} and W_{HFULC} have positive linear correlation (relatively strong relationship).

4) cluster analysis of human factor participation relative coefficients according to survey taxonomies.

Cluster analysis or clustering is the task of grouping a set of objects in such a way that objects in the same group (called a cluster) are more similar (in some sense or another) to each other than to those in other groups (clusters) [4]. In the research, we used hierarchical clustering (also called hierarchical cluster analysis). One of the best-known measure of the distance in a 2-dimensional space is Euclidean distance. It is given by formula (6):

$$E(x,y) = \sqrt{\sum_{i=1}^{n}\left(\left(x_i - y_i\right)^2\right)} . \tag{6}$$

Using Statistica software there were calculated in pairs Euclidean distances of human factor participation relative coefficients per 1000 causes across years 2008 to 2012 according to survey taxonomies. Depicted results of the calculation are presented in Fig. 9. Generally, they confirmed conclusions of Pearson's correlation coefficients analysis. Close distances are between pairs of coefficients W_{HFM} and W_{HFAF} and between W_{HFM} and W_{HFULC}. Outer Euclidean distances are calculated between following pair of coefficients W_{HFM} and W_{HIBL} or W_{HIBL} and W_{HFAF}.

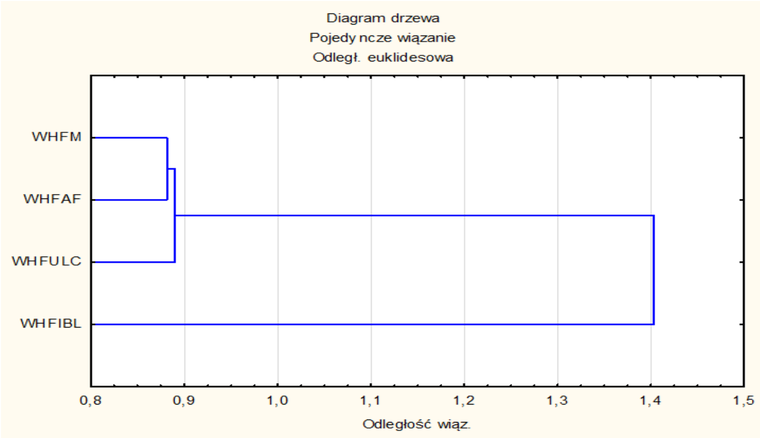

Fig. 9. Depicted results of the Euclidean distance calculations

5) stochastic analysis of distributions of human factor participation relative coefficients according to survey taxonomies

In our case, it is the process of generalizing from the sample of 133 causes to an entire population of air occurrence causes in the basis of the probability calculus [4]. It is assumed that calculated probability of human factor participation in causes of air occurrences is higher than 0.7. These calculations are presented for W_{HFM} coefficient. Other calculations were done in analogical way. It was assumed normal distribution N(812. 83), m = 812, σ = 83, where: m – mean, σ – standard deviation.

Probability is calculating using probability distribution function. It is given by formula (7).

$$P(X > a) = 1 - F(a)\,. \tag{7}$$

In first step, variables are standardised. Random variable X is replaced by standardised random variable U that has normal distribution. Value of probability distribution function Φ was calculated using Statistica software. There are given following formula and calculations:

$$P(X > 700) = P[(X-812)/83 > (700-812)/83] = P(U \leq -1.35) = 1 - P(U \leq -1.35) = 1 - \Phi(-1.35)$$

$$\Phi(-1.35) = 0.088 \text{ to } P(X > 700) = 1 - 0.088 = 0.912. \tag{8}$$

After calculation, we got probability equals 0.912. Probability density of the normal distribution and probability distribution function are depicted for this case in Fig. 10.

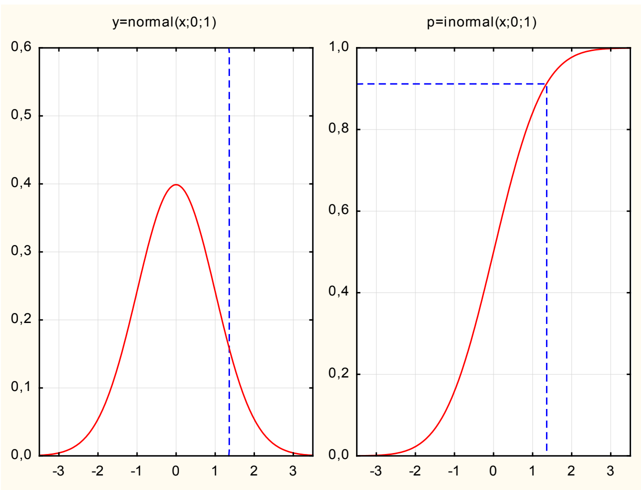

Fig. 10. Probability density of the normal distribution and probability distribution function for the new constructed model of taxonomy

To sum up of stochastic analysis of distributions of human factor participation relative coefficients according to survey taxonomies it was alleged that the new model of taxonomy got highest probability of human factor participation in causes of air occurrences. The next were taxonomy used by Air Forces Flight Safety Committee (Europe) (AFFSCE) and taxonomy used by Polish Civilian Aviation Authority (ULC). It is worth noting that foregoing taxonomy used by Polish Armed Forces Aviation (IBL2004) got probability equals zero. It means that IBL2004 taxonomy is useless as a tool of classification of human factor in air accident causes. The results were presented in Fig. 11.

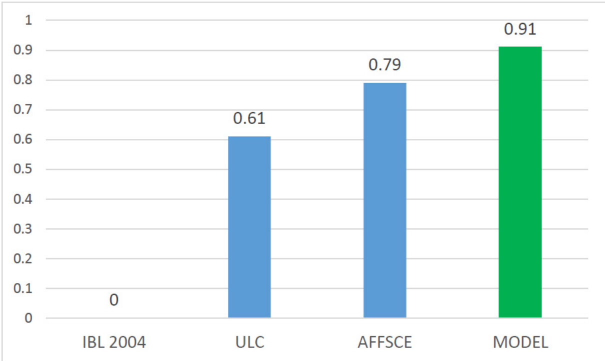

Fig. 11. Probability of human factor participation in causes of air occurrences higher than 0.7 per 1000 total occurrences according to survey taxonomies

6. Conclusions

The new constructed model of taxonomy comprehensively enables:

a) analyse of human factor associated with crews (Man), maintenance staff (Machine), ATC staff and infrastructure personnel (Media),
b) multicriterial analyse of human factor based on four levels of HFACS,
c) study in detail human errors in Depot or Overhaul facilities and also associated with wildlife hazard and Foreign Object Damage (FOD),
d) study causes connected with combat missions.

According to conducted survey, it is alleged that the new constructed model of taxonomy meets requirements as a tool of classification of human factor in air accident causes and it calibrates human factor participation in air occurrence causes just as literature data.

Taking into account practical aspects of the new taxonomy it was implemented both in the new Flight Safety Manual of Polish Armed Forces Aviation 2015 (Sztab. Gen. 1681/2015) and in the Flight Safety Information System "TURAWA" constructed by Air Force Institute of Technology.

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