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AIR TRAFFIC CONTROL STUDENTS' ASPIRATION LEVELS DISTRIBUTIONS

This paper proposes an analysis of an air traffic control students' survey describing self-assessment of their workload levels. The workload is defined as the number of aircraft simultaneously under control. The survey is performed over the gird with axes represented with aircraft number, their correspondent, and utility/satisfaction levels. The aspiration level values are calculated using workload differences. The safety background of risks in aviation activities is described. Risk and aspiration level links are highlighted. The aspiration level notion for the proposed research is inferred. Survey details and conditions are explained. The differences in four quarters at the workload charts specified by respondents are explained. The aspiration level parameters and basic statistics calculated for respondents are presented. Appropriate goodness-of-fit tests are performed with different sets of initially received answers. Whole samples and subsamples are considered. It is shown that for the full sample considered, the outlet removal provides significant increase of p-value, thus allowing to change the hypothesis approval status. Sub-samples list includes the whole sample without outlets and the whole sample aspiration level calculated for only positive values according to y-axis. Additionally, other values were considered. Namely regret values, i.e., the values on the descending half of the charts and a mixture of regret and aspiration level values in regard that is higher. Normal and exponential distribution significances are proven for the different options mentioned above. It is shown that the general chi-squared method provides the latter mixture to be insignificantly exponential, whereas specific Fisher's test approves the significance of the data. The role of air traffic control students' aspiration level in their estimation and possible education strategy personalization is described. The importance of human factor consideration during similar survey performance is once again proven. The connection of regret with aspiration level in a mixture is discussed. The conclusions on the results are provided. Further research directions are proposed.

Keywords: *flight safety; human factors; workload; aspiration level; education.*

Introduction

The problem statement. Safety support is important issue in aviation industry. International Civil Aviation Organization (ICAO) [1] claims that "safety is the state, in which risks associated with aviation activities, related to, or in direct support of the operation of aircraft, are reduced and controlled to an acceptable level". One of safety achievement approach lays in risks reduction. The risks in their turn can be generalized as [2] "possibility of undesirable situation with harmful consequences occurrence". For complex "flight crew – aircraft – environment – air traffic control authority" system risks might be assessed with help of operator's self-estimation. Risk reduction comes from the personnel efforts directed to the desired safety state attainment. This allows to talk about aspiration level (AL) as one of key risk mitigation components.

The AL determination and measurement is crucial in regard to all aspects of safety where operator is involved. This is caused by the fact that human behavior is still one of the most important part in risk management. Despite tendencies of robotization and automation of the complex technological processes it is clear that application of new AL management methods is a task of high importance.

1. Analysis of recent studies and publications

AL was developed since 1930-s and was intensively researched by such scientists as Hoppe [3], Frank [4], Lewin [5], Becker [6], Simon [7] and many others. More recent researches are dedicated to various aspiration applications fields like artificial intelligence [8], AL management [9] mismatches between AL and people choices [10], music influence [11], fatigue [12], etc. According to Kozeletsky definition AL is a measure of the match between personal goals and capabilities which brings satisfaction to a person [13]. Similar definitions are given by other scientists, e.g. Gardner [14] ("level of aspiration is a truly quantitative concept, which has two requirements that the subjects make some public indication of his aims and that, he makes this in quantitative terms") or dictionaries [15] ("hope or ambition of achieving something," as well as "the object of such an ambition; a goal").

AL can be addressed as representation of maximal increment of utility or satisfaction gained by person performing certain task. Here utility/satisfaction is estimated with biased achievements scale. AL takes important place in self-assessment researches. Aviation operators with high AL are claimed to have high confidence level, persistence, efficiency, and trustworthy criticism of their own achievements [16]. Severe link of self-assessment with AL is also proven by James formula. Firstly, it was presented in the following form:

$$\text{Self}-\text{esteem} = \frac{\text{Success}}{\text{Pretensions}}; \quad (1)$$

sometimes [17] being interpreted as:

$$\text{Satisfaction} = \frac{\text{Achievement}}{\text{Aspiration}}. \quad (2)$$

Hence original formula can be inferred in the following statement:

$$\text{Self}-\text{esteem} = \frac{\text{Success (result)}}{\text{Aspiration level}}. \quad (3)$$

Air traffic controllers (ATCOs) are dealing with certain number of aircraft under control. Such number can be considered as ongoing workload. Workload research importance and urgency is proven by various proceedings [18-22]. The change of workload can be taken as AL value by definition.

Despite AL concept implementation in various areas there are not many studies dedicated to the aviation operators. The vast majority of aspiration researches are considering the general students of even scholars as a respondents. Moreover, the methods used in various surveys are often simplified down to the aspirations statement. Those methods that actually perform indirect measurements have other flaws. Another issue is that aspiration calculated by majority of the methods doesn't consider the difference in aspiration itself and desire for getting out of unpleasant state. Addressing the Atkinson [23] we can clearly define four different sections on the final aspiration plain. Each of those sections has its own features in regard to the desired overall state. Thus, it is not quite clear whether the consideration of such detail would influence the results. Finally, the general distribution of the data is commonly taken as normal. However, it might be not valid for the particular case. Now we can formulate the tasks for the proceeding.

The research goals

On the base of all aforementioned there were formulated the goals of this proceeding:

1) to perform the research related to the ATCO students' self-assessment of the workload with further AL determination;

2) to describe calculation of some basic distribution parameters and determination of various probability distributions and verify whether we can consider AL of the participants to be normally distributed;

3) to compare general results of unmixed AL with other particular results of the same participants combined in different variations.

2. Research methods

Described survey involves 132 ATCO students of 4th and 5th grades who studies "Air traffic control" academic major. The survey took place in National aviation university (Kyiv, Ukraine) and Flight Academy of the National Aviation University (Kropyvnytskiy, Ukraine). Each participating student had no prior experience of real ATC and at least 100 hours within simulation training. The polling was anonymous. Respondents were notified that survey results not to influence their academic performance. Survey's chart example is shown on figure 1.

According to the survey's task the respondents were asked to specify several key points:

– maximal number of aircraft under control that is considered as boring and provides no utility/satisfaction (n_{min} point);

– minimal number of aircraft under control with highest strain and workload possible that provides absolute lack of utility/satisfaction (n_{max} point);

– such number of aircraft under control which provides maximal utility/satisfaction level (n_{opt} point).

On the base of these three points the utility/satisfaction function was plot on the proposed grid. All respondents estimated their level of utility/satisfaction during the task fulfillment. Having decrease of boredom and increase of workload they shown their attitude to risk of mistakes commitment with numerically expressed levels. These levels are numbers of aircraft being under control simultaneously. In line with previous researches the AL values were calculated for pairs of points representing neighboring aircraft numbers (e.g. 5 and 6, 11 and 12 etc.). The pair with maximum increment of utility/satisfaction in respondent's opinion was taken as AL. Such numbers show what does particular respondent thinks of its own professional capabilities. Thus, the satisfaction proposed to the respondent as a measure can be considered as their indirect efficiency self-evaluation.

Of all 132 people involved in the survey process there were 7 who gave no response. This leaves 125 available results. One participant misunderstood the task and gave totally wrong answer (with constantly rising

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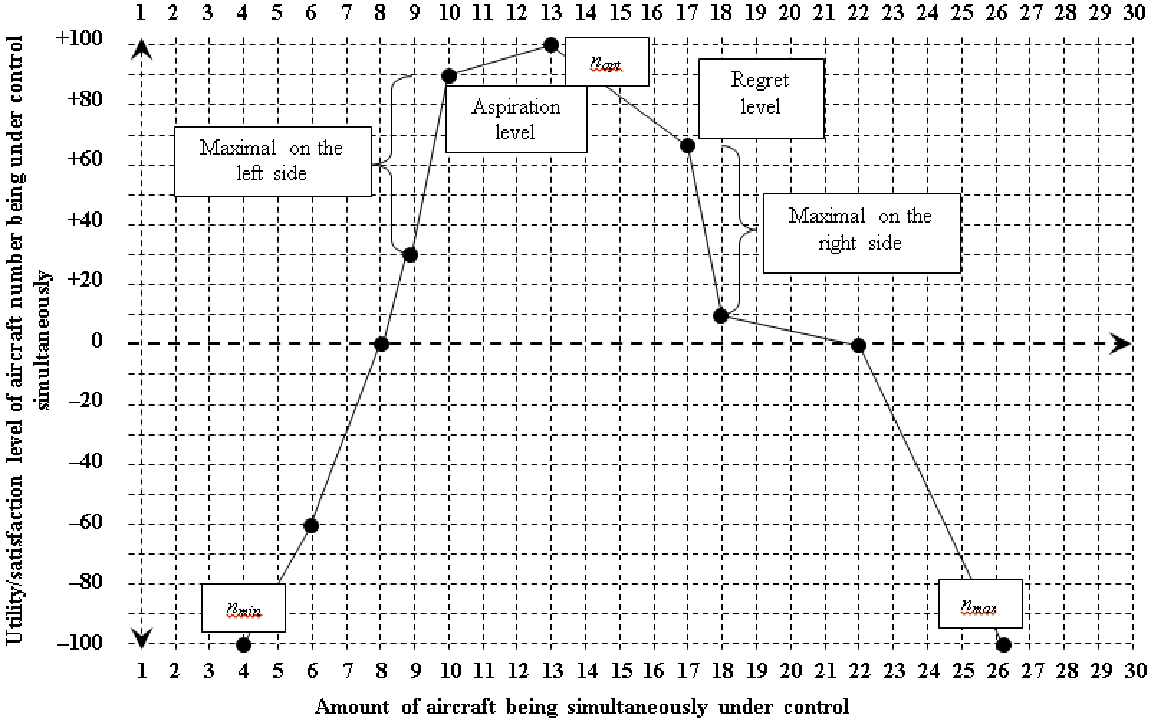

Figure 1. Example of survey chart with key points specifies

utility/satisfaction function). It was removed from the analyzed sample. All other 124 cases were accepted for subsequent analysis.

In the context of current research AL is considered as workload increase that brings maximal utility/satisfaction change. Important detail here is that sufficient level of flight safety support is implied. Such value is present on the increasing (left side) part of a chart on figure 1. The decreasing part (right side) of the chart also holds maximal utility/satisfaction difference value. However, it corresponds to the decrease of utility/satisfaction and thus cannot be considered as AL. It is referred as “regret” or “penalty” value caused by losing optimal workload preferred by respondent. Really, left side of the chart indicates respondent desire for best performance achievement whilst losing boredom. On the right side of the chart any respondent has stress increase caused by performance loss which makes him regretting.

For all cases the H_0 hypothesis is simple right-sided and formulated as goodness of fit test: whether the sample distribution significantly corresponds to the reference one. In different cases referred distributions are normal or exponential. The alternative H_1 hypothesis is always simple and directly opposed to the H_0.

Main goal of the survey is to define if various answers sets (for whole sample and sub-samples) belongs to the most common probability distribution functions. In some cases, the sample is taken as a whole. In other cases, a certain part of the initial sample is taken in order to test proper hypothesis. Two distributions were initially taken: normal and exponential. In order to test normality, the χ^2 method was used by default. Those cases when this is not true will be specified in text.

There are many responses with less than 5 votes in the initial sample. The whole sample was regrouped with Sturges formula in order to reduce number of intervals as χ^2 method requires:

$$h = \frac{D}{1 + 3.322 \ln n}, \qquad (4)$$

where H – is a new intervals number; D – is sample values range; n – is sample size.

3. Results and discussion

Only single maximal increment value is initially taken as an AL. For several equal increments only the first one is taken. For initially accepted results n=124 the following key values are calculated: expected value $\bar{x} = 7.702$, variance V=10.76, standard deviation s=3.28, skew A=0.98, kurtosis E=1.902. The distribution is show on figure 2.

3.1. Case I. Normal distribution test. Aspiration level

For this case all $n = 124$ responses were used with $D = 20$. Eventually $h = 2.51$ which brings 9 new intervals. Degree of freedom in this case is equal to 6.

Calculated statistics is $K = 44.34$ (p-value<0.001). This means that observed χ^2 criterion value reaches rejection region and hypothesis H_0 is not statistically significant. Both theoretical and empirical frequencies plots are shown on the figure 3.

3.2. Case II. Normal distribution test. Aspiration level adjusted

Previous results can be considered a bit detailed. After data regroup empiric frequencies are compared to the theoretic ones according to formula 5.

$$K = \sum \frac{(O - E)^2}{E}, \tag{5}$$

where $K -$ is referential statistic; $E -$ is expected frequency, $O -$ is observed frequency.

The K statistic determines the final conclusion. In “Case I” test these components are equal to:

K = (1.245+0.271+2.97+0.051+0.593+4.891+
+1.07+1.699+31.55) = 44.34.

The latest component here contributes the most. Denominator for the last component is equal to $O_9 = 0.1$ which leads to the extremely high impact. By removing this contribution $K = 12.79$ is received which makes H_0 statistically significant for $\alpha = 0.01$ (p-value=0.046). Since data pruning was not performed after regroup stage such approach is seen as reasonable and valid.

3.3. Case III. Normal distribution test. The sample with utility/satisfaction increment above 0 level

As it is presented on the figure 1 the left semi-plane is divided into two halfs by horisontal line. They are: $-100; 0$ negative utility range where satisfaction growth might be considered as attempt to get rid of the boredom; $0; +100$ positive range where satisfaction growth might be considered as attempt to achieve the best performance. At that point some respondents show no utility/satisfaction values more than 0 levels at all. Such answers don’t fit the very idea of “aspiration” as of a desire for some goal achievement. They might be considered as marginal and spare. For instance, an explanation of such attitude can be found in Atkinson’s paper. Thus, such responses were removed as unfit ones. As a result, 116 answers have left to be analyzed in this case.

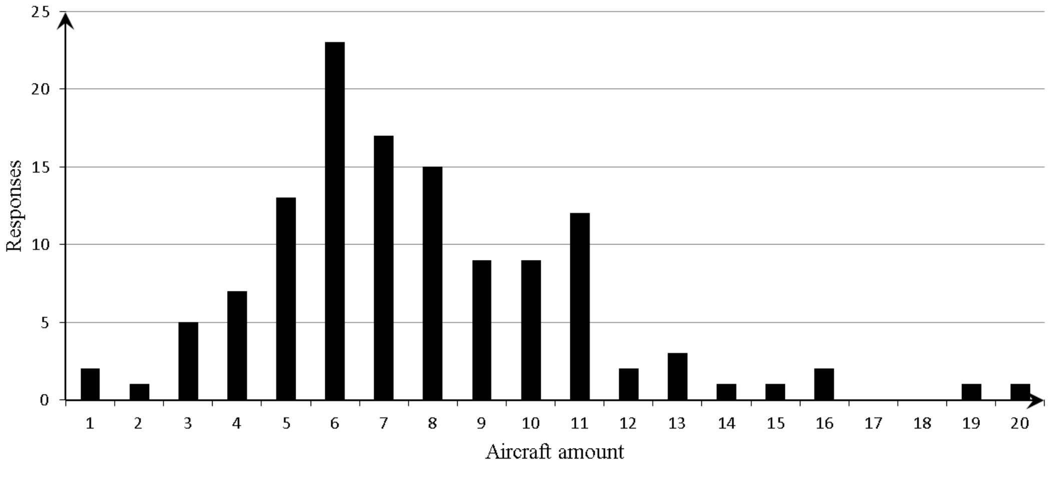

Figure 2. Initial frequencies for utility/satisfaction maximal increment

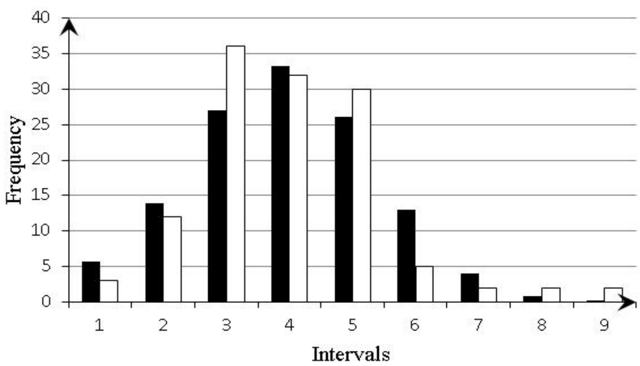

Figure 3. Theoretical (black) and empirical (white) frequencies

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Sample statistics are following: $n = 116$, $D = 18$, Sturges coefficient is $h = 2.29$, which gives 9 intervals. Method χ^2 is used as well with degree of freedom equal to 6 and $K = 15.07$ (p-value=0.019).This means that observed χ^2 criterion value is in acceptance region and hypothesis H_0 is statistically significant for $\alpha = 0.01$. Both theoretical and empirical frequencies plots are shown on the figure 4.

3.4. Case IV. Normal distribution test. Regret/penalty values

In order to check maximal decrement level at the right part of the chart the decrease values were taken.

They are mentioned above as “regret/penalty” values. Sample parameters are following: $h = 124$, $D = 25$, Sturges coefficient is $h = 3.14$, which gives 9 intervals. Method χ^2 is used as well with degree of freedom equal to 6 and $K = 12.89$ (p-value=0.044). This means that observed χ^2 criterion value is in acceptance region and hypothesis H_0 is statistically significant for $\alpha = 0.01$. Both theoretical and empirical frequencies plots are shown on the figure 5.

3.5. Case V. Normal distribution. AL united with regret/penalty values

For this case the one greater value (either AL or regret/penalty) is taken for a single respondent. Sample parameters are following: $n = 124$, $D = 30$, Sturges coefficient is $h = 3.77$, which gives 9 intervals. Method χ^2 is used as well with degree of freedom equal to 6 and $K = 39.75$ (p-value<.001). This means that observed χ^2 criterion value reaches rejection region and hypothesis H_0 is not statistically significant. Both theoretical and empirical frequencies plots are shown on the figure 6.

3.6. Case VI. Exponential distribution test. AL united with regret/penalty values

Exponential distribution hypothesis H_0 for mixed set of AL and regret/penalty values is also tested with χ^2 criterion. New probabilities are calculated as $p_i = e^{-\lambda x_i} - e^{-\lambda x_{i+1}}$ given intervals amount and boundary points from the first test. Here $\lambda = \frac{1}{\overline{x}_i} = 0.085$. Finally, $K = 55.13$ (p-value=0.009). This means that observed χ^2 criterion value reaches rejection region and hypothesis H_0 is not statistically significant. Frequencies plots are shown on the figure 7.

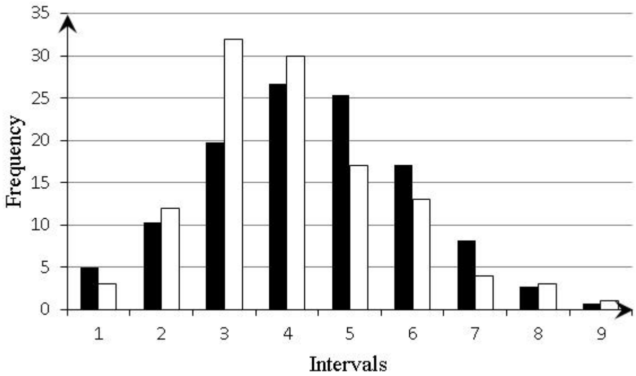

Figure 4. Theoretical (black) and empirical (white) frequencies

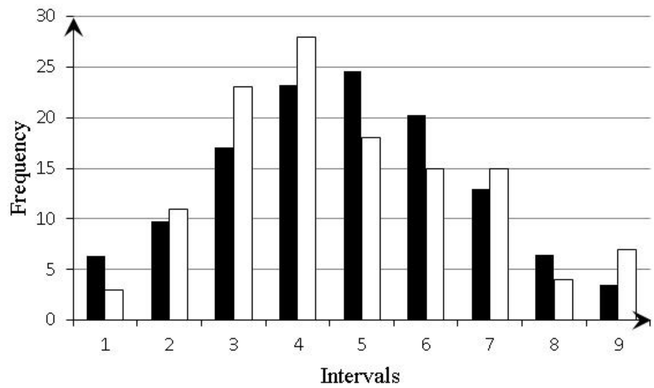

Figure 5. Theoretical (black) and empirical (white) frequencies

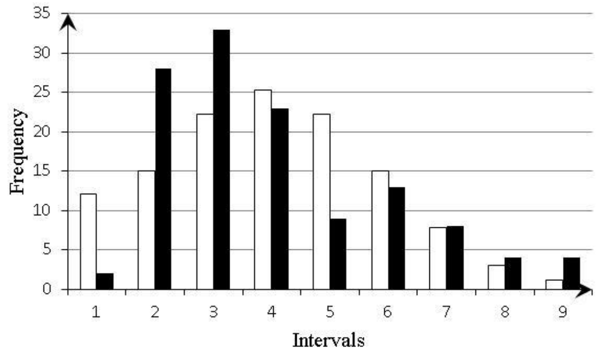

Figure 6. Theoretical (black) and empirical (white) frequencies

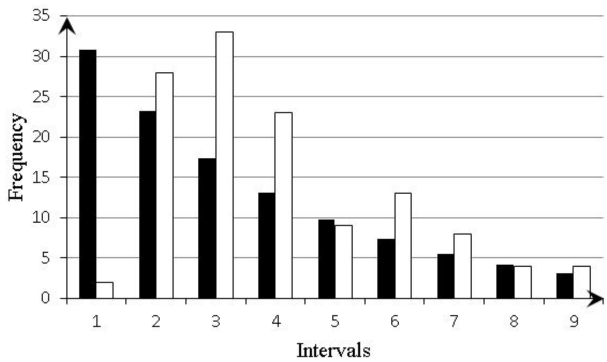

Figure 7. Theoretical (black) and empirical (white) frequencies

Disregard the absence of significance it is clear that p-value is close to acceptance region. Thus, it is reasonable to apply specific test in attempt for more precise verification. For this purpose, the Fisher's method was chosen to test the same sample for exponential goodness of fit case.

3.7. Case VII. Exponential distribution test. Fisher's method. Full sample

Specific Fisher's method is used to test again H_0 hypothesis about exponential probability distributions for mixed set of AL and regret/penalty. In order to do this Fisher's coefficient is found for arranged votes with

$$F = \frac{\sum_{i=1}^{n} x_i}{(n-1)x_i}, \qquad (6)$$

where x_1 – is the least value in the sample arranged incrementally.

After that it is compared with tabulated values having parameters α=0.05, $F_\alpha(2n–2.2)$. With original parameters x_l=1, n=124, $\sum x = 1476$, $F_\alpha(244.2)$=19.5 being used, F=7.2<F_α statistics is received. Thus the H_0 hypothesis is statistically significant for $\alpha = 0.05$. Overall hypotheses testing results are gathered in Table 1.

Table 1

Hypotheses tests results

Case	Distribution	Test details	The method	Accepted/rejected	Details if accepted
I	Normal	AL, $n = 124$	χ^2	Rejected	-
II	Normal	AL corrected $n = 120$	χ^2	Accepted	$\alpha = 0.01$
III	Normal	AL above 0 $n = 116$	χ^2	Accepted	$\alpha = 0.01$
IV	Normal	Regret $n = 124$	χ^2	Accepted	$\alpha = 0.01$
V	Normal	AL + regret $n = 124$	χ^2	Rejected	-
VI	Exponential	AL + regret $n = 124$	χ^2	Rejected	-
VII	Exponential	AL + regret $n = 124$	Fisher	Accepted	$\alpha = 0.05$ $F = 7.2 < F_\alpha = 19.5$

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3.8. Discussion

Obtained results clearly define ATCO students' AL distribution properties received via workload self-assessment. They are important in study of complex transport system operators' behavior. Normal distribution tests are crucial due to several reasons. Even taking into account deviation caused by human factors it is proven that AL related indexesare normally distributed. The trend of maximal workload efficiency difference being normally distributed is true for several options (NB: not for all though). This general information can be used during professional training and initial work process involvement. Calculated statistics allows evaluating the part of students who might reach the AL of professional ATCOs beforehand. Thus, they can be treated as such at the time of training. Also, it might be used as dropout parameter in order to avoid unnecessary resources waste. For students with such AL values that gives no definite information it is possible to change the training process in order to nudge them in either definite state. Other results refer to particular distribution.

The difference in "Case I" and "Case II" sampling approach vividly shows the importance of human factor consideration. Slight change in sampling formation (outlier drop) leads to large change of statistical significance. Such strong significance change indicates essential role of humanistic nature in the researched area. What is more important is that "Case III" results partially support chosen method. Indeed, removing votes that belong to less inherent behavior (according to AL definition) should result in better outcome. This phenomenon is exactly what occurs. As "avoiding" participants were removed the data converged better and meet significance requirements for normal distribution.

Case IV on its own shows the distribution of regret/penalty values. This is interesting in in perspective of utility/satisfaction difference research on the whole examined range. The facts that both incrementing and decrementing differences samples are significant for normal distribution allows performing further data processing with regard to normality. Such step from single to double independent variable requires standalone research though.

The very idea of "Case V", "Case VI" and "Case VII" is that since utility/satisfaction difference is present at both left and right parts of every chart their combination might be distributed in different or similar way. Having these values researched allows switching from the separate "aspiration level"–"regret/penalty" couple observation into a single indicator. Such indicator shows the sole distribution of the most significant impacts.

Final united AL and regret/penalty values distributionis of great interest. Commonly the final distribution of united samples is the normal one. However, the exponential distribution comes into action with rather solid significance levels. Such results witness that given normal distribution for separate indicators of utility/satisfaction can't be treated as such united together. Furthermore, additional analysis of utility/satisfaction differences is required as the predominance of decrementing difference might badly influence flight safety. Further researches in that area should be performed to explain this phenomenon and its details.

4. Conclusions and prospects for further research

We can conclude that all three goals of the research stated in the beginning are achieved. The research related to the ATCO students' self-assessment of the workload with further AL determination was performed with taking into account peculiarities of their professional activity. Basic distribution parameters were calculated and discussed. Probability distributions were tested. Participants AL can be considered as normally distributed in cases show in the table 1. Unmixed AL results were successfully compared with alternatively combined results for the same participants.

It is statistically proven that utility/satisfaction rates difference values are distributed normally with significance level $\alpha = 0.01$ for: AL values with outlier removed; AL values boredom avoidance removed; regret/penalty indicators for the efficiency loss. Indicators of AL united with "penalty/regret" having single topmost selected for each respondent are exponentially distributed with significance level $\alpha = 0.01$. Results received during analysis can be implemented for ATCO student's readiness evaluation. Further research should be held in comparison of the received results with indicators of real ATCO with professional experience, overall utility/satisfaction differences analysis and multidimensional significance testing.

Authors contribution: problem statement and research goal definition – **Oleksii Reva**; literature and publications research – **Serhii Borsuk, Larysa Sahanovska**; research methods selection – **Oleksii Reva, Serhii Borsuk**; survey performing, results collection and analysis – **Serhii Borsuk**; conclusions and further researches directions – **Larysa Sahanovska, Serhii Borsuk**.

All authors have read and agreed on the published version of the manuscript.

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РОЗПОДІЛ РІВНІВ ДОМАГАНЬ У СТУДЕНТІВ АВІАЦІЙНИХ ДИСПЕТЧЕРІВ

Сергій Борсук, Олексій Рева, Лариса Сагановська

Роботу присвячено аналізу опитування, проведеного зі студентами авіаційними диспетчерами, яке опису самооцінку їх рівня робочого навантаження. Робоче навантаження визначено, як кількість повітряних суден, що знаходяться під керуванням одночасно. Опитування проведено над сіткою із осями, на яких які представлено кількості повітряних суден та відповідні їм рівня корисності/задоволення. Значення рівнів домагань обчислено із різниць у робочому навантаженні. Описано засади безпеки для ризиків у авіаційних

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процесах. Висвітлено зв'язок між ризиками та рівнем домагань. Виведено дефініцію рівня домагань для розглянутого дослідження. Пояснені умови та деталі опитування. Роз'яснено різницю між чотирма чвертями графіків робочого навантаження, наведених респондентами. Обраховано та наведено параметри рівня домагань та базові статистичні показники респондентів. Проведено відповідні тести щодо узгодженості для різних множин початково отриманих відповідей. Розглянуті як уся вибірка, так і її підмножини. Показано, що для повної вибірки усування викидів призводить до значного покращення значення p-value, що дозволяє змінити статус прийняття початкової гіпотези. Список підмножин включає усю вибірку без викидів та рівні домагань, обраховані виключно для позитивної півплощини відповідей згідно осі ординат. Додатково, інші значення було узято для обчислень, а саме: значення жалю (тобто значення на спадаючій половині графіку) та змішані значення рівня домагань та жалю в залежності від того, яке більше за модулем. Значущість нормального та експонентного розподілу доведено для різних варіантів із тих, які наведено вище. Показано, що загальний метод хі-квадрат визнає статистично незначущим експоненційність об'єднання, наведеного останнім. В той же час спеціальний метод Фішера доводить статистичну значущість даних. Описано роль рівня домагань студентів авіаційних диспетчерів у їх оцінюванні та можливій персоналізації освітньої стратегії. Підтверджено важливість урахування людського чинника під час проведення подібних опитувань. Обговорено зв'язок між рівнем домагань та жалем у запропонованій комбінації. Наведено висновки за отриманими результатам. Запропоновано напрямки подальших досліджень.

Ключові слова: безпека польотів; людський чинник; робоче навантаження; рівень домагань; освіта.

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