Dunakavics

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Műszaki-, Informatikai és Társadalomtudományok

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Tartalom

ELIF KORUYUCU *–MELIH YILDIZ **–EBRU YAZGAN ***
–UTKU KALE ****–ANDRÁS NAGY *****

Evaluating and Comparison of the Ergonomic Conditions of Two Representative Training Aircraft Cockpit to Improve the Efficiency of Flight Training

Abstract: Cockpit design plays an essential role in educational programs for student pilots to improving the quality and efficieny of learning. This study focuses on cockpit design on identifying design factors for educational purposes. In this reaserch, two common trainer aircraft used in flight schools, namely TB-20 and Cessna 172 cockpits have been selected. In order to examine two different trainer aircraft in terms of ergonomics, a questionnaire is developed by obtaining opinion of aviation experts, flight instructors, and student pilots. The questionnaire is conducted to a total number of 40 flight instructors and student pilots for both trainer aircraft which includes different types of survey questions related to displays, control elements, communication in the cockpit, anthropometry, environment, and flight safety. In the statistical analysis, the significant differences between the TB-20 and Cessna 172 training aircraft cockpits are revealed such as (i) readings of the flight engine displays, (ii) placing switches and lever within reach of both pilots, (iii) headphone and microphone in terms of ease of use, (iv) comfort of the pilot back height of the seats, (v) clear hearing of conversations between student and instructor pilot and auditory signals in the cockpit, and (vi) distracting noise and humidity conditions in the cockpit. Finally, based on the results of the statistical and qualitative analysis in the study, the design issues and orientations in additive manufacturing for a better educational cockpit design are discussed. The outcomes of this study can be used for flight training organizations therby increasing the efficiency and effectiveness of flight training.
Keywords: Cockpit design, ergonomics, human factors, trainer aircraft

* *Eskisehir Technical University, Porsuk Vocation School, Unmanned Aerial Vehicle Technology and Operators Program*
E-mail: elifkoruyucu@eskisehir.edu.tr

** *Girne University, Faculty of Aviation and Space Sciences, Department of Aeronautical Engineering, Girne, Turkey*
E-mail: melih.yildiz@kyrenia.edu.tr

*** *Eskisehir Technical University, Faculty of Aeronautics and Astronautics, Department of Airframe and Powerplant Maintenance*
E-mail: eyazgan@eskisehir.edu.tr

**** *Budapest University of Technology and Economics Department of Aeronautics, and Naval Architecture*
E-mail: ukale@vrht.bme.hu

***** *University of Dunaújváros, Department of Mechanical Engineering*
E-mail: nagy.andras@uniduna.hu

Introduction

Cockpit design as a control room is of high importance for providing comfort, safety, and ease of communication for pilots. Aircraft certification standards give basic requirements about the cockpit design in terms of flight control systems (CS 23.2300), cockpit lightning (CS 23.2530), and crew compartment arrangements (CS 23.2600). [1]

Aircraft cockpit display and control systems provide much information to the pilot(s) and consist of a great many instruments and complex information. The number and complexity of the cockpit systems increase crew workload thereby leading to increasing the rate of incidents and accidents particularly under being in an emergency (Xiaoling et al., 2016).

Strickland et.al. defined pilots as a vital component of safe flight and emphasized the human aspects of the cockpit. They analyzed man-machine interface effects on pilot's performance during a flight. [2]

Anderson and Hendy (1984) [3] developed an anthropometric model to evaluate seat adjustment of CT-4A cockpit, for enhancing training effectiveness and improve flying safety. They performed an experimental study with thirty pilots to evaluate and propose modifications by means of ergonomics.

Ergonomics is the knowledge of maximizing human productivity by properly fitting the product or system accordingly. Prior to the development of the discipline of ergonomics, humans were required to use the design instead of designing according to human requirements such as height, weight, and strength for the use of the tools or systems. Besides, technology is advancing and changing rapidly which creates additional operational procedures to be introduced, adapted, and allocated for the use of the human. [4], [5]

Consideration of human factors during the design of the aircraft and up to operations is essential. Ergonomics takes account of the human capabilities and limitations during the performance of the tasks, use of equipment, the process of the information, and the environment in which human works suit to human working conditions. For example, the cockpit of the fighter jets can be defined as one of the most complex workplaces in the world which requires higher levels of information processing under stress conditions with the requirement of "no error". [6]

Indicator systems in cockpits are extremely complex. [7] The slightest mistake or negligence in aviation could result in an air disaster. Display panels should be designed in a way to prevent errors that may arise from the readings or use of these panels. In the study of Senol et al., (2009) [8] the positions of the analog indicators on the front panel were evaluated in terms of human factors using quantitative and qualitative methods. The "Multi-Criteria Decision Making (MCDM)" and "Card Sorting" approaches were adapted and used in the design of a display panel. In this research, 8 pilots were given cards with the names of the indicators, and the cards were asked to be placed correctly over the covered indicators. The examined pilots were expected to find the location of the indicators. Based on the pilot responses, the results were analyzed and evaluated.

Zaitseva et. al. (2020) [8] studied the features of the location of devices and controls in the cockpit of the aircraft, and the level of correct psychophysiological perception of their indications by the pilot during the flight. They emphasized that the placement of indicators, alarms, and controls in the operator workplace is an important factor for improving functional efficiency and reliability.

Zhang et. al (2014) [9] determined the ergonomics design elements in the transport category aircraft cockpit due to the importance of ergonomics design for the efficiency of flight crew operation and flight safety. Using a hierarchical cluster approach, researchers analyzed the design elements which is obtained from airworthiness regulations and industry standards. da Silva et.al (2020) used 33 anthropometric measurements for improving aircraft cockpit design ergonomically.

Jung, et al., (2009) [10] developed a quantitative method for assessing the physical workloads in a digital environment for the cockpit of the Korean Utility Helicopter (KUH). The proposed method quantified physical workloads for the target user under a 3-step process, aimed at identifying design features that need to be improved based on the workload evaluation results. The parameters of quantified physical workloads were posture, reach, visibility, and clearance.

The quality of the cockpit design affects the physiology, psychology, and situation awareness of pilots. In addition, it directly affects the pilots' working efficiency and flight safety. It is therefore essential to carry out an ergonomic assessment in advance for cockpit design. Lijing et al., (2009) [11] used the "Cockpit Ergonomics Layout and Assessment System (CEA)" which can simulate the human-computer interface. In this study, they evaluated the visibility, accessibility, and comfort of the pilot's operating posture in the cockpit. The mannequins of the pilots were seated according to the operational posture, and accessibility and visibility of cockpit layouts were evaluated with ergonomic analysis. In the cockpit, the accessibility and visibility of the main dashboard, front center pedestal control stand, central plinth control stand, upper control panel, sun visor, left and right side console, steering column, and pedal were evaluated by ergonomic analysis. The accessibility of the pilot's right arm and left arm accessible area was examined. A comfort assessment of typical operating stops during take-off, landing, and cruise was aálso made. The deficiencies in the cockpit layout design were identified by evaluating the cockpit ergonomics.

Kumar et al., (2019) [12] studied the ergonomics of pilot seats by means of the effects of cushion foam on the comfort of the pilot. They conclude that the cushion foam thickness has a direct relation with the seating comfort and at least a 100 mm foam thickness is required for minimal comfort.

In this study, in order to examine and compare two representative trainer aircraft in terms of ergonomics based on literature, a questionnaire was developed for collecting the opinion of instructors and student pilots. The survey results are analyzed statistically and the cockpits of the representative aircraft are evaluated. In the next section, representative trainer aircraft are briefly introduced as well. In the third section. the methodology and questionnaire are presented widely. In the fourth part, the statistical results are given and analyzed. The final section defines and explains the conclusion, discussion, and contributions of the study.

TB-20 and CESSNA 172 Cockpit

This study focuses on the design impact of human factors in the cockpits of the trainer aircraft namely, TB-20 and CESSNA 172. The cockpit design of these aircraft was examined ergonomically in the study.

The first representative aircraft, the Cessna 172 aircraft is a four-seat, single-engine, and high-wing aircraft manufactured by the Skyhawk, Cessna Aircraft Company. The Cessna 172s flew for the first time in 1955. The cockpit of the Cessna training aircraft is given in *Figure 1.*

Figure 1. Cessna 172 cockpit general view

The second representative aircraft, Socata TB-20 Trinidad is a metal semi-mono coke, a single-piston engine with fixed velocity propeller and retractable landing gear, manufactured by Daher-Socata and designed in the late 1970s. The cockpit of the TB-20 training aircraft is presented in *Figure 2.*

Figure 2. Socata TB-20 cockpit general view

Methodology

For evaluation of ergonomics factors of the representative trainer aircraft, a questionnaire is developed. The developed questionnaire has seven parts as following:
– General properties,
– Displays,
– Control elements,
– Communication in the cockpit,
– Anthropometry,
– Environment,
– Flight Safety.

In the first part of the questionnaire, an analysis of frequency and percent is used for the question related to demographic information. In the other six parts, the five-point Likert scale (poor (1), fair (2), average (3), good (4), and very good (5)) questions are used for taking pilots' opinions. Besides, there are also open-ended questions in the questionnaire. Analysis of open-ended questions is evaluated with the most frequent answers.

SPSS 22 program is used for statistical analysis of the questionnaire. For the two representative trainer aircraft cockpit ergonomic aspects, frequencies, and percentages, means, and standard deviations of the answers using the Likert scale are calculated. The difference between means of the answers given from pilots for Cessna-172 and TB-20 cockpits is examined by using ANOVA. Analyses are revealed significant differences between the TB-20 and the Cessna 172 training aircraft cockpits in terms of ergonomics. The detailed analysis and evaluation of the results are given below.

Demographic Information

The frequency and percentage distributions of the answers given by the flight instructors and student pilots who answered the survey questions related to the general information in the first part of the questionnaire are given in Tables 1 to 4. As can be seen in Table 1, 37.5% of the respondents are instructor pilots, while 62.5% are student pilots. 97.5% of the respondents were male pilots (Table 2) and 2.5% of them were female. 22.5% of the participants are under 22 years old, while 35% of them were over 40 years old (Table 3). In addition, 57.5% of the examined pilots are over 165 cm in height *(Table 4).*

Table 1. Distribution of job title

JOB TITLE	TB-20		CESSNA 172		TOTAL	
	N	%	N	%	N	%
Instructor Pilot	9	42.9	6	31.6	15	37.5
Student Pilot	12	57.1	13	68.4	25	62.5

Table 2. Gender distribution of pilots

GENDER	TB-20		CESSNA 172		TOTAL	
	N	%	N	%	N	%
Female	0	0.0	1	5.3	1	2.5
Male	21	100	18	94.7	39	97.5

Table 3. Distribution of age range

AGE	TB-20		CESSNA 172		TOTAL	
	N	%	N	%	N	%
18–22	0	0.0	9	47.4	9	22.5
23–27	11	52.4	4	21.1	15	37.5
33–40	2	9.5	0	0.0	2	5.0
> 40	8	38.1	6	31.6	14	35.0

Table 4. Distribution of height

HEIGHT	TB-20		CESSNA 172		TOTAL	
	N	%	N	%	N	%
155-165cm	6	28.6	11	57.9	17	42.5
166-175cm	13	61.9	8	42.1	21	52.5
>185 cm	2	9.5	0	0.0	2	5.0

Questions asked using the Likert scale

For both trainer aircraft cockpits, the frequencies, percentages, means, standard deviations of the responses using the Likert Scale are calculated and given in Table 5. In the questionnaire, it is accepted that the questions with „average + fair + poor" answers totaling 50% are factors open to improvement in terms of the ergonomics of training aircraft. Morever, the mean and standard deviation for each question is showed in *Table 5*.

Tablo 5. Distribution of the Answers Using the Likert Scale

Tablo 5. Distribution of the Answers Using the Likert Scale

	TB-20												CESSNA 172											
	Poor		Fair		Average		Good		Very Good		Mean	Std. Deviation	Poor		Fair		Average		Good		Very Good		Mean	Std. Deviation
	N	%	**N**	%	**N**	%	**N**	%	**N**	%			**N**	%	**N**	%	**N**	%	**N**	%	**N**	%		
A. QUESTIONS ABOUT DISPLAYS																								
	0	0.0%	2	9.5%	8	38.1%	11	52.4%	0	0.0%	3.43	0.676	0	0.0%	0	0.0%	3	15.8%	13	68.4%	3	15.8%	4.00	0.577
A2. Please evaluate the readings of the **engine** displays on the cockpit panel according to the normal viewing angle by both pilots.	0	0.0%	1	4.8%	6	28.6%	12	57.1%	2	9.5%	3.71	0.717	0	0.0%	0	0.0%	6	31.6%	10	52.6%	3	15.8%	3.84	0.688
A3. Please evaluate the adequacy of general lighting in the cockpit for documents such as a map and checklist.	1	4.8%	1	4.8%	3	14.3%	15	71.4%	1	4.8%	3.67	0.856	0	0.0%	1	5.3%	3	15.8%	14	73.7%	1	5.3%	3.79	0.631
A4. Please evaluate the adequacy of the interior lighting of the displays on the cockpit panel.	0	0.0%	1	5.0%	3	15.0%	14	70.0%	2	10.0%	3.85	0.671	0	0.0%	0	0.0%	1	5.3%	16	84.2%	2	10.5%	4.05	0.405
Please evaluate the flight and engine displays on the cockpit panel in terms of brightness and reflection.																								
A5. Brightness and reflection of flight displays	1	4.8%	1	4.8%	6	28.6%	12	57.1%	1	4.8%	3.52	0.873	0	0.0%	0	0.0%	4	21.1%	15	78.9%	0	0.0%	3.79	0.419
A6. Brightness and reflection of engine displays	0	0.0%	1	4.8%	5	23.8%	13	61.9%	2	9.5%	3.76	0.700	0	0.0%	0	0.0%	2	10.5%	17	89.5%	0	0.0%	3.89	0.315
A7.Please evaluate the conditions of seeing surrounding conditions (i.e. wing) of the aircraft during the flight	0	0.0%	0	0.0%	4	19.0%	14	66.7%	3	14.3%	3.95	0.590	0	0.0%	0	0.0%	7	36.8%	8	42.1%	4	21.1%	3.84	0.765
A8. Please evaluate the display arc limits and the moving speed of the finders	0	0.0%	1	4.8%	0	0.0%	18	85.7%	2	9.5%	4.00	0.548	0	0.0%	0	0.0%	4	21.1%	14	73.7%	1	5.3%	3.84	0.501
A9. Please evaluate to what extent it is useful to provide the same information with both analog and digital displays for the flight	0	0.0%	0	0.0%	1	4.8%	14	66.7%	6	28.6%	4.24	0.539	0	0.0%	0	0.0%	2	11.1%	6	33.3%	10	55.6%	4.44	0.705
A10. Please evaluate how well organized the descriptions of the displays on the cockpit panel	0	0.0%	1	4.8%	4	19.0%	14	66.7%	2	9.5%	3.81	0.680	0	0.0%	1	5.3%	2	10.5%	15	78.9%	1	5.3%	3.84	0.602

	TB-20												CESSNA 172											
	Poor		Fair		Average		Good		Very Good		Mean	Std. Deviation	Poor		Fair		Average		Good		Very Good		Mean	Std. Deviation
	N	%	N	%	N	%	N	%	N	%			N	%	N	%	N	%	N	%	N	%		
C4. How the conversations between the student and instructor pilot and auditory signals in the cockpit are heard clearly and transparently, please evaluate?	0	0.0%	0	0.0%	3	15.0%	13	65.0%	4	20.0%	4.05	0.605	0	0.0%	1	5.3%	8	42.1%	9	47.4%	1	5.3%	3.53	0.697
D. QUESTIONS ABOUT ANTHROPOMETRY																								
Please evaluate the comfort of the pilot seats in terms of seating																								
D1. The width of the seating area	0	0.0%	5	23.8%	13	61.9%	2	9.5%	1	4.8%	2.95	0.740	2	10.5%	7	36.8%	9	47.4%	1	5.3%	0	0.0%	2.47	0.772
D2. Length of the seating area	0	0.0%	4	19.0%	16	76.2%	1	4.8%	0	0.0%	2.86	0.478	1	5.3%	2	10.5%	16	84.2%	0	0.0%	0	0.0%	2.79	0.535
D3. The height of the seating area from the ground	0	0.0%	1	4.8%	19	90.5%	1	4.8%	0	0.0%	3.00	0.316	0	0.0%	2	10.5%	16	84.2%	1	5.3%	0	0.0%	2.95	0.405
D4. Back height of the seat	1	4.8%	7	33.3%	13	61.9%	0	0.0%	0	0.0%	2.57	0.598	0	0.0%	0	0.0%	18	94.7%	1	5.3%	0	0.0%	3.05	0.229
D5. Please evaluate the comfort of the pilot's seat in general	0	0.0%	3	14.3%	8	38.1%	8	38.1%	2	9.5%	3.43	0.870	0	0.0%	0	0.0%	11	57.9%	8	42.1%	0	0.0%	3.42	0.507
E. QUESTIONS ABOUT ENVIRONMENTAL CONDITIONS																								
E1. Please evaluate if there are uncomfortable vibrations in the cockpit	0	0.0%	0	0.0%	6	28.6%	15	71.4%	0	0.0%	3.71	0.463	0	0.0%	3	15.8%	8	42.1%	6	31.6%	2	10.5%	3.37	0.895
E2. Please evaluate whether there is distracting noise in the cockpit	0	0.0%	1	4.8%	5	23.8%	15	71.4%	0	0.0%	3.67	0.577	0	0.0%	5	26.3%	8	42.1%	4	21.1%	2	10.5%	3.16	0.958
E3. Please evaluate the humidity conditions in the cockpit	0	0.0%	1	4.8%	3	14.3%	16	76.2%	1	4.8%	3.81	0.602	0	0.0%	3	15.8%	8	42.1%	8	42.1%	0	0.0%	3.26	0.733
E4. Please evaluate the climate conditions in the cockpit	2	9.5%	5	23.8%	4	19.0%	10	47.6%	0	0.0%	3.05	1.071	2	10.5%	8	42.1%	7	36.8%	2	10.5%			2.47	0.841
F. QUESTIONS ABOUT FLIGHT SAFETY																								
F1. Is the cockpit designed to prevent the pilots from distracting? Please evaluate the cockpit from this perspective	0	0.0%	0	0.0%	4	19.0%	15	71.4%	2	9.5%	3.90	0.539	0	0.0%	1	5.3%	3	15.8%	15	78.9%	0	0.0%	3.74	0.562
F2. How is the cockpit designed to avoid errors in pilots monitoring the system, please evaluate?	0	0.0%	1	4.8%	6	28.6%	11	52.4%	3	14.3%	3.76	0.768	0	0.0%	1	5.3%	5	26.3%	13	68.4%	0	0.0%	3.63	0.597
F3. Please evaluate the comfort of entering and exiting to cockpit under normal conditions.	1	4.8%	5	23.8%	13	61.9%	2	9.5%	0	0.0%	2.76	0.700	1	5.3%	4	21.1%	10	52.6%	3	15.8%	1	5.3%	2.95	0.911

	TB-20												CESSNA 172											
	Poor		Fair		Average		Good		Very Good		Mean	Std. Deviation	Poor		Fair		Average		Good		Very Good		Mean	Std. Deviation
	N	%	N	%	N	%	N	%	N	%			N	%	N	%	N	%	N	%	N	%		
B. QUESTIONS ABOUT CONTROL ELEMENTS																								
Please evaluate whether the following control elements are placed within the reach of both pilots																								
B1. Switches	1	4.8%	0	0.0%	2	9.5%	17	81.0%	1	4.8%	3.81	0.750	1	5.3%	4	21.1%	8	42.1%	5	26.3%	1	5.3%	3.05	0.970
B2. Buttons	0	0.0%	0	0.0%	3	14.3%	15	71.4%	3	14.3%	4.00	0.548	1	5.3%	1	5.3%	3	15.8%	13	68.4%	1	5.3%	3.63	0.895
B3. Pedals	1	4.8%	1	4.8%	1	4.8%	10	47.6%	8	38.1%	4.10	1.044	0	0.0%	0	0.0%	0	0.0%	9	47.4%	10	52.6%	4.53	0.513
B4. Lever	1	4.8%	2	9.5%	1	4.8%	13	61.9%	4	19.0%	3.81	1.030	0	0.0%	0	0.0%	0	0.0%	7	36.8%	12	63.2%	4.63	0.496
B5. Throttle	0	0.0%	0	0.0%	2	9.5%	13	61.9%	6	28.6%	4.19	0.602	0	0.0%	0	0.0%	2	10.5%	8	42.1%	9	47.4%	4.37	0.684
How do you perceive the control elements as tactile feeling while using them in flight? (e.g. is it necessary to apply a very strong force when using the pedals?)																								
B6. Switches	0	0.0%	1	4.8%	3	14.3%	11	52.4%	6	28.6%	4.05	0.805	0	0.0%	0	0.0%	3	15.8%	13	68.4%	3	15.8%	4.00	0.577
B7. Buttons	0	0.0%	0	0.0%	2	9.5%	15	71.4%	4	19.0%	4.10	0.539	0	0.0%	0	0.0%	1	5.3%	15	78.9%	3	15.8%	4.11	0.459
B8. Pedals	0	0.0%	0	0.0%	1	4.8%	12	57.1%	8	38.1%	4.33	0.577	0	0.0%	0	0.0%	3	15.8%	9	47.4%	7	36.8%	4.21	0.713
B9. Lever	0	0.0%	1	4.8%	0	0.0%	15	71.4%	5	23.8%	4.14	0.655	0	0.0%	0	0.0%	1	5.3%	10	52.6%	8	42.1%	4.37	0.597
B10. Throttle	0	0.0%			3	14.3%	11	52.4%	7	33.3%	4.19	0.680	0	0.0%	0	0.0%	4	21.1%	9	47.4%	6	31.6%	4.11	0.737
B11. Please evaluate the control elements in terms of shape	0	0.0%	2	9.5%	1	4.8%	16	76.2%	2	9.5%	3.86	0.727	0	0.0%	0	0.0%	2	10.5%	15	78.9%	2	10.5%	4.00	0.471
B12. Please evaluate the control elements in terms of dimension	0	0.0%	1	4.8%	3	14.3%	16	76.2%	1	4.8%	3.81	0.602	0	0.0%	0	0.0%	2	10.5%	15	78.9%	2	10.5%	4.00	0.471
C. QUESTIONS ABOUT COMMUNICATION IN THE COCKPIT																								
Please evaluate the devices given below in terms of ease of use																								
C1. Headphone	1	4.8%	2	9.5%	2	9.5%	9	42.9%	7	33.3%	3.90	1.136	2	10.5%	6	31.6%	5	26.3%	6	31.6%	0	0.0%	2.79	1.032
C2. Microphone	1	4.8%	0	0.0%	4	19.0%	10	47.6%	6	28.6%	3.95	0.973	0	0.0%	4	21.1%	7	36.8%	8	42.1%	0	0.0%	3.21	0.787
C3. Radiotelephone	1	4.8%	0	0.0%	5	23.8%	11	52.4%	4	19.0%	3.81	0.928	0	0.0%	0	0.0%	2	10.5%	16	84.2%	1	5.3%	3.95	0.405

	TB-20												CESSNA 172											
	Poor		Fair		Average		Good		Very Good		Mean	Std. Deviation	Poor		Fair		Average		Good		Very Good		Mean	Std. Deviation
	N	%	N	%	N	%	N	%	N	%			N	%	N	%	N	%	N	%	N	%		
F4. Please evaluate the flight safety conditions of the cockpit in general	0	0.0%	3	14.3%	18	85.7%	0	0.0%	0	0.0%	3.86	0.359	0	0.0%	4	21.1%	14	73.7%	1	5.3%			3.84	0.501
F5. In case of receiving more than one warning from the displays at the same time in the cockpit, to what extent is it affected by the pilot's decision to prioritize these warnings?	0	0.0%	2	9.5%	8	38.1%	9	42.9%	2	9.5%	3.52	0.814	1	5.3%	4	21.1%	4	21.1%	8	42.1%	2	10.5%	3.32	1.108
F6. Please evaluate the overall quality (in terms of ergonomics) of the cockpit design	0	0.0%	2	9.5%	8	38.1%	11	52.4%	0	0.0%	3.43	0.676	0	0.0%	1	5.9%	5	29.4%	10	58.8%	1	5.9%	3.65	0.702

Results

The frequency and percentage analysis

Among the responses given in the survey, the questions with a total of „average + medium + poor" approximately 50% are considered to be ergonomically problematic issues. When Table 5 is analyzed in detail, it is seen that the factors that negatively affect the ergonomic conditions for both trainer aircraft cockpit *(Table 6)* are problematic issues open to improvement in cockpit design.

Table 6. Factors that negatively affecting the ergonomic conditions for both trainer aircraft cockpit

TB-20	**CESSNA 172**
Poor the readings of the flight displays according to the normal viewing angle by both pilots	Brightness and reflection of engine displays
Brightness and reflection of engine displays	Switches are not placed within the reach of both pilots
Uncomfortable pilot seats in terms of seating area dimensions and seat back height	Headphone and microphone are not easy to use
Poor climate conditions in the cockpit	The conversations between the student and instructor pilot and auditory signals in the cockpit are heard not clearly and transparently
Uncomfortable entering and exiting to cockpit under normal conditions	Poor environmental conditions such as vibration, noise, humidity, and climate in the cockpit
Poor the overall quality in terms of ergonomics of the cockpit design	Uncomfortable entering and exiting to cockpit under normal conditions

ANOVA analysis

The difference between means of the responses given from pilots for Cessna-172-SP and TB-20 cockpits is examined. The significance of this difference between means is determined at significance level α= 0,05 and H_0: $\mu_{\text{Cessna 172 SP}} = \mu_{\text{TB-20}}$ and H_1: $\mu_{\text{Cessna 172 SP}} \neq \mu_{\text{TB-20}}$. The ANOVA analysis results are given in *Table 7.*

Table 7. ANOVA analysis results

Question no		Sum of Squares	df	Mean Square	F	**Sig.**
A1	Between Groups	3.257	1	3.257	8.174	**0.007**
	Within Groups	15.143	38	0.398		
	Total	18.400	39			
B1	Between Groups	5.715	1	5.714536	7.70441	**0.009**
	Within Groups	28.185	38	0.742		
	Total	33.900	39			
B4	Between Groups	6.741	1	6.740852	9.982887	**0.003**
	Within Groups	25.659	38	0.675		
	Total	32.400	39			
C1	Between Groups	12.408	1	12.40758	10.4851	**0.002**
	Within Groups	44.967	38	1.183		
	Total	57.375	39			
C2	Between Groups	5.490	1	5.489724	6.928184	**0.012**
	Within Groups	30.110	38	0.792		
	Total	35.600	39			
C4	Between Groups	2.672	1	2.672	6.303	**0.017**
	Within Groups	15.687	37	0.424		
	Total	18.359	38			
D4	Between Groups	2.310	1	2.309774	10.84907	**0.002**
	Within Groups	8.090	38	0.213		
	Total	10.400	39			
E2	Between Groups	2.582	1	2.582018	4.230446	**0.047**

Results of open-ended questions

The responses given to the open-ended questions in the questionnaire for both trainer aircraft are given in *Table 8.*

Table 8. Answers to open-ended questions

TB-20 Cessna 172

TB-20	**Cessna 172**
Concerning the readability of flight indicators in an educational flight	
– Readability of RPM, manifold, and turn coordinator (TC) are found as difficult from the left seat for trainee pilots – Variometer located on the left side of the panel found as hard to read from the right seat – At night flights digital flow meter makes blin.	– Readability of RPM indicators, engine indicators is difficult from the left seat for trainee pilots – Flight and engine indicators should be placed on the cockpit panel at a certain angle – The heading indicator is poorly fitted by both pilots
Concerning the brightness and reflection of flight indicators and Control Elements	
– IAS, VST, ALT, and Horizontal Situation Indicator is unreadable from the left seat	– For the instructor pilot sitting on the right seat, indicators placed on the left part are not readable because of reflections (viewing dıfficult) – The lower view is better than upper – It is difficult to reach and activate buttons and switches from the right seat – Control systems should be supported by hydraulic systems – Lighting switches from the right seat have a poor view
Environmental Conditions	
– Disturbing vibrations in the cockpit is due to panel – Difficulty with entrance to cockpit is reported – Sun protective films are needed on front and side windows – The viewing angle can be increased – Seat adjustment also avoids setting viewing angle – Multiple bolt block is needed to avoid accidental operation	– Difficult to do adjustments without pulling back the command wheel on the indicators e.g. Difficult to adjust direction gyro and heading bug (could be mounted upright – Disturbing vibrations in the cockpit is due to engine indicator vibration when the engine starts turbulence and wind conditions also increase vibration perceptions – Disturbing noise is due to the air conditioner, transmitter, heating system, turbulence, and engine – It is difficult to reach and activate buttons and switches from the right seat – The temperature reaches 50 degrees inside the cockpit and its downsides will return to normal only after 1.5 or 2 hours if there is no sun. – Pedals are too hard and harder to feel

TB-20	Cessna 172
Anthropometry	
– Design suggestions in general focus towards, the seats in TB-20 are not adjustable in the height and besides back support is needed for flight comfort. – The seat belt is found as too tight	– Leather seats make sweaty in warm weather – The seat backrest should be adjusted for height
In-cockpit communication	
	– Headphones need to be replaced with less permeable ones to increase student concentration – Headphones do not insulate the sound enough. – Headphones and microphones are problematic in terms of hy giene.
Flight Safety	
	– It is difficult to secure a fire extinguisher after usage – Engine noise is distracting. – It is better to give visual and audio warning together in error monitoring – Cessna is better in emergencies (an airplane that can fly at low speeds when there is a problem with the engine (due to its wings)

Conclusion and Discussion

In this study, a survey is conducted to evaluate the ergonomic conditions of the cocpits of the common trainer aircraft, namely, TB-20 and CESSNA 172. The questionnaire developed is applied to the instructor and student pilots in training aircraft. When the results of the frequency and percentage analysis are examined, it can be seen that there are important subjects open to improvement in terms of ergonomics for the cockpits of these training aircraft.

The research results provide the following issues for the cockpit design to be improved:

TB-20: (i) the reading, brightness, and reflection of the engine and flight displays, (ii) the comfort of the pilot seats, (iii) climate conditions, and (iv) overall quality in terms of ergonomics of the cockpit design.

CESSNA 172: (i) the brightness and reflection of the flight displays, (ii) access of switches by both pilot, (iii) ease to use of headphone and microphone, (iv) audio quality of the conversations between the student and instructor pilot and auditory signals in the cockpit, (v) environmental conditions.

In order to increase the efficiency of piloting training by improving the ergonomic conditions of the training aircraft cockpit, the recommendations of the authors determined in this study are as follows:

– Analog displays are better for education
– Colors can prioritize the warning inside the cockpit
– Air-condition is needed in the aircraft for effectiveness
– Engine displays can be positioned in the middle where both pilots can see
– The fuel indicator system should be changed from resistive to capacitive
– A digital display can be placed inside the analog display. Thus, cross-check during flight decreases cognitive workload.

Based on the results, It can be indicated that the outcomes of ANOVA analysis provide enlightening results. It is demonstrated that the (i) readings of the flight engine displays, (ii) placing switches and lever within reach of both pilots, (iii) headphone and microphone in terms of ease of use, (iv) the comfort of the pilot back height of the seats in terms of seating, (v) clear hearing of conversations between student-instructor pilot and auditory signals in the cockpit, (vi) distracting noise and (vii) humidity conditions in the cockpit have significant differences with regards to two representative trainer aircraft.

Flight training consist of different flight stages such as initial, development, and advanced. The results of this analysis can be used to determine the suitable aircraft for training phase to increase the efficiency of the training. It is anticipated that this study will be a useful guidance document for flight training organizations and aircraft manufacturers by means of ergonomics.

With this study, it is clear that examining the ergonomic conditions of the cockpits of the widely used trainer aircraft is very important in the efficiency and effectiveness of the pilot training. Considering the findings obtained from this study, especially in the improvement areas of the training aircraft cockpits design, this research may play an important role in minimizing errors and accidents in pilot training.

This study has limitations such as the data were collected from a single flight training organization. In future work, it is planned to prioritize the investigated risk factors ergonomically in the cockpit design determined by this study with the help of risk analysis and Multi-Criteria Decision-Making methods such as Analytic Network Process (ANP).

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MEHIL YILDIZ *–UTKU KALE **–ANDRÁS NAGY ***

Analyzing Well-To-Pump Emissions of Electric and Conventional Jet Fuel for Aircraft Propulsion

Abstract:
Purpose
Aviation, being one of the main transportation and economical driver of global trade and consumerism, is responsible for an important ratio of anthropogenic emissions. Electric energy use in aircraft propulsion is gaining interest as a method of providing sustainable and environmentally friendly aviation. However, the production of electricity is more energy and emission sensitive compared to conventional jet fuel.
Design/methodology/approach
A well-to-pump (WTP) energy use and emission analysis were conducted to compare the electricity and conventional jet fuel emissions. For the calculations, a software and related database which is developed by Argonne's Greenhouse gas, Regulated Emissions, and Energy use in Transportation (GREET®) model is used to determine WTP analysis for electricity production and delivery pathways and compared it to baseline conventional jet fuel.
Findings
The WTP results show that electricity production and transmission have 9 times higher average emissions compared to conventional jet fuel. The future projection of emission calculations presented in this paper reveals that generating electricity from more renewable sources provides only a 50% reduction in general emissions. The electricity emission results are sensitive to the sources of production.
Originality
The main focus of the study is to analyze the well-to-pump emissions of electric energy and conventional jet fuel for use on hybrid aircraft propulsion.
Keywords: Sustainable aviation; hybrid electric aircraft; electric energy use in aviation; well to pump emissions.

* *Girne University, Faculty of Aviation and Space Sciences*
E-mail: melih.yildiz@kyrenia.edu.tr

** *Budapest University of Technology and Economics Department of Aeronautics, Naval Architecture and Railway Vehicles Budapest*
E-mail: ukale@vrht.bme.hu

*** *University of Dunaújváros, Department of Mechanical Engineering*
E-mail: nagy.andras@uniduna.hu

Introduction

Climate change is now a reality (McKie, 2018). Aviation is one of the factors in this climate change (Beck et al., 1992; Marsden and Rye, 2010; Masiol and Harrison, 2014) which affects human health in broader parameters (Jadaan, Khreis and Török, 2017; Diaz, 2018; Lee et al., 2021) in return. For minimizing the emissions, every sector is looking for environmentally friendly means of operation. It is obvious that the lifestyle needs to be changed in order to prevent further advert effects on the environment, as present conditions are a result of how humans conceive and consume natural habitat (Baumeister, 2020).

Demand for aviation is increasing with increasing commercialism and global movements of people and freight. Passenger kilometers growth estimation is given in Table I. It can be seen that annual growth is expected to be around 4.2% in passenger traffic.

Table 1. Route Group and Global Compound Annual Growth Rates (CAGR) of Forecasted RPKs (ICAO, 2019)

Long-Term Forecasts Route Group	2018-2028 CAGR	2018-2038 CAGR	2018-2048 CAGR
Africa	4.6%	5.0%	5.2%
Europe	2.6%	2.8%	3.0%
Middle East	3.6%	3.9%	4.0%
North America	2.3%	2.5%	2.7%
North Asia	2.2%	2.5%	2.5%
World	4.2%	4.2%	4.2%

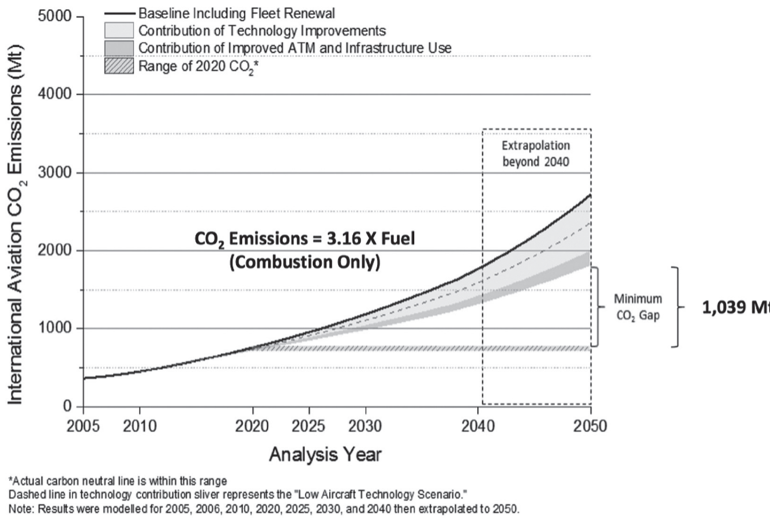
According to ICAO's forecast, the air cargo traffic is also expected to grow, slower than the passenger traffic, at a rate of 3.5% annually. Growth rate per region is given in Table II. The growth rate given is modelled and represents an estimated figure. Both passenger and freight traffic are expected to double in the next two decades.

Table 2. Region and Global Compound Annual Growth Rates of Forecasted Total International FTKs (ICAO, 2019)

Region	10 Year CAGR	20 Year CAGR	30 Year CAGR
Africa	3.5%	4.0%	4.1%
Asia and Pacific	3.8%	3.2%	2.8%
Europe	1.4%	1.7%	1.9%
Latin America/ Caribbean	0.8%	1.1%	1.2%
Middle East	6.1%	6.2%	6.1%
North America	3.3%	3.3%	3.3%
Total	3.5%	3.5%	3.5%

Energy sustainability and emission reduction is a key issue for aviation in order to overcome environmental and economic issues (Larsson et al., 2019). The demand growth of the aviation makes it more complex to cope with the sustainability efforts. Aircraft exhaust gases have a direct impact on environmental pollution and global warming (European Comission (EC), 2011). CO_2 emission estimation depending on models provided by ICAO is presented in *Figure 1*. While growing economies result in increasing utilization of air travel, increasing operating costs make the operators search for fuel-saving measures (Li and Trani, 2013).

Figure 1. CO_2 emissions trends from international aviation, 2005 to 2050 (Fleming and Ziegler, 2016)



The above-mentioned requirements push the academy and industry to develop fuel-efficient and environmentally friendly propulsion technologies (Lapeña-Rey et al., 2008). The most promising technology came out to be electric propulsion which is widely analyzed in the research (Berton and Haller, 2014; Epstein and O'Flarity, 2019). Electric propulsion do not produce emissions during operation and thus assumed as environmentally friendly (Meszaros, Shatanawi and Ogunkunbi, 2020). However, storing the electric energy onboard the aircraft with current battery technology creates additional weight problems to be dealt (Pornet et al., 2014). Because of this limitation, all-electric propulsion does not seem to offer competing performance with the fuel counterparts (Benjamin J Brelje and Martins, 2018).

Because of the battery technologies, hybrid propulsion seems to fill the gap (Wall and Meyer, 2017; Xie, Savvaris and Tsourdos, 2018). Various configurations of hybrid-electric propulsion are analyzed in the literature. They include distributed propulsion (Steiner et al., 2014), series, and parallel architectures (Cinar et al., 2017; Benjamin J. Brelje and Martins, 2018).

Among the flight phases, during descent the throttle setting of the engine drops. According to findings of Glowacki et.al. (Glowacki and Kawalec, 2016), the fuel spend in take-off and climb phases are the highest, three times to cruise phase, and is approximately 15 times to descent.

Using hybrid configuration, the engines can be used to charge the batteries during the low-fuel flow phase, which can be used in high-power phases.

Design considerations of hybrid-electric aircraft show that the technology is applicable (Riboldi and Gualdoni, 2016; Finger, Braun and Bil, 2018; Hoelzen et al., 2018; Vratny and Hornung, 2018). Conceptual design studies of mid-range aircraft show that the battery weight will be around 15% of Maximum Take-off Weight (MTOW) for hybrid (Pornet and Isikveren, 2015) and 28% for all-electric aircraft (Steiner et al., 2012) which are given as 12tons and 30tons of battery weight respectively. Such amount of batteries need to be charged on ground, without spending valuable on-board fuel.

Assuming a charging rate of around 1C, charging the batteries would require around 1 hour. In the literature, faster charging have drawbacks such as thermal heating, degradation of useful life, and handling problems (Farrington, 2001; Zheng et al., 2015; Schipper and Aurbach, 2016). Also, as the servicing time of an aircraft in a domestic route is approximately 25 minutes (Marais and Waitz, 2009), battery charging is not an option during aircraft servicing. Yet, safety and other operational requirements such as charging during ground servicing operations are not discussed.

The practice of charging the batteries of ground service equipment (GSE) in a station (Justin et al., 2020; Yildiz and Mutlu, 2020) can be applied for aircraft batteries. The battery is removed and placed in the charging station, while another already charged battery is installed on board. By employing such a charging option, aircraft ground servicing time can be kept under a minimal duration. The duration needed will then be the unloading and loading time of the battery.

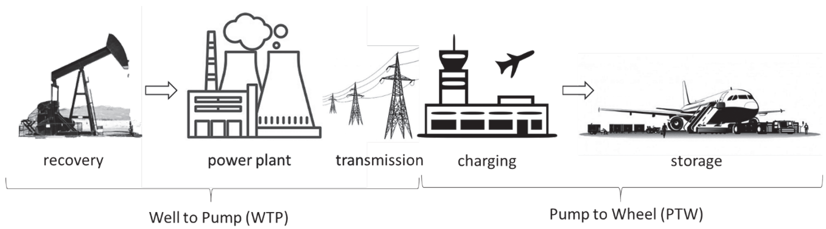
Electric Energy Use: Production, Transmission and Storage

Electric energy use in aviation seems to be a future solution for overcoming emission and cost factors, at least in the mid-term. The usage of the battery will create the necessity of charging, preferably at the airport as explained above. At present, there is no published standard nor application of battery charging stations for aircraft batteries.

This paper, analyzes the scenario of electricity generation, and transmission up to the airport where aircraft batteries are charged and stored onboard the aircraft, with present electricity mix. In this scenario, it is assumed that the batteries on board the aircraft are being charged on the airport using electricity provided by the grid which is already established. The batteries in this scenario can be still charged on board, using the generators during the low-power flight phases. The initial, ground charge of the batteries can be used during take-off and climb.

The cycles of electricity production, transmission, and charging are discussed under the respective sections. A brief relation of the cycles is given in *Figure 2.* The findings are gathered and analyzed under the following sections.

Figure 2. Electric energy path from well (source) to airport (pump) in the case of using onboard batteries charged on the ground



Production

Electricity demand is increasing due to economic development and urbanization. Current electric energy production mostly and widely depends on fossil fuels in the world (He et al., 2017; Li, Patiño-Echeverri and Zhang, 2019). The fuels used to generate electricity can be listed as coal, lignite, petroleum, and natural gas (Kaygusuz, 2003). Emissions, produced by electric generation processes can reach up to 34% of all emissions in the case of China (Li, Patiño-Echeverri and Zhang, 2019) and 39% in Turkey (Kaygusuz, 2003).

In general, renewable energy production is increasing and as a result fossil fuel consumption and CO_2 emissions are decreasing (Kasten et al., 2016). The benefits of renewable resources are known (Gibon and Hertwich, 2014). Wind and solar generation may reveal cleaner energy, but recent research is suspicious about the adverse effects on climate (Keith et al., 2004; Barrie and Kirk-Davidoff, 2010; Caduff et al., 2012; Abbasi, Tabassum-Abbasi and Abbasi, 2016). The literature shows that although using renewable sources such as wind gives the possibility to reduce emissions, indirect adverse effects on climate is a problem for mid-term.

Another dimension of the conventional production of electric energy is the security and transportation of the fuel from well up to the generation plant (Bouman, Ramirez and Hertwich, 2015). The downstream of fuel has its own emission profile and has an adverse effect on climate and social life (Kruyt et al., 2009; Winzer, 2012; Shepard and Pratson, 2020).

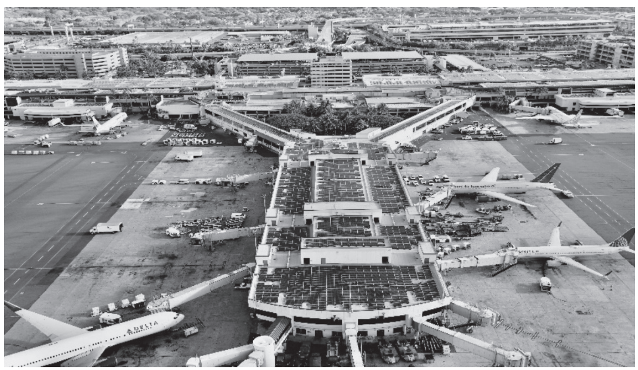
Transmission

Electric energy transmission is not as environmentally clean as expected (Blackett et al., 2008; Turconi et al., 2014). Various studies show that the transmission of 1 MWh of electric energy could create up to 7.8 kg of CO2 because of the inefficiencies and losses on the grid (Arvesen et al., 2015).

Power restrictions on the grid is also another negative aspect that should be evaluated for aviation. For the case presented in this paper, a concentrated transmission is required from the production plant up to the airport where the electric energy is used to charging the aircraft batteries besides present consumption. As the present grid is designed according to the energy demand of the airport and related infrastructure, the addition of an aircraft battery charging load may lead to limitations.

There are already some applications of roof-top solar panel installations in some airports (HDoT, 2019). The investment is said to be secured using the energy cost of the airport and thus have no direct effect on the energy supply cost to the aviation system. Application on the airport of Honolulu is shown in *Figure 3*.

Figure 3. Solar panel installation at HNL airport on Terminal 2 (HDoT, 2019)



Storage

The current technology of batteries depends mainly on lithium electrochemistry. The current technology has a drawback by means of capacity degradation depending on usage and time (Marcicki et al., 2012; Zheng et al., 2015; Jaguemont, Boulon and Dubé, 2016). This capacity degradation of the lithium-ion batteries creates further economic and safety problems for aviation. Thus comprehensive health monitoring and life extension methodologies and measures are needed in order to achieve a safe use for aviation (Penna, Nascimento and Rodrigues, 2012). Current battery technologies also have a deficiency by means of power capability (Vutetakis, 2013). In case of higher instantaneous power required by the aircraft systems, the designer is urged to install a higher amount of battery which also means more added weight and volume to aircraft. A recent calculation using current battery power and energy capacities yields a 28% increase in MTOW of the aircraft which has a 1300 nm range and 180 passenger capacity (Pornet and Isikveren, 2015).

Batteries also have inefficiencies such as loss of energy during charging and discharging by means of Joule heating (Deng et al., 2018). Although this inefficiency is not high by means of energy loss, it bears a safety problem and needs robust cooling systems (Hendricks et al., 2015).

The calculated battery capacity for a medium-range aircraft is above 10 tons of weight (Pornet and Isikveren, 2015). A general turnaround time of a domestic aircraft is 25 minutes in which a battery charging would require the use of over 2C charging currents regardless of the battery capacity. Charging a battery in high current values requires high power which again would create a high capacity demand on transmission grid. Besides, high-speed charging also is known to degrade battery health (Maher and Yazami, 2014; Rezvanizaniani et al., 2014; Gong, Xiong and Mi, 2015; Zheng et al., 2015). Heat production during the charging of a high amount of battery and related safety issues will also add up to the list of drawbacks (Yildiz, Karakoc and Dincer, 2016).

Data and Models

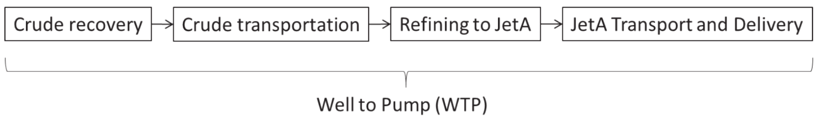
System Boundary

In this research, we have performed an analyze to compare the emission performances of electric energy used to charge the aircraft batteries and current state of jet fuel emissions on the well to pump (WTP) phases. The system boundary to analyze the effects of fuel production and delivery stages (i.e., WTP) is given in Figure 4. We used Argonne's Greenhouse gas, Regulated Emissions, and Energy use in Transportation (GREET®) model to determine WTP analysis for electricity production and delivery pathways, and compared it to baseline conventional jet fuel (Wang et al., 2020). We focus exclusively on the fuel cycle. Emissions related to aircraft operation is out of scope of this research.

We evaluated fuel production and delivery pathways for jet fuel and electricity to compare the WTP emission and energy performance. For electricity production, European mix values with transmission and distribution for year of 2019 is used.

The system boundary for jet fuel is assumed to be started at the well where crude oil recovered. Search and drilling efforts and emissions related to it is not included in this study. The schematic of the system boundary for jet fuel WTP is given in *Figure 4.*

Figure 4. Conventional jet fuel WTP system boundary



Well to pump emissions for conventional jet fuel includes transportation and refinery emissions. During the refinery process of crude oil other types of energy sources are also utilized which ends up in additional emissions which have to counted in the emission budget of fuel use (Sun et al., 2019). Same research also shows that downstream jet fuel pathway emissions (WTP) found to be around 1:8 of all the emissions related to well to wheel (WTW), which is the result of fuel burnt during flight.

Electricity Production Mix

Electricity production model parameters are given in *Table 3.* The ratios of European mix for electricity depends on mainly nuclear, coal and natural gas fired thermal generation which give the source of production of over 80% where hydroelectric and biomass generation fulfil the rest. Wind power generation also seem as an emerging source and has a ratio of 15.5% for the 2019. In this study, electricity transmission efficiency for Europe is taken as 93.56% in the model.

Table 3. Electricity production mix and related emissions for Europe (2019)

Electricity generation power source	European mix share (2019)	Energy and Emission Intensities per 1 MJ of Electricity at Wall Outlet			
		CO_2 Total (g)	CO (g)	NOx (g)	GHGs (g)
Oil fired	0.10%	260.00	0.65	1.17	270.00
Coal-fired	21.50%	282,120.00	24,300.00	140.00	259,790.00
Natural Gas-fired	20.50%	129,270.00	97.29	120.00	137,590.00
Nuclear	26.60%	1.89	0.00	0.00	2.03
Biomass	6.30%	6,510.00	1,390.00	310.00	18,590.00
Hydroelectric	9.50%	0.00	0.00	0.00	0.00
Wind	15.50%	0.00	0.00	0.00	0.00

In the model raw source emissions are also included in emission calculations. The source emissions in the pathway of biomass power generation, arising from poplar, willow, forest residue productions are also included in ethanol production phase. Coal production emission are included in pathway to coal fired power generation. Natural gas production by conventional means is included in natural gas fired power plant emission calculations. Nuclear power generation calculations are inclusive of uranium fuel enrichment process emissions. Oil fired power generation calculations include residual oil production emission from both crude oil refining and heavy butane production. The above mentioned emission parameters are used as in the default values in the model (Wang et al., 2020).

In order to simulate the change in emissions using possible future alternative mix projections are calculated. Possible future mix are dependent on the assumption of further deployment of renewable sources such as solar and wind, in greater ratios. Introduction of higher renewable sources allowed the reduction of coal and natural gas use, neglecting the effect of population and energy demand increase in those years.

Jet Fuel Production

Conventional jet fuel WTP steps were given in Figure 5. Emissions related to the steps are calculated using GREET model. The model also regards the emissions related to energy used in refinery. The energy forms used in refinery includes natural gas, unfinished oil, gaseous hydrogen, electricity, butane, naphtha and crude oil. Emissions related to the recovery and transportation of these energy forms are also included in the model (Wang et al., 2020).

WTP Analysis Using The GREET Model

The simulation year for upstream energy mixes and emissions for all fuel production pathways was selected as 2019. Emission values for each energy type and pathways are calculated by the GREET tool. We assumed that the electricity used is sourced from the current average European grid generation mix. Since the electricity source plays a critical role in determining the environmental profile of energy used in aviation, alternative mix ratios for possible future scenarios are also studied in this paper. In order to give an overview of changes of emission values by introducing further renewable energy sources in the mix, hypothetical future mix values for 2030 and 2050 are introduced.

Results and Discussion

WTP Fossil Energy Use and GHG Emission Results

Table 4. shows the GHG emissions for the WTP of 1 MJ of electric energy transmitted up to airport in order to use charging the aircraft battery. Electricity transmission efficiency for Europe is taken as 93.56% in the model. The emissions related to transmission and distribution in Europe is calculated by the GREET model is also included in the results.

Table 4. WTP emissions of European electricity mix at wall output per 1MJ of electricity

Emissions	
CO_2 Total (g)	89.53
VOC (mg)	12.54
CO (g)	120
NOx (mg)	78.2
PM10 (mg)	49.09
PM2.5 (mg)	15.93
SOx (mg)	170
GHGs (g)	95.05
POC (mg)	4.49

Table 5. shows the WTP GHG emissions for recovery, refining, transport and storage of 1 MJ of jet fuel up to the airport. The WTP GHG emissions of the fuel energy is nearly one ninth of the emissions related to electricity. As the thermodynamic processes of electric production is performed earlier in the upstream of energy, WTP emission results of jet fuel seem cleaner compared to electric energy. On the other hand, the PTW emissions including the burning of jet fuel in aircraft engine is not included in the results.

Table 5. WTP Emissions of 2019 figures for 1 MJ of Conventional Jet Fuel

Emissions	
CO_2 Total (g)	8.41
VOC (mg)	6.61
CO (mg)	0.01
NOx (mg)	19.74
PM10 (mg)	1.12
PM2.5 (mg)	0.94
SOx (mg)	6.01
GHGs (g)	11.23
POC (mg)	0.29

In a combined flight phase, aircraft emissions depend on several parameters such as take-off weight, engine model and age, flight range, environment temperature, elevation, etc. The relative amount of exhaust emissions produced by engine, depends upon combustor temperature and pressure, fuel to air ratio values and the extent to which fuel is atomized and mixed with inlet air, which also depends on flight phase related conditions of the aircraft.

ICAO provided a databank which can be used for simplified approximation of jet fuel and related emissions with specific values of aircraft and engine types (ICAO, 2011). Using this databank, an example aircraft of Boeing 737 with CFM56-7B engine emission values is used. For the takeoff of the said aircraft type, duration is given as 42 seconds and at a fuel flow rate of 1.154 kg/s which totals 48.468 kg of jet fuel. Using lower calorific value of 42.8 MJ/kg, the spent fuel for the takeoff is found to be around 1.132 MJ. The emissions related to takeoff phase of the aircraft for 1 MJ of fuel burnt are calculated as 1.32 kg NOx/MJ and 8.56 g CO/MJ. As it can be seen, NOx emission well passes the value of electricity when added to fuel emission, but CO emission of fuel added to the takeoff value still stays well below the electricity CO emission. Again, the values calculated here are for only takeoff settings of engines. During cruise and other phases, specific emissions differs and need to be calculated accordingly. As the aim of this paper is to discuss the possible emission factors using hybrid electric propulsion in aircraft, flight phases are not included. The simplified calculation given here is for having a general idea and do not resemble the whole flight cycle.

Impact of electricity generation mix on WTP energy use and emissions

It can be seen that the GHG emissions related to WTP electricity production and transmission is around 9 times higher than the emissions related to WTP fuel emissions. We have conducted a what-if analyze using a hypothetical future projection for electricity production mix for Europe for 2030 and 2050. The mix ratios are given in *Table 6.*

Table 6. Projected future electricity production mix shares

Electricity generation power source	**mix share (2019)**	**mix share (2030)**	**mix share (2050)**
Oil fired	0.10%	0.10%	0.10%
Coal-fired	21.50%	16.50%	11.50%
Natural Gas-fired	20.50%	17.50%	10.50%
Nuclear	26.60%	20.10%	16.60%
Biomass	6.30%	6.30%	2.30%
Hydroelectric	9.50%	9.50%	9.50%
Wind	15.50%	30.00%	45.50%
Solar	0.00%	0.00%	4.00%

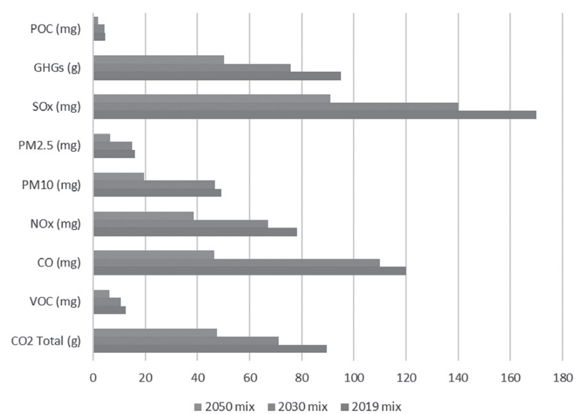
The hypothetical approach depends on the main idea of introducing more renewable sources in electricity production, while reducing the ratio of coal and biomass sources. Here it is assumed that in 2030 wind power generation will prevail all others while coal, biomass, natural gas and nuclear sources are reduced. In 2050, it is assumed that the coal fired, natural gas fired and biomass production will be nearly halved compared to 2019 and wind power source is tripled, with an introduction of solar energy supply with a share of 4%. The emissions related to these shares are given in *Table 7.*

Table 7. Emissions of electricity production depending on projected mix values

Emissions	2019 mix	2030 mix	2050 mix
CO_2 Total (g)	89.53	71.18	47.38
VOC (mg)	12.54	10.65	6.17
CO (mg)	120	110	46.28
NOx (mg)	78.2	66.97	38.65
PM10 (mg)	49.09	46.81	19.66
PM2.5 (mg)	15.93	14.97	6.59
SOx (mg)	170	140	90.83
GHGs (g)	95.05	75.75	50.18
POC (mg)	4.49	4.34	1.76

It can be seen that the emission related to WTP electricity can be significantly reduced with the introduction of renewable sources. Bearing in mind that the figures still inclusive of transmission losses and emissions related to that. In case the renewable energy is produced in site such as in the example of Honolulu airport, the efficiency loss of the transmission will be omitted thus the emissions will be further reduced. The comparison of the emissions are given in *Figure 5.*

Figure 5. WTP GHG emissions of electricity according to mix values



It can be seen that the WTP emission values of electricity nearly halved by using more renewable energy sources in production. More reductions can be seen on CO and PM10, while VOC and CO2 emission could not be reduced in parallel, at the same rate.

Conclusion

Aviation, being one of the main transportation and economical driver of current lifestyle, is responsible for an important ratio of the anthropogenic emissions. This paper compared the WTP energy use and emissions of the electricity and conventional jet fuel supply to airport. The WTP results show that average emissions related to electricity is nearly 9 timed higher than the WTP emissions of conventional jet fuel. The WTP results are sensitive to the source of power used to generate electricity. With introduction of more renewable energy sources in the mix, an average reduction in emissions is gained at a rate of around 50%. It can be concluded that turning from only fuel flight to electric-fuel hybrid is not a promising change in practical means of eliminating the environmental effects of aviation in a radical order. In order to benefit from the fuel-electric hybrid on especially mid-range aircraft, electric energy production using fossil fuel and transmission inefficiencies have to be eliminated. The solution to this problem seems to have the capability to produce electric energy just-in-place, for example, as in our case, at the airport. The possible use of solar panels on top of the airport rooftop. With such installation and production capability, inefficiencies and emissions resulted from production and transmission will also be eliminated. In addition to this, the electrification of airports and ground support equipment would also benefit in case of the application of the said method.

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MELIH YILDIZ *–SAVAŞ MUTLU **–UTKU KALE ***–ANDRÁS NAGY ****

Environmental and Economic Analysis of Emission Reduction Strategies for Airport Ground Operations: A Case Study of Esenboga International Airport

Abstract: Aviation is a system of systems whose success depends on the performance of each sub-system. Concerns on environmental protection makes the aviation industry focus on reduction in emissions produced during operation. Although aircraft emissions are widely discussed in the literature, ground handling systems which are an integral part of the whole aviation system also need to be studied regarding the environmental issues. Besides, EU has set out targets of reducing emissions at the airports during ground operations to zero. Ground handling is performed by using Ground Service Equipment (GSE) which is historically powered by diesel and such internal combustion engines. The emissions of these types of engines are well known for their high emission rates. As the airports reside in or near the populated areas as cities, GSE emissions need to be evaluated for reduction. For reducing emissions of GSE, electric energy is thought of as an alternative. It is shown that the emissions of electricity production are high, which causes it to decide further on the electric energy use by environmental reasons. This paper evaluates the hypothetical situation; in a resembling airport of Esenboğa Airport and analyses the condition of all GSE equipment to be supplied by electricity produced by solar panels mounted on the rooftop of the terminal building. The case is discussed by means of environmental emissions and economic feasibility. It is concluded in this research that installation of solar panels on the airport in order to energize the electrical GSE, offers the operators not only environmentally but also an economically feasible way of operation. The results of the resembling case can be generalized to all airports for the reduction of emissions caused by ground operations of the aviation.

Keywords: Airport emissions; sustainable aviation services; renewable energy infrastructure.

* *Girne University, Faculty of Aviation and Space Sciences E-mail: melih.yildiz@kyrenia.edu.tr*

** *Atilim University, School of Civil Aviation Ankara*
E-mail:savas.mutlu@atilim.edu.tr

*** *Budapest University of Technology and Economics Department of Aeronautics, Naval Architecture and Railway Vehicles Budapest*
E-mail: ukale@vrht.bme.hu

**** *University of Dunaújváros, Department of Mechanical Engineering*
E-mail: nagy.andras@uniduna.hu

Introduction

The aviation sector has a constant growth rate for years. Ground handling is an important part of the aviation sector hence growing in parallel to increasing demand. The equipment used to provide service to the aircraft and passengers at the airport is called Ground Support Equipment (GSE). Historically the GSEs are powered by diesel engines which are well known for their high levels of hazardous emissions. With increasing interest in environmental protection and high oil prices, electric propulsion is getting more and more important. There are several projects all over the world in order to convert conventional GSE to electrical ones (i.e.eGSE).

Regulations are also limiting the use of diesel engine GSE in closed areas such as under the terminal building. The use of eGSE is started to get interested although its higher initial cost, in order to comply with this regulation. There are several pros and cons about the eGSE compared to its diesel counterparts.

In this paper emissions and their effects are briefly explained. A survey on globally possible actions in order to reduce the emissions is provided. Detailed information about Esenboğa Airport and the GSE park of one ground handling company is given in the following section. Using real data collected by the ground handling company in Esenboğa Airport, the total CO_2 emission of the GSE park is calculated on monthly basis. Then a what-if analysis is provided for totally electrical eGSE park. The emissions of the electric and diesel are compared, afterward, the possibility of providing all-electric energy via solar panels which to be placed on representative Esenboğa Airport Terminal building rooftop is discussed.

It has been seen that the indirect emissions of electric GSE depend on the electric production emissions of the country. Besides the electric production, the transfer of energy is also causing emissions which makes the indirect emission figures higher. It is the aim of this paper to investigate the possibility of providing electric energy needed by GSE as much as possible by a sustainable source that is closer to the airport and also enough for seasonal GSE activity fluctuations.

Also, the growing interest in solar electricity production at airports (Sreenath et.al, 2020: 698) led to the investigation of the opportunity to use solar PV to recharge eGSE.

Emissions Produced in GSE Operation

Emissions are produced as a byproduct of fuel burn in internal combustion engines. These are Sulphur oxides (SOx), nitrogen oxides (NOx), carbon monoxide (CO), and particle matters (PM) which are known to be harmful to human health (Winther et al., 2015).

An ICE engine can convert 15 cubic meters of air which is needed for one day of breathing for humans, into a harmful state in only 10 minutes (Marangoz, 2004). Emissions of ICE have been determined to cause a large variety of diseases such as asthma, cancer, diabetics (Stettler, Eastham and Barrett, 2011).

An environmental perspective, emissions from combustion engines also cause global warming by its greenhouse effect. Global warming in turn cause the polar ice to melt and raise the sea level. This is one of the main reasons for the change of seasons which affects human health by means of water resources, agriculture, and food availability (Çelik and Toprak, 2016, Soruşbay 2003).

All aviation-related activities are responsible for 2% of human-produced emissions and 12% of transport-based CO_2 production (IATA, 2013). Airport operations have a share of 5% CO_2 emission among the aviation emissions (Stimac at.al., 2013). On the other hand, it is suspected that aviation operations are related to around 10.000 premature birth per year (Stettler et al., 2011).

GSE emissions take a major part in aviation emissions. Analyses of GSE propulsion system emissions show that these systems have the same emission characteristics as automobiles (Winther et.al, 2015).

A comprehensive study performed on Copenhagen airport including hourly measurement of fuel consumption showed that the GSE consumes 2% of the fuel consumed in all airport operations and 24% of all airside consumptions. Also, the study showed that the NOx and PM emissions of the GSE are a couple of times the APU and aircraft engine emissions. As an example, at the early hours of the day, GSE produces 3.2 kg NOx per hour compared to 1.2 kg produced by APUs and 0.5 kg NOx produced by the aircraft engines. On the PM side, APUs produce approximately 50 gr/hour PM besides, GSE can produce as high as 200 gr/hour PM. In the light of these figures, it can be seen that the GSE can be a more polluting factor compared to APUs and aircraft engines (Winther et al., 2015).

There are some legal mechanisms in order to courage the use of electric GSE at airports. Those are green airport certificates, limitations for use of ICE GSE on some parts of the airport, etc. Currently, there are 35 airports in Turkey which are certificated as “green airport” (SHGM, 2019).

Emission Control Strategies in the Sector

According to EPA report (EPA, 1999) there are some control strategies to reduce the emissions of GSE in both the long and short term. They can be summarized as follows;

– The development of standard requesting low emission for combustion engines used in GSEs.
– Use of LPG or CNG type engines instead of diesel and gasoline type engines in GSE.
– Use of electric power instead of combustion engines.
– Use of bridge-connected systems instead of GSE.
– Installing filters, catalytic converters, and particulate traps for combustion engines.
– Replacement of two stoke engines with four-stroke engines.

This paper concentrates on the replacement of electric power use instead of combustion engines for GSE. The selection of a suitable strategy depends on the GSE usage characteristic per each case. Both the feasibility and cost-effectiveness of emission reduction strategies should be considered.

There are also strategies to replace combustion engines with electric motor and battery systems (Delta, 2013; AA, 2011) and fuel cell energy conversion and electric motor integrated systems. One example is a demonstration project performed by Charlatte company by using 15 electrical tug at Memphis/USA Airport which were used by FedEx, in real loading conditions. The demonstration showed that the system is capable of extreme environmental conditions and even for high load requirements (Petrecky, 2014).

Some companies offer using of tug system during aircraft taxi, in order to reduce Auxiliary Power Unit (APU) and aircraft engine used in airports. By reducing the APU and engine use during taxi, it is reported that a fuel consumption worth 7.3 billion USD and 23 million tons of CO_2 emission would be saved per year. This offer also can be a reduction strategy for aircraft Foreign Object Damage (FOD) that can occur during taxi which is reported as 700 million USD in magnitude yearly (Decoux, 2015). Electrification of baggage tractors can help most with this emission reduction strategy as their utilization is the highest among all the GSE fleets.

Although the industry reports LNG/CNG/Gas power systems are not viable solutions for emission reduction (Decoux, 2015), it is still an alternative and being used at airports (EPA, 1999). Decoux also reports that some applications of tow tractors with hybrid power systems are not found to be cost-effective.

General Information About Esenboğa Airport

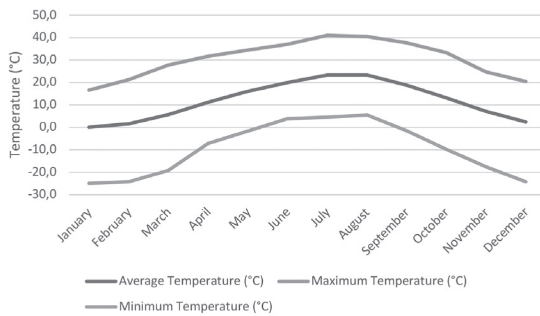
Esenboğa International Airport (ICAO Code is LTAC, and IATA Code is ESB) is located in Ankara, the capital city of the Turkish Republic. Altitude is 952 meters (3125 feet). The terminal area is 182,000 square-meter. International and domestic terminals have a 10 Million passengers per year capacity. Two runways (3400 mt. and 3750 mt.), taxiways (Total 4320 mt), and seven aprons are available (www.esenboga.dhmi.gov.tr). There are three A-type ground handling companies operate in Esenboğa which are Çelebi, Havaş, and TGS.

Esenboğa Airport aerial view is presented in Figure 1. The total area of the airport is 10.7 sq km.

Figure 1. General view of Esenboğa Airport

Monthly climate conditions at Esenboğa Airport vary from hot (41 °C maximum) in summer and cold (-24.9 °C minimum) in the winter time. The yearly temperature variation is shown in *Figure 2.* with an average between the years 1927 and 2019 (MGM 2020). As it can be seen, there can be a temperature difference of around 60 °C between winter minimum and summer maximum. The average temperature variation is 24 °C between summer and winter. The GSE equipment and personnel are expected to work under extreme environmental conditions.

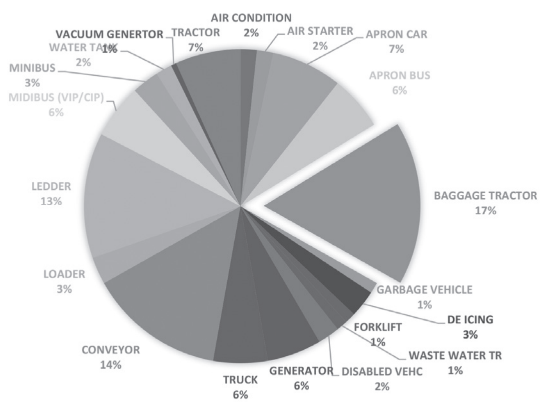
Figure 2. Temperature variations throughout year at Esenboğa Airport (1927-2019)



Monthly Energy Consumption of GSE at Esenboğa

TGS has a fleet of 178 GSE, 21 of them are electric and 157 of them are ICE powered. The general distribution of the fleet according to powertrain type is given in *Figure 3*. It is reported that the 21 pieces of electric GSE consumed a total of 867,068 kWh electric energy in 2018. On the other hand, the ICE-powered GSE fleet used a total of 735,715.17 liters of diesel in 2018. All of the GSE listed in the fleet can be converted and be used as electric-powered GSE (eGSE).

Figure 3. Fleet distribution of ground handling company at Esenboğa Airport



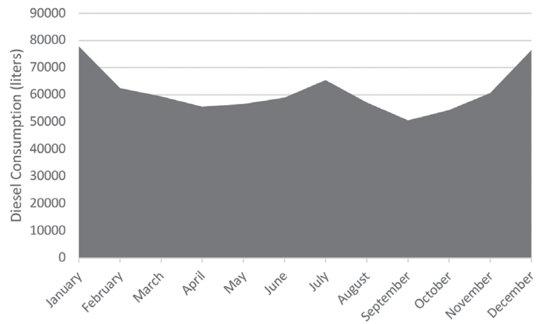
The relative energy content of 1 liter of diesel can be assumed as 35.86 MJ which is approximately 10 kWh. With the assumption of average thermal efficiency of 32% of diesel engines, the overall average energy of consumed diesel oil by GSE can be calculated as 2,354,288.54 kWh equivalent. Monthly equivalent electric energy demand for the GSE fleet using the diesel usage data of 2018 given in *Table 1*.

Table 1. Monthly diesel consumption in 2018 and equivalent electric energy requirement

Month	Diesel Consumption (liters)	Equivalent Electric Energy (kWh)
January	77835.23	249,073
February	62491.18	199,972
March	59378.66	190,012
April	55645.3	178,065
May	56594.76	181,103
June	59018	188,858
July	65431.46	209,381
August	57171.33	182,948
September	50598.28	161,914
October	54393.96	174,061
November	60726.75	194,326
December	76430.26	244,577
TOTAL	735715.17	2,354,290

Table 1. data is given in graph in *Figure 4.* that interpret the demand is not stable during the whole year. There is a high season which can be seen as a peak in July where air traffic is higher. The values also pitch up for the winter season which starts around November and lasts up to March for Ankara when the diesel expenditure gets higher. Taking into account the data given in *Figure 2.* it can be estimated that the higher figures for December and January can relate to cold weather by means of fuel spent for the engine and personnel heating.

Figure 4. Monthly diesel consumption for 2018



Emissions of GSE

In the literature, several studies show a high correlation with the model developed by ICAO. The models for calculating the emission of GSE is provided by ICAO (ICAO, 2011) is as follows:

$$\text{Emission-Y(g/GSE)} = \text{Fuel (Year kg.)} \times \text{Emission Factor-Y (g/kg.fuel)} \times \text{DF} \quad (1)$$

Where DF = Deterioration Factor. As the GSE park of TGS consist of various GSE of various age, all GSE are assumed to be new hence deterioration factor is taken as 1. Using the emission factors, the emissions are calculated per pollutant and are given in *Table 2.*

Table 2. Emission factors of pollutants and calculated emission figures for 2018

Pollutant	Factor (g/kg)	Average total emission (tons)
NO_x	48.2	29.50
HC	10.5	6.43
CO	15.8	9.67
PM	5.7	3.49
CO_2	3150	1,928.16

Solar Energy (Photovoltaic-PV) Electricity Production

With the advances in technology, mankind is more interested in producing energy from renewable sources. Wind, sea waves, and sun are some of those types of resources. Sun is an important heat source for the earth for billions of years and people now are trying to use its energy in electricity form.

One way of doing this is using cells that convert sunlight into electricity and called "Photovoltaic" or PV in short. In this way, solar cells are composed of semiconducting layers (and when sunlight hits the surface of those cells, electric fields across the layers start the electricity to flow (Tyagi et. al, 2013: 443).

According to Kim (2020:1), in the USA during the last ten years, 20% of public airports started to use solar PV. One of the biggest reasons for that is the energy cost saving in the long run.

The aviation industry is blamed for greenhouse gas emissions and within that context, airports are trying to decrease their carbon footprint. One way of doing that is using renewable and clean energy resources instead of conventional ones (Sukumaran and Sudhakar, 2017: 309).

Monthly Electric Production Capability with the Terminal Rooftop Installed Solar Panels

The rooftop area of the airport terminal building is given in *Figure 5*. The total area of the roof of the terminal building is 27,662 sqm. In this research, although the suitable area of the airport is much bigger, the only terminal building is preferred in order to save the energy transfer investment costs and emissions. Also, most of the field area is used for landing instrument installations. Another reason for offering the terminal building roof is to visualize the order of electric production in such a limited area. It can also be postulated that the bigger the area of the terminal building, the higher the electricity need in that airport.

Figure 5. Esenboğa Airport Terminal Rooftop Area

In addition to the advantage of eliminating emissions generated by the electricity production, the transfer cost and emissions related to the transfer will also be minimized by installing solar panels over the roof of the terminal building, as the electric production will be in the vicinity of the consumption.

Photovoltaic panel efficiencies vary depending on production technology. A research performed in Düzce, Turkey (Nearly 200 kilometers North-West of Ankara) showed that mono-crystalline PV panels' performance ratio is highest (i.e. 91%), followed by polycrystalline (81%) and amorphous silicon (a-Si) (%73) (Elibol et.al., 2017: 651-661). So, it is recommended to use mono-crystalline PV panels in real-life applications in the Ankara region.

The solar energy that can be harvested by solar panels can be defined as;

$$\text{PV capacity (kWh)} = \text{Area (m2)} \times \text{average standard irradiance (kWh/m2/day)} \times \text{days} \times \text{Efficiency} \quad (2)$$

Ankara has a high solar energy potential (Çağlar et.al., 2013; Yeşilbudak et.al., 2018). The solar energy potential of Ankara is given in Table 3. Using the data provided by Çağlar et.al., the monthly global radiation value is calculated in kWh, using the average figure and multiplying it with the number of days of that month. Then using an average solar panel efficiency of 14%, the energy potential of PV panel installation of 27,000 sqm on the Esenboğa Airport Terminal Building is calculated using (2). The results of the calculation are listed in *Table 3.*

Table 3. Solar radiation converted to monthly radiation and calculated monthly electric production potential

Month	Monthly average global radiation ($MJ/m^2/day$)	Monthly global radiation (kWh/m^2)	Roof installation electricity production (kWh)
January	6.28	54.08	204,414
February	9.61	74.74	282,534
March	13.57	116.85	441,704
April	17.30	144.17	544,950
May	21.86	188.24	711,543
June	24.25	202.08	763,875
July	24.91	214.50	810,821
August	21.92	188.76	713,496
September	17.62	146.83	555,030
October	12.13	104.45	394,832
November	7.64	63.67	240,660
December	5.45	46.93	177,398

Daily radiation variations which will also cause variations of electric energy production can be compensated via batteries that can be installed in the stations or the airport building. On the other hand, it is known that aircraft movements are decreased during night time which also reduces the need for GSE utilization.

Electricity Production Mix

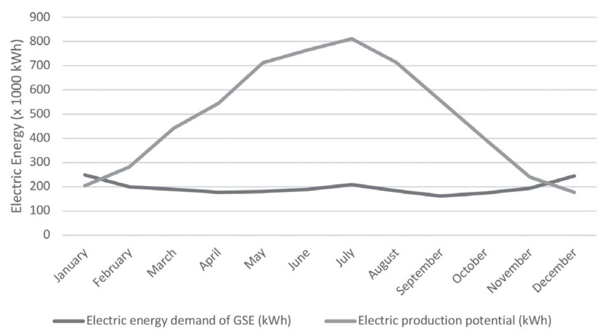
Value for kg CO_2 per kWh of electricity generated for Turkey is given in the literature. The values vary depending on calculation methods. The value presented by the electric production authority of Turkey is used which is 0.67 kg CO_2/kWh for 2012 (EUAS, 2017). It is assumed the value given is not changed in 6 years. With this assumption, the total CO_2 emission to produce 2,354,290 kWh will be around 1,577,374.30

kg. Thus, it can be accepted that, by installing solar panels, this will be the amount of CO_2 saved per year. The figure is calculated by multiplying the 0.67 kg CO_2/kWh with the total electric energy demand calculated in Table 1. The figure given is exclusive of emissions related to transmission. Without the use of a sustainable energy source, the amount of CO_2 emission calculated here (1,577,374.30 kg) will be produced in the vicinity of the electric energy production plant.

Results and Discussion

The comparison of the electric energy requirement of GSE given in *Table 2.* and electric energy production potential of installed PV over terminal roof given in *Table 3.* are compared in Figure 6. It can be seen that the low radiation months of January and December fall short against demand but fits very well for the demand for the rest of the year.

Figure 6. Comparison of monthly electric energy demand and production potential at Esenboğa Airport



It can be also said that January and December are cold months and some of the energy spent for heating the diesel engine, which in the case of electric conversion, can be assumed to be required in a lesser amount. Another solution for the shortage can be overcome by storing the electric energy during high solar times and spending at high demand periods.

Solar panel installation in the vicinity of the consumption may also pave the way to investigate the possibility of using tethered GSE which also removes the need for an on-board battery. The removal of the on-board battery would nearly halve the cost of the GSE, which would also make the electric use in ground handling preferable by means of cost reduction.

Airport operators and ground handling companies are different entities. Therefore, in order to achieve renewable energy production and usage in relevant areas of the airport needs close collaboration between them. In order to achieve this collaborative approach towards environmentally friendly airports, regulatory institutions shall take the required steps.

It can also be estimated that the surge electric energy for high radiation months can also be consumed at other parts of the airport.

Economic Assessment

According to Kırıkkale 1st Organized Industry Region Solar Power Production Feasibility Report (Kırıkkale, 2019: 26–27), an investment of 12,171,945 US $ is necessary for the installation of 20,216,693 kWh/year capacity solar electric production facility. Esenboğa Airport is 54 kilometers away from that region and the same solar conditions are valid here. Using this figure, the calculation for installation of 5,841,257 kWh/year solar electric production facility, an investment of 3,516,868 US $ is needed. With the economic life duration of photovoltaic panels as 25 years (Kırıkkale, 2019), the annual investment cost is calculated 140,674 US $/year.

In Turkey, 1 kWh electricity is 0.5827 TL/kWh which is equal to 0,074 US $/kWh currently. Assuming all economic conditions are stable for 25 years, the cost of buying 5,841,257 kWh from the network for each year is 432,253 US $/year. The resulting reduction in energy cost is two-third which is approximately equal to 70% cost saving per year, for a period of 25 years.

Conclusion

In this study, the possibility of using solar energy for the charging of electrical Ground Support Equipment (eGSE) in Esenboğa Airport is investigated. Solar radiation data collected by experimental research is used to calculate the solar energy potential. Diesel consumption of the fleet provided by the Ankara station of the largest ground service company is used. Monthly consumption data converted into equivalent electric energy. The results compared with solar energy production potential. According to results, solar energy production falls short of the requirement only in December and January which have the lowest and shortest radiation of the year. As seen from the comparison, powering eGSEs with solar energy, provides important reductions in hazardous emissions. In our representative case study a CO_2 reduction of around 1,500 tons per year.

It is also important to note that producing the electric energy on the site where it is also consumed eliminates electric energy transfer costs and emissions. This production-on-site method is only possible with the collaboration of civil aviation authority, airport terminal operator, and ground support service provider. These are three separate entities and need a means of the collaboration platform. In addition to this, a legislative structure may be needed with the inclusion of energy administrations.

Another important point to note is that a new approach of energy transfer or storage can be discussed for the GSE would be possible if such a production infrastructure can be established. Such as tethered GSE or other means of energy transfer from ground to GSE would make higher cost savings. This approach is immediately possible for preferring cables instead of using diesel generators. The generators mentioned are consuming over one-tenth of all diesel. They are easy to convert to cables only and would reduce over one-tenth of all CO2 emissions.

In economic terms, an investment of 12,171,945 US $ for the installation of solar panels for electricity production that would be used a total return on the monthly savings of electric cost will be 291,579 US $ and at the end of the 25-year period, the sum of the savings will be 7,289,475 US $. This economic saving will accompany the environmental saving of 50,000 tons of CO_2 emission at the end of the 25-year period. The figures conclude that the investment will be feasible by means of both economic and environmental aspects.

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MARIA PAPANIKOU *–UKTU KALE **–ANDRÁS NAGY ***
–KONSTANTINOS STAMOULIS ****

Macrocognition for Predaredness in aviation: An opinion paper

Abstract: The current opinion paper discusses key technological developments both in aviation and lays out the potential for foresight under a systemic macrocognitive view. The proposed approach is aimed to address the changing aviation context, the organisational cognition and knowledge structures for safe preparedness in information-driven environments. Following the key tenets of the systemic paradigm and of naturalistic decision making, we posit the added value of macrocognitive studies able to understand the shifts in tacit and explicit knowledge. Deep understanding of transitions can aid capturing the prerequisites for the safe prepardeness of aviation organisations and their members. A systemic mapping is presented with the inclusion of different levels of analysis in contrast to cognition being studied in a confined problem space. Macrocognitive studies proposed should complement microcognitive analyses.
Keywords: Macrocognition; systemic approach; aviation safety; foresight.

* *Amsterdam University of Applied Sciences, Faculty of Technology, Aviation Academy*
E-mail: m.papanikou@hva.nl

** *Budapest University of Technology and Economics, Department of Aeronautics, Naval Architecture and Railway Vehicles*
E-mail: ukale@vrht.bme.hu

*** *University of Dunaújváros, Department of Mechanical Engineering*
E-mail: nagy.andras@uniduna.hu

**** *Amsterdam University of Applied Sciences, Faculty of Technology, Aviation Academy*
E-mail: k.stamoulis@hva.nl

Introduction

Innovation is a driver for transitions and change management. Past transitions have aided aviation reach an advanced knowledge over safety risks, creating foresight. During the last decade organisations adjust or transit in a much greater digitalised way of doings things, signifying a major transition. Industry 4.0., commonly referred to as the 4th industrial revolution reflects the shift to even more advanced technologies and 'smart' industries (e.g., digital manufacturing). This shift comes with drivers and barriers at the management level (e.g., strategy and resource management), and at the workforce level (e.g., lack of qualification, knowledge, understanding of interfaces, employee readiness) (Stentoft et al., 2020). Neumann et al., (2021) find that the focus so far has been brief mentions of on organisational factors. This context requires a better understanding of such transitions. For example, now, as in other contexts (Ferrari et al., 2020), human – data interactions (HDI) and over-reliance on machine-related information (McDonnell et al., 2018; Victorelli et al., 2020) become of seminal importance to the aviation domain. Furthermore, Ton et al., (2020) report that in prognostics there is little expert knowledge on application-specific aspects such as failure behaviour of components. Studies hence emphasise on the need to understand "the black boxes" in transformation (Sgarbossa et al., 2020) and the situational awareness of decision makers (Giacotto et al., 2021).

Over the decades, and following this focus, advances in technical systems have become so separated from the human that there are documented concerns regarding human related data, and that these are overlooked in industrial advancements (McDonnell et al., 2018). Foresight is hence under question, since the negative transfer of (past) knowledge may endager future safety, as the organisations drift away from learning. Softer approaches of learning, problematizing, including organisations and practitioners (Ison 2008) are confined to strategic levels, and human factors are ignored (Ton et al., 2020). Research (Golightly et al., 2018) reports problems affecting the deployment of new technologies in predictive maintenance due to issues of knowledge gaps and human-machine interface, amongst other higher level organisational factors of strategy and culture. Furthermore, the cultural shift A-CDM undergoes, data management, responsibility allocation and the complexity of the required collaboration (Netto et al., 2020) and communication (Zuniga–Boosten, 2020) need addressing. As a wide range of teams and systems collaborate in this process (e.g., ground handling, air traffic control, aircraft operators) emphasis is placed on the importance of information flow, management, and processing.

Gaps are, therefore, observed in the understanding of higher levels of cognition, within an advanced technological environment, involving hybrid teams, complex and multidisciplinary teams and overloaded users. The organisational 'collective memory' comprises of experiences and tacit rules, aiding the operator to recall the learning from safety issues, protecting it in the future (ESReDA 2020). Due to the emerging interactions amongst users, teams and ultimately of systems, the current paper places the emphasis on the need for systemic considerations, enabled by macrocognition. To this end, this paper proposes a systemic-driven macrocognition framework placing the focus on a greater understanding of macrocognition in an interacting environment.

Macrocognition for prepardeness

Aviation is characterised as a system of systems. Human performance and safety in high-risk industries are emergent behaviours of a domain - a systemic web of interactions between complex systems and their users. Foresight requires deep understanding of contemporary decisions, emergent interactions and complexity that can affect the future (ESReDA, 2020). Systems thinking in aviation, however, is characterised by theoretical pluralism. In particular, different theories assume different "boundaries of analysis" of the aviation system (Richardson–Midgley, 2007). Systemic analysis in aviation follows a legacy of systems engineering thinking, lacking in broader analysis; and the term 'systemic' being commonly confused with systematic or within system approaches that centre on a system of interest. Systems thinking, as such, has been developed according to scientific silos and leads to the underexploring of systemic softer fields in safety and in the impeccable increase of systematic approaches in other ones such as the technological areas.

The literature assumes a static structure of the aviation domain and a confined problem space. The focus remains on latest developments such as those of predictive maintenance, single pilot operations and of collaborative platforms, yet addressing only microcognitive concerns. For this reason, we posit that foresight requires a greater understanding of systems collectively and these to be studied in their natural operational setting. This approach is known as naturalistic decision making (NDM) and addresses macrocognition. Macrocognition is linked to knowledge creation in aviation, as knowledge is the product of schemas, cognitive structures, that precede the transformation of data and information processing (Cacciabue–Hollnagel, 1995, Fiore et al., 2010). The cognitive functions within the macrocognition movement that originated in the 1980s include decision making in natural settings, where pressure and dilemmas prevail, and include situation assessment, planning, adaptation, problem detection and coordination (Klein et al., 2003). This paradigm addresses the background of symptoms such as inattention and lack of situational awareness. We posit that this paradigm is of importance in advanced technologies that pose the emphasis on a different, evolving, set of knowledge, attitudes and skills for systems' users and operators, since it includes developing teams, a highly technological context and thus a broader inclusion of cognitive functions (Klein et al., 2003). Such thicker descriptions can be useful in complex-adaptive systems such as aviation.

We therefore draw on Simon's (1991) conceptualisation of human cognition relating to their information environments and that the human cannot simply choose between fixed alternatives as part of their decision-making process. Within unexplored interactions, schemas – the collective memory – are being developed and information is being processed and interpreted to fit the pattern (Axelrod, 1973). Prior knowledge is hence key here as it activates information processing (Widmayer, 2004). Specifically, these schemas are formulated both by technical – explicit and tacit knowledge (Mortier–Anderson, 2017). The role of macrocognition, therefore, encompasses the broader collective memory and information processing of the aviation systems required for foresight.

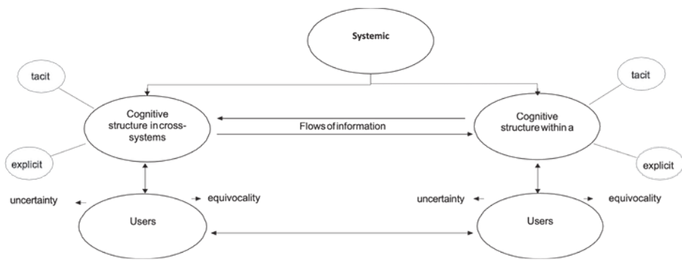
Systems are hence characterised as information processing machines, also researched as decision-making systems and communication systems (Egelhoff 1991), with emergent macrocognitive structures. The system's evolving knowledge leads to its schemas and cognitive structures, a collective memory and ultimately performance (Obrenovic et al., 2015). The advanced systems in aviation, within and between organisations and their operators/users, have a common ground of relying on a heavy load of information and data, timely responses and reactions that require and promote a nexus of cognitive functions.

These systems also require communication amongst them as they are synergetic in terms of operations and collective in terms of a common goal (safe performance) and these co-comprise the broader aviation system. Their users also share common required characteristics and face problems that underpin the technological advancements. For example, as it has been mentioned, cockpit operators – whether these will be on the air and/or on the ground- are going through a change in terms of their knowledge (e.g., from tacit to explicit- reskilling). In addition, A-CDM airports involve multiple users that collaborate, yet are largely unexplored. Finally, predictive maintenance shifts the levels of knowledge and practice to real time monitoring and prediction methodologies requiring a different set of skills and knowledge, and thus creating a new cognitive structure. All these systems will also transform organisationally. Knowledge however comes from the organisations and as they become data-driven, explicit knowledge will have an effect on information processing. Such examples illustrate the complexity and adaptation required to aid foresight. With the current focus on the interactions between the human (operators, users) and the automation/new technology, the analysis is being stripped of context. Attempts to merely control the system will create new interactions and implications, which initially require understanding.

Mapping of systemic macrocognition

Aiming to address the underexplored areas comprising of high change scenarios we propose a broader analysis presented in the concept mapping *(Figure 1)*. Because complex systems involve nonlinearity and a dynamic space, the conceptual model is intended as an initial guide for systemic considerations of macrocognition. Following the systemic approach, Figure 1 maps systems at an interconnected level of analysis, considering users within a broader nexus of cognitive structures and functions. To showcase the interconnectedness the mapping's arrows are iterative, as the evolving cognitive structures feedback and feedforward due to their interacting nature as explained. The double-sided arrows indicate these interactions amongst cognitive structures, the transfers of information, as well as the dynamic relationship between top-down and bottom-up approaches. Specifically, higher levels of cognitive structure indicate the evolvement of the organisational long-term cognitive structure, comprising of both the evolving explicit and tacit knowledge. The flows of information, and the results of interactions between and within organisational teams, affect the cognitive structures. The flow between systems, and within a system as an organisation of processes, resources and assets, are important for inter-domain teams, systemic relationships and flows of information.

Figure 1. Concept mapping of the systemic macrocognition architecture (developed by authors)



At a theoretical level, there are implications for lack of multidisciplinary and interdisciplinary research and the communication and engagement of a variety of fields. In order to understand the emergent behaviour of the aviation domain following change, in particular what the implications might be for safety, the analysis needs to include knowledge of what drives this change – i.e., it is the result of which interaction – and how this change is affecting current or creating new interactions. Safety and human factors are, however, currently approached as a control problem, following the reductionist path of system decomposition. By doing so, a static equilibrium is created, a static problem space of the observer (Asbhy 1961).This tradition of the aviation cognitive studying now has implications for knowledge gaps and knowledge transfer, and hence prepardeness and foresight.

Aviation holds a mix of explicit and tacit knowledge. Manuals, training files, performance documentation and data management involve explicit knowledge, and skills, experience, etc. tacit knowledge. Hence parts of aviation's knowledge are external, and the rest is internalised to the users of its systems. The technological advancements in aviation have implications for both knowledge aspects. On the one hand, it is unclear how new technologies' users will be able to capture the required knowledge, and on the other it is unclear what kind of tacit knowledge is being built and is required so that the new technologies are supported. Despite notions that technology focuses on creating explicit knowledge – and hence relying less on tacit aspects that are less controllable –, the collective information processing within and between systems can affect the individual's information processing and will ultimately create a different set of explicit and tacit knowledge. It is unclear how foresight will be created to support future developments. There is an ample gap of such research in aviation, where high automation, big data technologies and higher levels of information processing are prevailing and further developing. For this reason, the current paper proposes that microcognitive studies are supported by the inclusion of a systemic, emerging macrocognitive perspective. Since highly advanced technological systems create greater information load amongst users of different systems that collaborate, the naturalistic decision-making focus of macrocognitive is proposed. For this reason, the systems that include those users are conceptualised as cognitive structures driving information processing and affecting the capacity of the users.

The mapping hence shows that the systemic view can be applied to understand within and across systems interactions, as for example would be required in a A-CDM approach where multiple stakeholders collaborate. The analysis can, in addition, focus on the organisational level – alone or in combination with other analyses-. For the intraorganizational analysis, certain methods can be of use and multiple analyses are advised in complex cases. For example, in maintenance, there can be various modes of safety management (early adaptation to lack of safety management systems), different resources and lack of readiness (e.g., SMEs, Stentoft et al., 2020), and new implementations (e.g., predictive maintenance). Bottom up and top-down analyses on the integration of old and new maintenance technologies is required. At the management level, aspects of measures, and indicators, as well as intra-organisational processes, policies, and tacit and explicit knowledge can be explored. At the bottom level, skills, knowledge (tacit and explicit), experience, behavioural characteristics) can be targeted. Structural and technological (e.g., data, sensors) aspects can be examined encorporating aspects of work groups and job (re)design.

Despite the advanced technologies, little knowledge is being captured and shared amongst aviation systems. Since advanced information systems and data banks prevail – and will growingly do so-, explicit and tacit knowledge should be explored in relation to cognitive functions. However, boundaries can differ depending on the interaction with other systems (e.g., a weak or strong interaction with systems). In other words, boundaries of system may not only be expanding but also to be shrinking (e.g., human factors). Under this observation, the role of feedback loops should be explored and whether in systemic analysis these can be useful or if these are reverting the analysis back to pairings. Furthermore, it is important that the human capabilities are understood in a) context, i.e., the changing environments and b) in much greater depth, since past changes and their effect are still under analysis and exploration. Before greater, and much more fundamental, changes are introduced, we must better understand the change effects on systems' users and their macrocognition to aid foresight.

Conclusions

This paper discussed why human and organisational factors should be addressed for safety foresight and for the effective deployment of new technologies and structures.The opinion paper argued that a systemic view under macrocognition should be adopted to aid foresight. Macrocognitive studies can explore the knowledge transfers in the changing context. In addition, macrocognitive studies can complement microcognitive studies by producing insights from the dominant information processing models of operators, and revealing areas in need of transformation and intervention. To this end, we proposed a systemic analysis under macrocognition through assessments and interventions that are able to capture shifts and reveal and close gaps in a naturalistic setting. However, some limitations should be noted, such as aspects of organisational and safety culture, and resources may prove as barriers for smaller organisations. Future research should aim to apply novel tools through an open systemic view in settings with different challenges. The macrocognitive profile of users should also be researched and how it can complement microcognitive approaches through mixed methodologies.

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MARIA PAPANIKOU *–UKTU KALE **–ANDRÁS NAGY ***
–KONSTANTINOS STAMOULIS ****

Understanding aviation operators' variability in advanced systems

Abstract:
Purpose
Research has commonly addressed human factors and advanced systems in broad categories according to a group's function (e.g., pilots, air traffic controllers, engineers). Accordingly, pilots and air traffic controllers have been treated as homogeneous groups with a set of characteristics. Currently, critical themes of human performance in light of systems' developments focus the emphasis on quality training for improved situational awareness (SA), decision making, and cognitive load. We posit that to this end a greater understanding of the operators' groups is required.
Design/methodology/approach
Since key solutions center on the increased understanding and preparedness of operators through quality training, we deploy an iterative mixed methodology to reveal generational changes of pilots and air traffic controllers. 46 participants were included in the qualitative instrument and 70 in the quantitative one. Preceding their triangulation, the qualitative data were analysed using NVivo and the quantitative analysis was aided through descriptive statistics.
Findings
The results show that there is a generational gap between old and new generations of operators. Although positive views on advanced systems are being expressed, concerns about cognitive capabilities in the new systems, training and skills gaps, workload and role implications are presented.
Practical implications
The practical implications of this study extend to different profiles of operators that collaborate either directly or indirectly and that are critical to aviation safety. Specific implications are targeted on automation complacency,

* *Amsterdam University of Applied Sciences, Faculty of Technology, Aviation Academy*
E-mail: m.papanikou@hva.nl

** *A2Budapest University of Technology and Economics, Department of Aeronautics, Naval Architecture and Railway Vehicles*
E-mail: ukale@vrht.bme.hu

*** *University of Dunaújváros, Department of Mechanical Engineering*
E-mail: nagy.andras@uniduna.hu

**** *Amsterdam University of Applied Sciences, Faculty of Technology, Aviation Academy*
E-mail: k.stamoulis@hva.nl

bias and managing information load, and training aspects where quality training can be aided by better understanding the occupational transitions under advanced systems.
Originality
In this paper we aimed to understand the changing nature of the operators' profession within the advanced technological context, and the perceptions and performance-shaping factors of pilots and air traffic controllers in order to define the generational changes.
Keywords: Pilots; air traffic controllers; typologies; advanced systems; quality training.

Introduction

During the last decades technological advancements in systems and high use of automation in industries including aviation have characterised the fourth industrial revolution. Despite the positive implications of these advancements in operations and in safety, unintended consequences developed as the role of technology grew. For example, due to the automation changes, concerns were placed on information processing aspects and the functions of the pilots, the computer, and their interface (Parasuraman et al., 2000). In this changing context, quality training in aviation is considered as one of the building blocks for the effective addressing of contemporary issues that affect human performance, and commonly center on situational awareness, decision making and communication, as well as developing skills. For example, developments since the early conceptualisation of airmanship, now emphasise on the reverse of a pilot's profile from "aviate-navigate-communicate (-manage)" to "manage-communicate-(navigate-aviate)" (Mohrmann–Stoop, 2019). Similarly, air traffic controllers (ATCOs) are in transition, whilst they are working simultaneously with old and new systems (Miller et al., 2020). In order to develop appropriate training programmes, the current paper posits that, as the operators' work environment changes, it is seminal to understand the generational changes in their occupations, with the insight of their current perceptions, and the experience that is being built.
Previous research in understanding variability of pilot performance, centered on distinguishing civil from military pilots, and, in civil aviation pilots, it was mainly focused on selection (Damos, 2003), personality profiling (Hörmann–Maschke, 1996) and risk attitudes in order to prevent errors (Makarowski et al., 2016). Personality profiling has also been attempted by distinguishing pilots from other groups outside aviation (e.g., Glicksohn–Naor-Ziv 2016). Other studies aimed to consider institutional factors (e.g., business-government interactions) to categorise pilots in terms of their attitudes to their work (Stensdal 2019). Similarly, ATCO performance has been studied though understanding training success variability by investigating selection procedures (Peneca et al., 2013). Other studies aimed to find differences between ATCOs and maritime navigators (Makara-Studzinska et al., 2020). Within the ATCOs group, there

have been no studies asides the team level performance inquiries (e.g., Mathieu et al., 2009). The role of experience, and the nature of that experience, in operators' performance has received less attention, and in advanced systems it is rather assumed according to hours of experience and age. A few studies, albeit in General Aviation (GA), report insights on experience and performance. For example, it is found that more experienced pilots are less prone to error-induced accidents (Bazargan–Guzhva 2011).

Less studies have, however, investigated and contextualised the role of experience. Specifically, Taylor et al., (2007), engage in the role of age and accumulated expert knowledge and find that older pilots may show lower performance but over time their performance declines less than that of younger pilots due to expertise compensating on the ageing-induced cognitive degradation. Experience in the latter study was accounted as a result of advanced training and extensive engagement in tasks. Similarly, in a group of young (20-25 y/o) pilots, Galand–Golebiewska et al., (2020) find that acquired skills and training were critical in managing the impact of cognitive load, and that greater experience and knowledge of the aircraft lowered their load. However, in another experimental study, more experienced, older pilots showed degradation in their cognitive skills despite their experienced background over the decades (Papanikou et al., 2020). Intra-group research (i.e., within civil aviation operators) has hence generalized amongst hours of experience and ranks in order to address experience levels and performance issues under a physiological and/or a psychological perspective. To this end, a number of tools have been broadly utilised to measure factors affecting operator performance and emphasise on specific training needs. However, quality of training has not been considered before, meaning whether the operators' profiles are understood. The current paper aims to address this gap through exploring possible generational typologies within the change environment of the operators' profession in order to aid the development of quality training.

Operators in advanced systems

Advanced systems in aviation encompass the notion of technological developments in aviation systems such as cockpit/avionics and air traffic control. The increase of such developments is observed since the aviation industry grew post-deregulation, focusing on the increase of cockpit automation to reduce accidents. Under the view that risk and safety are controlled processes, advanced systems were introduced as risk barriers, amongst other reasons, to human error. However, Woods (2010) indicates that the developments in technology hide the complexity of machines, making it appear as simple and results in overconfidence of the operator. Following changes in the cockpit, research (Young et al., 2006) found that the emphasis on automation has a negative effect on the manual flying skills of pilots, while those with greater flying experience were less affected. Pilot experience is highlighted as key for managing automation issues (Wise et al., 2009), however it has not been understood as the pilots' profession has been under change following the introduction of new business models, new training principles, and as automation grew. In addition, little is known about ATCOs, yet the changes in their work systems are fast. Specifically, automation level transitions in air traffic control were addressed in a European project, where the changes in the ATCOs tasks was highlighted (Deep Blue, 2018). In ATCOs skill-based errors are documented as the most prevalent factors in incidents and accidents (Pape, Wiegmann–Shappell 2001). According to Reason (1990) such errors describe a skilled user that performs tasks with little effort and has little conscious attention on the tasks.

Hence, the argument for increased advanced systems, and less need for training, is offset by the fact that new technologies do not require less but more knowledge, as well as more use of operator judgement (Geiselman, 2013, Wise et al., 2009, Woods, 2010). Another study on ATCOs also reports that training, physical fatigue and mental state, monitoring, and the systems themselves, have an effect on their performance (Lyu et al., 2019). Furthermore, advances in air traffic control, has shown that the transition between old and new systems has an impact to stress, vigilance, attention and workload of ATCOs (Deep Blue, 2018). Therefore, the technological changes are affecting operator aspects such as workload, skills and experience. However, there is lack of understanding of operator changes within their occupational group, and their potential typologies to aid the appropriateness and design of training programmes. In this context, international aviation organisations (cf. ICAO, IATA) note their concern about the lack of data from the modified aviation system. Furthermore, the criticality of boredom, albeit not a new concern, and the trust issues of pilots and ATCOs in the new systems, as well as older challenges of automation bias and automation complacency are re-emerging. All the above discussed aspects create a challenging, contemporary profile of operators, with critical distinctions from the earlier generation of airmen and controllers, which are however underexplored. Training programmes are then developed generically, without considerations of changes and the operators' generational gaps. In order to explore this problematic gap, we present a mixed methodology that aimed to greater understand the different generations of operators.

Methods

In order to explore the operators' perceived changes, the study deployed a mixed methods framework of inquiry. Initially, the study deployed civil aviation pilots in two qualitative methods. Using these experts in nominal groups and in semi-structured interviews, the current study helps understand 'work as done'. The current study employed the nominal group technique (NGT), a structured group process used to increase participation and gain consensus on a topic (Van de Ven–Delbecq, 1972). The study included two nominal groups of 23 pilots. Following this, the study deployed 23 civil pilots in semi-structured interviews about their profession, such as training and their role. The sampling strategy was a mixed purposeful one (maximum variance and stratified cases), so that different backgrounds, ranks and experiences were represented in the sample. The data were analysed using the qualitative software NVivo by creating nodes and subnodes from the raw data. Following the analysis of the qualitative data, as an iterative research process, the study then deployed a survey comprising of general demographical questions, five-point Likert-scale questions and two open-ended questions. The Likert scale questions were developed by following the emergent qualitative themes of the operators' role, training, views on automation and advanced systems, their workload shifts, confidence in systems and differences in terms of skills and knowledge. The questions used generic terms and not specific systems as this span across aviation functions, and due to the transition whilst working with old and new systems. The open-ended questions asked participants to report three aspects that are affecting their work, and positive and negative effects of advanced systems on their performance and were analysed through thematic analysis. The convenience sample included 70 operators from various countries, including an even balance between pilots and air traffic controllers. In the following section we initially present the survey findings before we triangulate the Likert-scale data with the qualitative data.

Results

From the 70 administered questionnaires, 69 were completed. The respondents were mainly male, from a variety of nationalities, and their average age was 35 years old. Most pilots were fairly experienced with flying hours spanning between 1000-5000 and between 100-500, or less than 50, whereas a smaller percentage was of pilots with flying experience over 5000 hours. The ATCOs had 15 years of experience in average. The results showcase mixed views on a variety of issues but also consent amongst operators in the cockpit and in air traffic control. Table 1 shows the overall scores for each of the questions of the survey that included questions on perceived role and value of the operators' work, their view on advanced systems, and of those on their knowledge, skills, and training. Most respondents agree that their experience is enough for the operation of current systems, their job is being valued, and that they have gained more knowledge and that their skills improved in the new environment, posing a distinction from past contexts. In addition, most respondents view that they have control over their work outcomes and that their training is appropriate and enough. Most respondents hence appear positive in the technological advancements in their function and work field, as their workload decreased, and the job became easier, and they are fascinated by advanced systems. However, startle events are experienced, and most respondents believe that their role is in transition to more passive monitoring of systems. In contrast to previous responses about their skills, the respondents don't feel they can fully rely on advanced systems to operate as intended and prefer to use a manual control that allows for inputs. Accordingly, most respondents report that there is a generational gap in terms of manual skills of operators. Lastly, despite the decrease in workload, the information load from a variety of sources creates confusion to most of the respondents. Below we present the results from open ended questions, nominal groups and interviews.

Pilots and air traffic controllers' perceptions on advanced systems

The results comprise of three categories of views on advanced systems. The positive views revealed advantages in an operational and procedural manner. Specifically, the benefits focused on error prevention and early identification of failures, access to data and accuracy, standardization, quality of service, cost and time efficiency, and what was characterised as a "hassle free" way of working. The operators work becomes faster and easier, including time of traffic planning and conflict resolution. These benefits are perceived as having a decreasing effect on their workload, stress, and an increase of their mental capacity to address "more important tasks". As seen in Table 2, positive views include that technology is decreasing mechanical failures dramatically and mishandling of avionics. However, the participants viewed that, at the other side of the same coin, this environment is affecting pilots' skills and is making air traffic controllers "lazy" and "relaxed" and when needed their alertness levels are affected. Such negative views reflect the deeper issues such as interactions with the systems. Respondents indicate problems where there is contradictory information, malfunctions and the unpredictability of the systems' behaviour, lack of comprehensive procedures, too much complexity, and unharmonized information. The negative views on technology were supported by the effect on awareness, distractions, confusion, a tunnel vision of scenarios, decreased communication and an increase of workload, stress and mental load when there are failures. Respondents noted there is a lot of reliance on automation and an increase in events such as runway excursions.

Table 1. Descriptive statistics: responses of operator

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
I believe I have enough experience in order to use advanced systems in my work field.	31,90%	55,10%	11,60%	1,40%	0,00%
I believe that due to technological advancements I have more knowledge over my function.	18,80%	55,10%	21,70%	4,30%	0,00%
During my work, I experience events that surprise me.	14,50%	53,60%	17,40%	13,00%	1,40%
I believe I have control over the outcomes of my work.	23,20%	65,20%	10,10%	0,00%	1,40%
I believe that my skills have improved due to technology.	24,60%	43,50%	20,30%	10,10%	1,40%
I believe that my role as an operator is in a transition from active controlling to passive monitoring.	18,80%	26,10%	23,20%	27,50%	4,30%
I feel I can fully rely on the automation in the aircraft/ATM tower to operate as intended.	5,80%	23,20%	24,60%	40,60%	5,80%
I prefer to use a manual control system than relying on automation that requires minimal operator input.	14,50%	27,50%	29,00%	27,50%	1,40%
I believe that the new generation operator's hands-on flying/controlling skills are lacking in comparison to the old generation ones.	20,30%	36,20%	21,70%	20,30%	1,40%
I believe I have appropriate training for the advanced technologies in my field.	13,00%	55,10%	17,40%	10,10%	4,30%
I believe I have enough training to keep up with the advancements in my field.	11,60%	50,70%	17,40%	17,40%	2,90%
I find the technological advancements in my field positive.	23,20%	60,90%	15,90%	0,00%	0,00%
I believe that the technological advancements make my job easier.	20,30%	60,90%	13,00%	5,80%	0,00%
I believe that due to technological advancements my workload has decreased.	20,30%	49,30%	18,80%	10,10%	1,40%
I believe that my workload is decreased by increasing the level of automation, but I receive more information from many sources in the current system which occasionally confuses me.	17,40%	37,70%	30,40%	13,00%	1,40%
I feel that my job is valued.	29,00%	44,90%	13,00%	13,00%	0,00%
I believe that my role has changed over time in a positive manner.	8,70%	36,20%	40,60%	14,50%	0,00%
I am confident that I am able to react fast when things go wrong.	27,50%	65,20%	7,20%	0,00%	0,00%
Advanced systems in my work fascinate me.	29,00%	56,50%	13,00%	1,40%	0,00%

Table 2. Perceptions of operators on the role of advanced systems.

Sub nodes	Data/indicative quotes
Positive	For example, the failure of equipment is less and less important in the way accident chains develop. And the human element of it is taking a large part.
	I can do more operations the same time, conflict predictions can help provide safety, so you can handle more traffic the same time. [It is] time saving, hassle free.
Negative	This results in distraction, increased workload, and a big loss in flexibility. Unless one is very ‚on to it' […] it's actually very easy to end up making a mistake without realizing it. When there is a failure or worse, a partial failure, the workload becomes much higher than it used to be with more basic systems.
	Making the operator lazy and not self-independent. – Even if it's an automatic system, you still need to monitor the process effectively which I can't guarantee all the time.
Mixed	By exactly the same token {automation}, workload increased, and automation can significantly increase confusion.
	Automation saves from small mistakes – daily incidents – but it leads to big accidents. For example, the Air France crash is one of the biggest mistakes that automation causes.

Lastly, mixed views of "technology being good if it helps you" is noted by most operators. In detail, pilots noted that the increased reliance on automation "solved old problems and created new ones" and that technology "appears to be lowering the workload but increases confusion" and it depends on "the normal operations and the abnormal operations division". For example, the operators' role and skills are affected by highly advanced systems, which are presented in the next subsection. However, automation is noted as a medium that "saved {us} from small mistakes and daily incidents", yet the outcomes are conditioned by the operators "manual background, knowledge and experience levels". In addition, respondents note that there may be "faster decision making", but that "this may lead to overconfidence", and that "there is no such thing" as "stall-proof airplanes", meaning that pilots can lose sense of the aircraft's condition and cannot recover from a case of low air speed due to confusion. In that sense respondents noted that the view on advanced systems is "positive but sceptical".

Performance in advanced systems

A positive feedback loop is observed between the operators and the advanced systems, meaning that the changes in systems increase the changes in operators in the way these are already changing (e.g., manual skills deteriorate, advanced system skills improve). Training was linked to lowering costs and to being convenient to operations, compliance to minimums, and learning gaps. Specifically, training is characterised as "of poor quality and incomplete" and "shorter than before", having the "wrong focus" and being "inadequate for advanced systems", and rather "a convenient, blunt tool". For this reason, respondents noted the tendency to do the minimum training needed in order to be legally compliant. Pilots are "trained to legal base minimums", and this approach to training indicates the lower investments in people, since "the organisation itself invests very little in training". Legal minimums hence dictate the training needed without investing in more training that respondents found "not enough".

Table 3. Advanced systems and performance concerns.

Sub nodes	**Data/indicative quotes**
Training gaps	I haven't seen anything new over the last years in terms of training. It (the material) is usually a copy and paste from others.
	some seminars like 'Dangerous Goods' {…} there is too much emphasis here without placing the emphasis on flying.
Skills gap	Pilots today are Airbus kids. I am afraid they don't know what to do if something goes wrong.
	There is a paradoxical system – safety through increased technology and automation washing out the skills, which are needed for safety.
Cognitive capabilities	Their perception of raw data is when the computers are still telling me where to fly and what to fly and what altitude to set and I leave the auto-throttle connected.
	The pilots are startled by it because it is an anomaly. And they tend to over-react on the problem and make things even worse {…} you get too comfortable.
Workload	Automation should reduce workload but actually by exactly the same token, workload increased.
	ATC often give aircraft shortcuts on a standard arrival. This creates unnecessary high workloads in the cockpit. I have found this to be unsafe at times and not every crew member is able to handle it well.
Role of operators	Sometimes, automation makes me less sensitive about the movement of air traffic through radar screen.
	You are the bus driver, but if something goes wrong you are a pilot.

As shown in *Table 3,* respondents characterised their changing roles for pilots as "Airbus kids" and "bus drivers", and for air traffic controllers as "lazy and dependent on systems", "less sensitive about air traffic movements" and the environment creating overall in operators a "overconfidence in the system", adding that there is a "generational gap creating two tempos" in the use of advanced systems. Their "changing role" was hence reported with "low morale", and as "passive workers" due to the "lack of value" in their work. The role of operators is characterised as "decreasing", and that there is "lack of responsibility amongst colleagues". The role of operators changed to monitoring the systems, and that pilots are simultaneously required "to protect the system from failure", and air traffic controllers find it difficult to "use their brains" following "too much reliance on systems". This was characterised as a "paradigm shift", where there is a need to "make operators that save the system". Specifically, pilots are noted as "being in the business of managing the autopilot system {...} reluctant to practice manual flying", becoming "rustier and rustier", and they "end up in a circle", having "no experience in manual flying", as these were "not allowed to be practiced". Furthermore, it is reported that more "confirmation bias" is being developed and that "too many rules and procedures ultimately kill common sense and airmanship", and "loss of analytical thinking". "Old school skills" as the previous generations of operators were characterised, involved "human skills" that are now "lost", leading to a "loss of confidence".

This changing role of operators paired with a "degradation of basic skills", creates different types of workload. Specifically, workload was found to be different instead of being decreasing, and to be conditioned by other factors. For example, as respondents noted "workload has shifted", "it is much higher during failures", and "simple monitoring skills are not effective". For this reason, respondents noted that focus is needed "on specifically what workload it is reduced or minimised". There is hence "workload fluctuation", where load depends on the level of air traffic and flight hours, erratic roster patterns, and extra hours for training, with an emphasis on "more efficient processes". In addition, the respondents reported that advanced systems affect their cognitive capabilities. Specifically, respondents noted that operators "get too comfortable" with automation, their "mental abilities are degraded". For example, one respondent explained that "what you do is you monitor the speed on the approach because the assumption in your brain is that this has always been handled by the auto throttle". The operators find that the increased reliance on systems affects their "situational awareness loop", and that in several cases there is more "head down time" and "serial thinking". Hence when something goes wrong operators stress increase, they are confused and "overreact on the problem", as they "don't know exactly what is hiding behind the screens".

Discussion

The study's results show concerns of high investments on systems whilst training is lagging in light of the operators' changes. These results are in accordance with concerns of inadequate training, and training in automation, producing in the past 26 automation-related accidents[1] (Endsley, 2019) and the latest B737-Max8 crashes. The data paint a picture of deskilled and reskilled operator typologies. These are labelled generically in Table 4. as old generation (OldGen) and new generation (NewGen) operators to reflect their skill change, knowledge gaps, and their work mentality. These changes support suggestions and concerns of a shift in airmanship, as reported by Mohrmann and Stoop (2019). The results show that there are changes that underpin the operators' profession, in terms of their role, skills, mentality, workload, and that these changes bring forward challenges to their performance. The NewGen's observed functional mentality is also critical. Functional mentality implies the need for a reengineering of the operator's role, as the training demands raised will be much more difficult to address in the future.

Table 4. High level typologies of operators and their characteristics.

Higher level typologies	**Characteristics**
OldGen	Experience and skills- manual
	Knowledge of systems
	Old mentality- low acceptability of new systems
NewGen	Experience and skills- advanced systems
	Decreased cognitive capabilities in handling unusual circumstances
	Functional mentality- dependent on systems

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The functional mentality observed is linked to issues of automation complacency, since the former can increase the latter and develop greater monitoring problems, and ultimately a decrease in performance (Bailey–Scerbo, 2007). Moreover, as the two generations are distinct in mentality, skills, knowledge and views of advanced systems, the findings support problems of automation bias, whether NewGen overlies in automation and OldGen under-relies on automation (Mosier et al., 1997).

For example, as studies on automation bias and complacency suggest (Parasuraman–Mazey, 2010), under periods of multi-task loads, experts and naïve users are both affected. In line with the researchers' assumption, the respondents noted negative aspects of great reliance on technology, but also positive and mixed views emerged. The negative views were mainly associated with the OldGen operators, whilst NewGen operators portrayed a more functional culture on automation. Furthermore, the skills', training and knowledge gaps have implications for studies researching the relationship between performance and experience, the role of advanced training, knowledge of systems and task-based experience. In addition, the researchers observe the changes in the piloting profession and lack of adequate training to support the challenging aspects of pilot tasks in advanced automation systems, i.e., knowledge decay, fatigue, failures diagnosis, and overseeing complexity (Mohrmann–Stoop, 2019) and different typologies of competencies that affect operational performance (Mohrmann et al., 2015). Lastly, since the relationship between skill and experience has not been studied in depth, the current study brings to light several concerns and challenges, not only for current operations, but for the designing of quality training the operators need in advanced systems. To this end, generational changes that add to the complexity of performance require more attention as increased automation is creating a shortage of OldGen operators, creating a negative transfer of knowledge. Current concerns centre on workload, boredom, confusion, and low situational awareness (Endsley, 2019). The typologies can aid developments and research in high- and low-performing flights crews (Mohrmann et al., 2015; Mohrmann et al., 2019). Further intra-group research is required to capture within operator variability and address targeted training and other mitigation means.

Conclusion

Safety critical aviation operators that perplex the literature are pilots and ATCOs within new interfaces. Challenges in advanced systems and their operators focus on cognitive and load aspects, quality of training as well as fatigue factors in the performance processes. However, research has commonly addressed human factors in broad categories according to a group's function (e.g., pilots, air traffic controllers, engineers). To address the changes in operators for more quality training depending on their transitional needs, the current study led to a high-level underpinning in the categorisation of operators, and in the way their profession, skills, and mentality has shifted over the years. The findings indicate variability in perceptions of advanced systems and their effect on the operators' performance and acceptance of the new work setting. Changes are recorded in terms of skills, knowledge, and work attitudes of the operators. Further research should aim to develop further and validate typologies within the two overarching OldGen and NewGen types and explore the issue of a possible middle generational typology, that of operators in transition. Lastly, considering the documented acceptability issues in advanced systems, operators' variability could support future developments such as reduced crew operations.

Author Contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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THURY MÓNIKA *

„Digitális mentőöv”
A munkaerő-piaci szereplők készségeinek és felkészültségének fejlesztése a kikötői logisztika területén alkalmazható automatizálási technológiák használatára

* *Magyar Dunai Kikötők Szövetsége*
E-mail: popeiproject@gmail.com

Összefoglalás: 2021. augusztus 31-én eredményesen zárult a Magyar Dunai Kikötők Szövetsége és az Ecotech Nonprofit Zft. konzorciumában megvalósított, GINOP-5.3.5-18-20108-00025 azonosító számú, *Digitális mentőöv* című projekt. A 18 hónapon át tartó fejlesztés célja az volt, hogy javítsa a kikötői ágazat munkáltatóinak és munkavállalóinak technológiai fejlődéshez való alkalmazkodóképességét, és ezzel kapcsolatos megoldásokat dolgozzon ki az ágazat munkaerő-piaci kihívásaira, amelyek többek között a szakképzett munkaerő hiánya, az idősödő munkavállalók utánpótlásának nehézségei, a „digitális írástudás” alacsony szintje, a munkaerő-igényes, sok papírmunkával járó munkafolyamatok és a fiatal munkavállalók bevonzása. A projekt a technológiai trendek kutatásával és azok ágazatra való adaptálhatóságának elemzésével és a digitális kompetenciaszint felmérésével indult, majd ezekre alapozva átfogó kompetenciafejlesztés valósult meg a kikötők munkavállalói körében. A projektben kidolgozásra került egy KPI-rendszer is, amellyel a hazai kikötők felmérhetik saját digitális fejlettségük szintjét, amelyre fejlesztési javaslatokat is kapnak. Végül, a projekt eredményeit és tanulságait egy Ágazati HR-stratégiában összegezte a konzorcium, amely egy javaslatcsomagot tartalmaz a döntéshozók és oktatási intézmények részére a projekt során feldolgozott témában, a kikötői ágazatra vonatkozóan.

Kulcsszavak: Digitalizáció, technológiai fejlődés, kikötői ágazat, kompetenciafejlesztés, KPI.

Abstract: On August 31, 2021, the EU-funded project named “Digital rescue belt” (GINOP-5.3.5-18-20108-00025) was implemented successfully by the consortium of Hungarian Federation of Danube Ports and Ecotech Nonprofit Zft. The 18 month development was aimed at improving the adaptability of employers and employees in the port sector to technological developments and developing solutions to the sector's labour market challenges, including the lack of a skilled workforce, the difficulty of replacing aging workers, digital literacy, labour-intensive and paper-intensive workflows, and the involvement of young workers. The project started with research of technological trends and analysis of their adaptability to the sector and the assessment of the digital competence level. Based on these analyses, a comprehensive competence development was implemented among the port employees. The project has also developed a KPI system that allows port operators to assess the level of their own digitization development, for which they will receive development proposals. Finally, the results and lessons learned from the project were summarized by the consortium in a Sectoral HR Strategy, which includes a set of proposals for decision-makers and educational institutions on the topic addressed during the project, for the port sector.

Keywords: Digitization, technological development, port sector, competence development, KPI.

1. A projekt rövid bemutatása

A kikötői logisztikában, más ágazatokhoz hasonlóan, egyre fontosabb tényező lett a megfelelő munkaerővel való ellátottság mind az itt dolgozók számát, mind a munkatársak szakmai felkészültségét, kompetenciáit tekintve. A kikötők versenyképességének megőrzése érdekében elkerülhetetlen a szakmai tudás folyamatos fejlesztése és a felkészülés az egyre újabb technológiai kihívások és lehetőségek kezelésére.

A *Digitális mentőöv* című projekt a Magyar Dunai Kikötők Szövetsége és az Ecotech Nonprofit Zrt. konzorciumában valósult meg 2020. március 1. és 2021. augusztus 31. időszakban, 18 hónap alatt.

A konzorcium célja az volt, hogy a megvalósított fejlesztésekkel hozzájáruljon a kikötői logisztikai ágazat munkáltatóinak és munkavállalóinak technológiai fejlődéshez való alkalmazkodó-képességének növeléséhez, valamint konkrét megoldásokat, javaslatokat dolgozzon ki az ágazat munkaerő-piaci kihívásaira. A szakmai feladatok tapasztalt külső szakértők és magasan képzett, a digitalizációban jártas oktatók bevonásával kerültek megvalósításra.

Az alábbiakban a megvalósult projekt-eseményeket és azok eredményeit foglaljuk össze.

2. Elemzések, kutatások

A projekt átfogó elemzéssel, kutatási munkával indult, amely több lépésben valósult meg.

A konzorcium külső szakértői elsőként megvizsgálták az ágazatban a munkavégzés során alkalmazható technológiai megoldások körét, összevetve a meglévő munkakörökkel, hogy ezek alapján előre jelezzék a jövőben várható munkaköröket, valamint az ezek ellátásához szükséges kompetenciákat. A felmérés és elemzés fókuszában a *technológiai változások, nemzetközi trendek*, hasonló ágazatokban használt *adaptálható megoldások* álltak. A kutatás során elsősorban olyan technológiák keresésén volt a fókusz, amelyek az aktuális munkafolyamatokat segíteni tudják.

A munkakörök és lehetséges technológiák elemzésére és a jövőbeli munkakörök előrejelzésére alapozva, a szakértők *megoldási javaslatokat* dolgoztak ki a kiválasztott tagszervezetek számára a *munkafolyamatok átszervezésének lehetőségeire*, az egyes folyamatelemek technológiával való helyettesíthetőségére vonatkozóan, megvizsgálva a cégek közötti hasonlóságokat, bemutatva az ágazati szinten alkalmazható technológiákat és azok sajátosságait.

10 közép-magyarországi régión kívül tevékenykedő kikötői munkáltató került bevonásra a projektbe, melyek mindegyike válaszolt egy *digitalizációs helyzetképet felmérő online kérdőív*re, majd a vezetőkkel készült egy-egy *személyes interjú.* Mindezek eredménye feldolgozásra került az elkészült tanulmányokban.

3. Képzési igények felmérése, átfogó kompetenciafelmérés (pilot projekt)

Az elemzések és a munkáltatók helyzetének felmérését követően vette kezdetét a kísérleti (pilot) projekt, amely az ágazatban dolgozók átfogó kompetenciafelmérésével kezdődött. A vizsgálat során 150 kérdőív került kiosztásra, amelyből 127 megkérdezett (24%-a nő, 76 %-a férfi) küldött vissza értékelhető kérdőívet.

Kiderült a felmérésből, hogy informatikai felkészültségben, internethasználati szokásokban, a digitalizációhoz kapcsolódó fogalmak és különféle informatikai megoldások ismeretét tekintve a vezetők és a beosztottak csoportja teljesen eltérő szinten mozog. Az érzelmi intelligenciánál látható eltérések is arra engednek következtetni, hogy a vezetők nyitottabbak a újításokra, könnyebben alkalmazkodnak a változásokhoz. Éppen ezért a digitális kompetenciák kialakítását célzó képzéseknél szükségszerűen el kell különíteni ezt a két csoportot és eltérő tematikával kell megkezdeni a fejlesztéseket. A kísérleti projekt során a konzorcium a munkavállalók (beosztottak) fejlesztésére helyezte az elsődleges fókuszt, ahol nagyobb elmaradás tapasztalható a digitalizáció terén.

4. Kikötői munkavállalók és digitális mentorok képzése (pilot projekt)

A kutatások és az átfogó kompetenciafelmérés eredményeiből építkezve, a konzorcium egy digitális kompetenciákat fejlesztő tananyag kidolgozásával és két munkavállalói képzési alkalom megszervezésével támogatta az ágazat munkáltatóit a felkészülésben, felzárkózásban.

A 25 tanórás képzés összesen 4 elméleti modulból áll, melyek az alábbiak:
– A digitális kompetenciák értelmezése.
– Az IKT-eszközök és rendszerek alkalmazása a vállalati működésben.
– IKT-rendszerek a folyami kikötői logisztika területén.
– IT-biztonság.

2 képzés valósult meg a projekt során, 2021 május és június-július hónapjában, a májusi képzés személyesen, míg a nyári képzés személyes jelenléttel zajlott. A tapasztalatokból tanulva, azokat beépítve, a második alkalom három külön napból állt a korábbi egymás utáni három nap helyett.

A kísérleti (pilot) projekt következő lépéseként a fenti képzésből egy olyan *online tananyag* (oktatói segédanyag) került kidolgozásra, amely lehetővé teszi a vállalkozások számára a *„házon belüli" digitális kompetenciafejlesztést és szemléletformálást,* belső mentorok segítségével. A belső mentorok (digitális mentorok) felkészítése 2021. július 19-én valósult meg, online formában. A kidolgozott online tananyagot a konzorcium az ágazati munkáltatók számára elérhetővé tette.

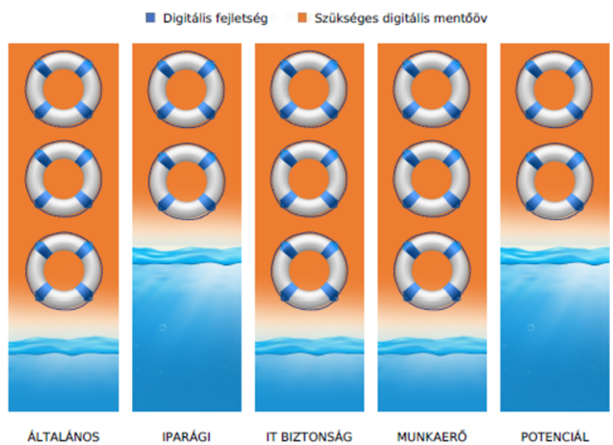
5. KPI-rendszer kidolgozása és bevezetése

A digitális kompetenciafelmérésből és a nemzetközi technológiai trendekből kiindulva a konzorcium kidolgozott egy fejlesztési és disszeminációs célokat is szolgáló *KPI-rendszert (mérőeszközt)*, amely lehetővé teszi a vállalkozások számára, hogy saját magukat felmérjék és beazonosítsák digitális alkalmazkodóképességük, fejlettségük szintjét. A rendszer lényegében egy önállóan használható programozott Excelt, kiegészítve egy módszertani segédlettel, kitöltési útmutatóval, referencia-értékekkel. A KPI-rendszert ugyancsak külső szakértők bevonásával, a pilot projektben kidolgozott képzési programmal összhangban, annak témaköreit beépítve dolgozta ki a konzorcium.

Az önállóan használható mérőeszköz *öt dimenzióban* ad reális képet a munkáltató digitális felkészültségéről:
– Általános szervezeti digitalizáció.
– Iparágspecifikus digitalizáció.
– IT-biztonság.
– Humánerőforrás digitális kompetenciái.
– Digitális potenciál.

A KPI-rendszer az eredeti Excel formájából elektronikus formát öltött, és egy programozott online kérdőív formájában érhető el a Kikötőszövetség honlapján. A kérdőívet bármely ágazati munkáltató bármikor kitöltheti, és ezzel felmérheti jelenlegi felkészültségének szintjét digitalizáció szempontjából. Az eredményről egy pdf-ben letölthető összefoglaló riportot generál a rendszer, amely a grafikus ábrázoláson túl, az eredmények függvényében konkrét fejlesztési javaslatokat is tartalmaz.

1. ábra. A kikötőüzemeltető digitális fejlettségi szintjének grafikus ábrázolása



6. Szakmai rendezvények megvalósítása

A projekt során két szakmai rendezvényt valósított meg a konzorcium, online formában.

A 2021. június 2-án megrendezett *szakmai workshop* célja az volt, hogy a projekt keretében készülő Ágazati HR-stratégia tervezett tartalmát, főbb irányait megismerhessék a résztvevők, és lehetőséget biztosítson a kapcsolódó észrevételek, ötletek megfogalmazására. A workshopon az ágazati munkáltatókon túl más szakmai szervezetek, képzőintézmények és a Magyar Kereskedelmi és Iparkamara is képviseltette magát, összesen 22-en vettek részt.

A 2021. június 29-én megrendezett *szemléletformáló konferencia* célja, hogy minél több érintetthez eljuttassa a projekt eredményeit, és támogassa a szemléletformálást a digitalizációs trendek irányába. A félnapos konferencia a kikötői és logisztikai ágazat digitalizációját, illetve annak munkaerő-piaci vonatkozásait érintő témaköröket ölelt fel, és a kikötői logisztikai ágazatban tevékenykedő munkáltatók, képzőintézmények, ágazati döntéshozók és egyéb érintettek részvételével (összesen 57 fő) valósult meg.

7. Ágazati HR-stratégia

A projekt során megvalósított kutatások, módszertani fejlesztések során kirajzolódtak olyan trendszerű problémák, amelyeket érdemes az oktatási rendszer szintjén is kommunikálni – például milyen technológiai ismeretekre, „soft skillek"-re lesz szükség az ágazatban a jövőben. Ezek alapján, kiegészítve az oktatási intézmények bevonásával szervezett workshop eredményeivel egy ajánlás készült a magyar oktatás és a döntéshozók részére, *Ágazati HR-stratégia* formájában.

A stratégia megfogalmaz fejlesztési irányokat a feltárt képzési igények mentén a szemléletformálásra, a vezetők képzésére, valamint a szellemi és a fizikai munkavállalók továbbképzésére vonatkozóan. Ajánlásokat fogalmaz meg továbbá az ágazatot érintő szakképzési rendszerek összehangolásának, egyszerűsítésének és átjárhatóságának biztosítása érdekében.

A stratégia rövid távú céljai:

1. Általános szemléletformálás a kikötői munkavállalók körében, a digitalizációval kapcsolatos ellenállás csökkentése.
2. Digitális felkészültség önértékelése, fejlesztési irányok meghatározása a KPI-rendszer segítségével.
3. Belső képzések megvalósítása az ágazatban a digitális mentorok közreműködésével.
4. Javaslatcsomag benyújtása a döntéshozók felé az ágazatot érintő szakképzés rendszerének finomhangolására vonatkozóan.

A stratégia hosszú távú céljai:

1. A kikötő-üzemeltető képzés funkciójának bővítése, presztízsének emelése.
2. A hiányzó képzésekre más logisztikai ágazatokkal és képző intézményekkel együttműködve célzott képzési programok kidolgozása.
3. A kikötői logisztikai, hajózási ismeretek integrálása a meglévő szakképzési rendszerbe.

Az Ágazati HR-stratégia, ahogyan a projekt további eredménytermékei is, a kikötőszövetség honlapján, a projekt aloldalán elérhetők.

Galéria

Halász Iván fotói