Examination of the influence of the integrated mission management system on the pilot's situational awareness

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Abstract

Purpose – This paper aims to present research carried out on the influence of GUI graphical elements design for an integrated mission management system (IMMS) display flight planning process.

Design/methodology/approach – Surveys and research were conducted among students/pilots to explore graphic presentation methods for flight planning displays. Guidelines for graphical layout of the IMMS flight planning interface are proposed.

Findings – A research concept was obtained, enabling GUI tests for IMMS using prepared templates and questionnaires.

Practical implications – This study improves cockpit information readability, understanding and presentation, particularly for flight planning elements such as terrain, weather, traffic and zones influencing route organisation.

Social implications – This study targets possible improvements to the flight path planning process in aviation, inducing a reduction in errors related to human factors while processing the visual data on-board.

Originality/value – The study verified the impact of drawing and rendering methods on IMMS flight planning, suggesting that current display methods may be error-prone when showing hazard information from multiple sources on a single screen.

Keywords IMMS (integrated mission management system), Flight planning, Pilot visual perception, Integrated display, GUI (graphical user interface)

Paper type Research paper

Nomenclature definitions, acronyms and abbreviations

AC = advisory circular;
ADS-B = automatic dependent surveillance – broadcast;
ARN = air traffic service route network;
ATC = air araffic control;
ATPL = airline transport pilot license;
ATM = air traffic management;
ATZ = aerodrome traffic zone;
AWAS = advanced weather awareness system;
AWC = aviation weather centre;
COAST = cost affordable avionics system;
CCP = compact computing platform;
CONUS = continental United States;
CTR = control zone;
CWSU = central weather service unit;
EASA = european aviation safety administration;
EFIS = electronic flight instrument system;
EGPWS = enhanced ground proximity warning system;
FAA = federal aviation administration;
FCS = flight control system;
FL = flight level;
FMS = flight management system;
FND = flight navigation display;
FRS = flight reconfiguration system;
GAIRMET = graphical airman's meteorological information;
GNSS = global navigation satellite system;
GUI = graphical user interface;
ICAO = international civil aviation organisation;
IMMS = integrated mission management system;
IPFD = integrated primary flight display;
KLM = royal dutch airlines;
LGT = light;
MCTR = military control zone;
METAR = meteorological aerodrome reports;
MFD = multifunction display;
MOD = moderate;
MRMS = multi-radar multi-sensor system;

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MTMA = military terminal movement area;
NIL = none;
NOAA = north oceanic and atmospheric administration;
PIREP = pilot reports;
PPL = private pilot license;
RGB = red green blue;
SAE = society of automotive engineers;
SEV = severe;
SIGMET = significant meteorology information;
TMA = terminal manoeuvring area;
TRA = temporary reserved area;
TSO = technical standard orders;
TSS = tactical separation system;
VFR = visual flight rules;
VOR = very high frequency omnidirectional range; and
WPT = waypoint;

1. Introduction

For a considerable period, the trend of integrating interesting and innovative elements into vehicle equipment to provide information to occupants, such as car drivers or aircraft pilots, has developed within the transportation industry. Analysing this trend from the perspective of selected technologies and human perception, particularly focusing on eyesight, it can be said that vision plays a predominant role in decision-making. The perception of shapes, colours, contours, textures and effects in both 2D and 3D allows individuals to identify the actual state of the environment accurately.

In aviation, the information displayed to pilots in cockpits has undergone a profound evolution. Flight planning requires information about airspace, weather, terrain and traffic. Currently, we have real-time data acquisition capabilities and methods for presenting this information. Standard cockpits are interfaced with multiple displays arranged in a "T" layout for civil aircraft and an inverted "U" layout for combat aircraft. Pilots can also reorganise displays. Commonly used MFDs present a lot of information, such as FND data or flight parameters like EFIS readings, in a more flexible way, as at the beginning of the 21st century, due to advancements in electronics. Organisations like ICAO, FAA, EASA and SAE have established guidelines for aircraft design and graphic layout.

Glass cockpits have replaced analogue versions, reaching a peak in both the quantity and quality of information. Until recently, many concepts in land transport proposed complex central consoles containing navigation and information systems that were not continuously necessary for display (e.g. speedometer, tachometer, engine parameters, obstacle information and weather were all displayed on one screen).

In the task of route planning, it is essential to consider not only safety but also the efficiency of flight planning itself as an equally significant concern. Ergonomics plays a crucial role in this task. Therefore, improving the flight planning process by integrating important factors such as weather conditions, topography, restricted zones and air traffic updates, and displaying them efficiently is warranted. Currently, information for pilots is displayed on separate displays, forcing them to follow each kind of piloting information from different sources, increasing their workload.

2. Analysis of current research

The current state of science related to the problems of presenting information for pilots and crew shows several trends. The publication (Wei *et al.*, 2014) presents the experimental results of the pilot's information load and the impact on performing flight operations, where the aircraft cockpit display interface based on Fisher's Bayes classification was shown. In Moacdieh *et al.* (2013), the authors analysed the impact of visual notifications on PFD, pilots' load by following and analysing the behaviour of the pilots' eyeballs. The study (Anderson *et al.*, 2003) reviews aspects of the anatomy and physiology of the human visual system, especially spatial orientation maintained by subconsciously derived cues from peripheral vision. The extensive study (Collinson, 2023) describes the operation of avionics systems that allow for flight management, flight planning, calculation of aircraft position, course optimisation, maximum recommended altitude, etc. The article (Starr and Hoogeboom, 2007) discusses the work undertaken in the Human Integration into the Lifecycle of Aviation Systems (HILAS) project. It mentions certain technological achievements that can be implemented on board the aircraft to make a certain evolution. In the article (Nicholl, 2014), the author emphasises the issue of the importance of the human factor on the performance of operations by the pilot and the inherent influence of avionics devices on this fact. The authors in de Ree (1990), based on the KLM pilots research, developed a unique method of aeronautical chart colour coding because of map readability problems. Paper (Jose *et al.*, 2022) describes a model-based approach to the purpose-independent development of avionics display graphics and its implementation on embedded platforms. The avionics display design model is based on the SCADE Display graphical user interface (GUI) development tool. Article (Anand *et al.*, 2022) demonstrates a method for creating an HMI for a two-seater aircraft. Paper (Sabatini *et al.*, 2020) presents the views of the IEEE Aerospace and Electronic Systems Society (AESS) Avionics Systems Panel (ASP) on the potential for the evolution of avionics systems. Research on the pilots' perception methods of presenting graphic elements is shown (Gaska *et al.*, 2016; Zuschlag *et al.*, 2010; Ahlstrom, 2015). In Gaska *et al.* (2016), the authors focused on the graphic elements pilot's recognising efficiency. The investigation focused on the size, shape and colour characteristics of graphical elements used on the displays of fifth-generation fighters. Pilot's ability to learn and remember air traffic symbols is discussed in Zuschlag *et al.* (2010). The tested displays transmit data from the ADS-B and the associated Aircraft Surveillance Applications System. Aspects of acquiring symbols presented separately in a static display illustration. Symbol sets were with various features to represent directivity, data quality, air/ground condition, alert level, aircraft condition. In Ahlstrom (2015), the issues of distinguishability and the influence of symbolism on decision-making behaviour from weather displays were examined. The weather display was changed for pilots, using varied symbols and colours. Variables and cognitive engagement were assessed. Changes in METAR, rainfall, SIGMET info and lightning were included. The experiment found discrepancies in symbol recognition, highlighting how display diversity affects pilot behaviour. The literature (Livada *et al.*, 2012; Lu and Wang, 2014;

Jovanovic *et al.*, 2009; Hockenbrock and Murch, 1989; Yeh *et al.*, 2019) focused on the perceptual issues of pilots, the aspect of displays and their physical parameters. In Francis (2003) and Francis and Rash (2000), the verification of the MFDTool for MFD design was undertaken. For research on integrating automatic systems, e.g. FCS, with the related information displayed (see Lampl and Hornung, 2018; French *et al.*, 2006). Publication (He *et al.*, 2009) presents the concepts for displaying and evaluating the integration of FMS with Honeywell's IPFD. Background display in the IPFD perspective view allows terrain presentation by obstacle scenes generated by EGPWS databases. In articles (Chudy *et al.*, 2011; Daniel and Byrd, 2003; Yang, 2017; Braseth *et al.*, 2019), the authors focused on examining the unusual arrangement of simulator displays, the impact of chrominance and luminance of displays on the ability to read information. In Ahumada *et al.* (2006), the image discrimination model was presented. It includes the compensation model of the observer's position for approximating the upper limit of graphic symbols identifying efficiency. The authors (Fares and Jordan, 2015) suggest that aligning colours and symbols enhances display standardisation and information presentation. Authors highlight three key factors for RGB colour in mission performance: transparency display, information categorisation and remote perception of colours. Understanding their interplay is crucial for designing display symbols and colours. By analysing literature, the current research directions, does not consider the influence of the graphic presentation of symbols and colours, factor of, e.g. on the effectiveness of flight planning, rather focus on the aspect of general legibility, nor does it address the interaction of display of hazards from various sources.

Within the COAST project, multiple technologies have been tested (Lucky *et al.*, 2024), including the AWAS (Montesarchio *et al.*, 2021; Montesarchio *et al.*, 2022; Zollo *et al.*, 2023), which provides pilots with information on weather phenomena; the TSS (Di Vito *et al.*, 2021a, 2021b; Di Vito *et al.*, 2022a, 2022b, 2022c, 2023), which suggests traffic resolution manoeuvres and displays nearby traffic from ADS-B; and the FRS (Grzybowski and Szpakowska-Peas, 2020), which addresses aircraft recovery issues when the pilot is incapacitated. These technologies were initially developed as separate systems. However, given the promising results obtained midway through the project, a decision was made to integrate them into the IMMS (Di Vito *et al.*, 2021a, 2021b). This integrated system consolidates hazards from multiple sources onto a single screen while retaining the original functions of AWAS, TSS and FRS. The integration justified further research into effective hazard display methods by combining these technologies.

2.1 Regulations and actual formal guidelines

The design of displays and the graphic arrangement of information on them are limited by guidelines. Unfortunately, there are no clear indications of a potential direction for further development. The information in Barbur *et al.* (2009), Chamberlain *et al.* (2013), Yeh *et al.* (2013), International Civil Aviation Organization (2016), European Union Aviation Safety Agency (2019), Airbus (2017), Gildea *et al.* (2018) and Gildea *et al.* (2020) shows how the information in the cockpit should be designed and organised for MFDs. Analysing certified solutions, common features can be noticed. This is because of the aforementioned limitations of the possibility of presenting graphical information. The current ways of drawing and presenting information have evolved. The current methods of graphic coding on MFDs indicate more potential of computer graphics, the possibility of alternative information presentation. The current reporting standards (Network portal (SAE Aerospace Standards), 2022; Network portal (Radio Technical Commission for Aeronautics Standards), 2022; Network portal (European Union Aviation Safety Agency), 2022b; Network portal (Federal Aviation administration), 2022d) suggest the basic elements that create a proven pilot display environment. This includes graphic elements such as labels, icons, symbols, images, maps or the methods of their integration, applying the information as layers, and colour coding of the information displayed to pilots. The guidelines that the IMMS GUI has to comply with are presented in the following list.

Guideline description:

- Labels should be legible, contrasting and provide information only when this cannot be done.
- Standards for labels' minimum and maximum size have to be set.
- Labels should be clearly related to a window or graphic element.
- The system must prevent too short exposure time for auxiliary information and a non-obfuscated appearance.
- Auxiliary information should refer to active functions or be highlighted in relation to inactive ones.
- Icons and symbols should not introduce ambiguous associations.
- Icons and symbols should not obscure important information, and their meaning must be consistent.
- Icons and symbols should be presented simply, without distracting from the rest of the information.
- In relation to the background, contrast should be sufficient for interpreting objects with no significant delay.
- Icons and symbols must be of sufficient size and detail.
- Objects should retain their quality and readability.
- Objects' coverage should be compatible with the maps used in aviation.
- Designations for wind shear and wind speed/direction should be compatible with the maps used in aviation.
- Graphics should be specific to objects such as waypoints, VOR and aircraft.
- Graphics should refer to previously adopted conventions; otherwise, they require crew retraining.
- Stationary objects in relation to the ground must remain stationary.
- Dynamic objects should indicate the actual direction of the object's movement.
- Objects should be characterised by parameters such as luminance, contrast and colour.
- Graphics may have some additional features (e.g. borders, textures).
- Dynamic elements must not behave unnaturally (e.g. vibrations, jumps).
- Objects posing a threat should be drawn more clearly than those not posing a threat on the planned or actual route.
- Symbols relating to paths must be connected by lines that define a route.

- The active route must be distinguished from the alternative route.
- The route editing mode must differ from the readout mode.
- All information necessary for operational requirements should be displayed.
- When multiple pieces of information are displayed side by side, grouping should be used to avoid clutter (e.g. overlapping shapes on top of each other).
- Not relevant information should be turned off or obscured, prioritising appropriate drawings to retain information while indicating the level of relevance.
- It is possible to lighten, darken or introduce the effect of partial transparency of overlaid graphics.
- Information about air traffic, weather, terrain and airspace must be distinguishable among groups.
- A convention of using red, amber and yellow as the colours in which warnings and alerts are coded must be followed.
- Blue should not be used for essential information that covers a tiny area of the map and, due to low luminance, should not be displayed next to red.
- The colours used on maps should be unsaturated, similar to paper maps.
- The colour coding scheme should comply with regulation AC-23.1311 or the conventions TSO-C146d/DO-229D; 2.2.1.1.4.2.
- It is recommended not to use more than 6–9 basic colours on one display, as stated in TSO-C165a/DO-257A; 2.1.6, TSO-C115d/DO-283B; F, F.2.2.4, AC-25-11B/5.8.3, and SAE ARP 4032B; 4.2.2.1, DO-256; 2.1.3.6.
- Colour pairs such as saturated red to blue, saturated red to green, saturated blue to green, saturated yellow to green, yellow to purple, yellow to green, yellow to white, magenta to green, magenta to red, green to white, blue on black and red on black should be avoided according to TSO-C115d/DO-283 F, F.2.2.4.

Such guidelines limit the possibilities of using colour combinations and make the process of graphic interface design a difficult task as there are no clear analytical methods/algorithms how to complete it. The current state of knowledge is rather based on research performed on pilots closed groups, but there are no formal guidelines on how to present hazards presented on multiple screens into one.

2.2 Review of current solutions in flight planning interface

A flight planning tool based on navigational aids and aeronautical publications is an instrument that makes it easier to prepare and submit a flight plan, considering weather information, which is often accessible separately. In consequence, a pilot refers to different sources.

2.2.1 Exemplary flight planning tools

The portal "lecimy.org" is popular among Polish pilots. They display information as layers corresponding to altitude. As the higher airspace block is located, the layer becomes more transparent. The colour depends on the airspace block function. Aerodrome neighbourhoods like CTR/TMA are marked differently than areas burdened with restrictions, such as ATZ, MTR, MTMA/MCTR [Figure 1(a)]. Airports and aerodromes are marked using circle-like symbols. WPTs are in triangle form. The background is a physical map. There is a possibility to outline a ladder-like path. When wind impacts are more favourable, ladder rungs are farther apart, and vice versa (Network portal (Lecimy.org), 2022e). Skyvector.com projects aeronautical charts and makes it feasible to apply half-transparent weather information. Besides, they use pictograms, providing information such as PIREP and wind distribution [Figure 1(b)]. As a background, they use different charts together. When the sectional chart is selected for VFR flights, the background changes tone colour, so saturation is stronger where there is higher terrain elevation. Information captured from MRMS, satellite IR4 and cloud top height can be visually presented (Network portal (Skyvector.org), 2022g).

2.2.2 Weather data services

The NOAA and AWC deliver consistent and accurate weather information. They present information in various forms, including interactive displays (Figure 2). SIGMETs issued by the CONUS or CWSU vary; however, each type of hazard is coloured differently, and this remains consistent for both issuances. The GAIRMET is presented in polygon form along with pictograms. It is possible to manually adjust the transparency of the polygon layer. When information concerns a PIREP, pictograms are used next to the altitude (FL) of predicted occurrence. The colour saturation for GAIRMETs and PIREPs seems to be opposite. Threats are marked using a colour gradient as well. A standardised technique is used to show multiple pieces of data at a particular site. The Winds and Temperature page displays the layout of data such as wind speed, direction and temperature at the selected flight level. There is even a brief description of threats when any block on the interactive map is highlighted (Network portal (Aviation Weather), 2022a).

Windy.com is a portal that can support flight preparation. Although wind speed and direction are not presented in wind barb form (as commonly used in aviation), the visible light spectrum-like arrangement supports the understanding of wind component distribution (Figure 3). Besides that, the portal allows the display of clouds, thunderstorms and temperature distribution using different colour tones and symbols (Network portal (SWindy.com), 2022h).

The Eurocontrol Network Operations Portal is popular because it contains data that is important for ATC activities. It supports different ATC, ATM staff or even pilots. Called the current network situation, such delays make the portal unprecedentedly significant (Figure 4). The portal makes it possible to observe pressure, rain spectrum, clouds, thunder risk, winds, turbulence risk, jetstream, fog and temperature distribution. Each piece of information is provided on a different chart page, with visible light spectrum, numbers and pictograms (Network portal (Eurocontrol), 2022f).

2.2.3 Advantages and limitations of the graphical data display and the ambiguity problem

In the daily life of society, some colours seem to be treated as universal. For example, shades of red are alerting, blue colour conveys a non-verbal message about safety and green has multiple meanings – it can denote military areas, low-level

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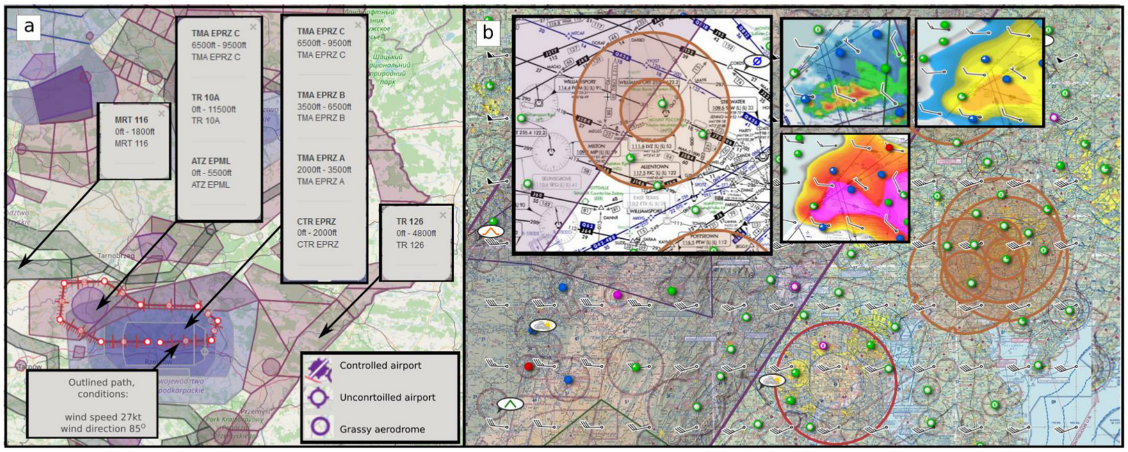
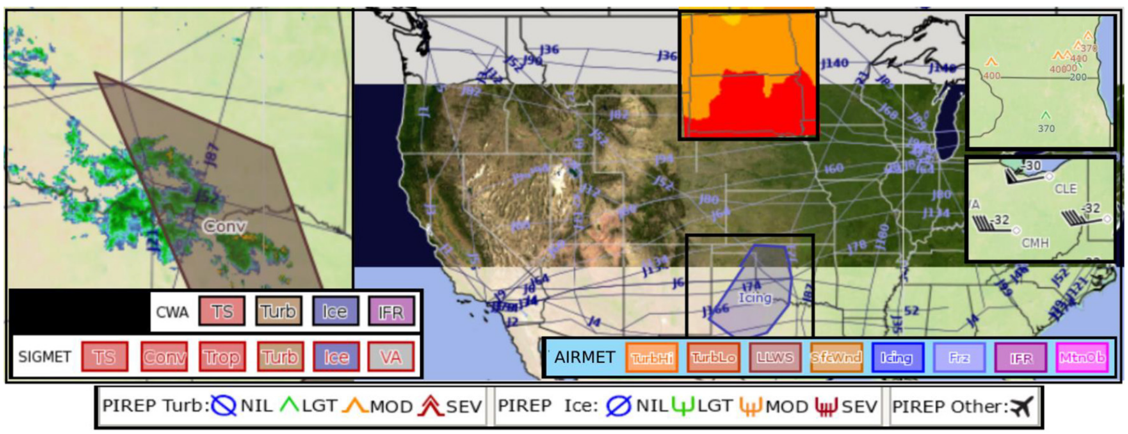
Figure 1 Selected flight planning portals overview



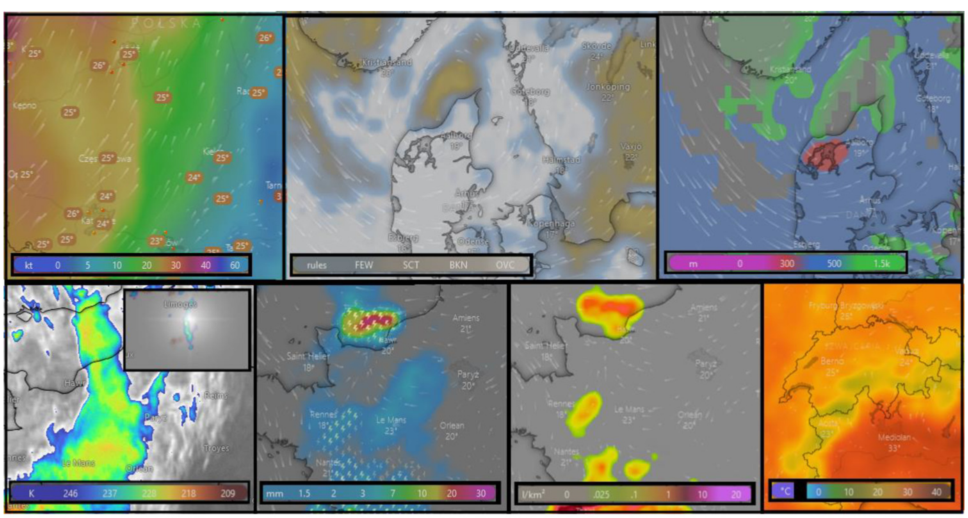
Notes: (a) Lecimy.org; (b) skyvector.com
Source: Figure by authors

Figure 2 North Oceanic and Atmospheric Administration Aviation Weather Centre facilities cross-section



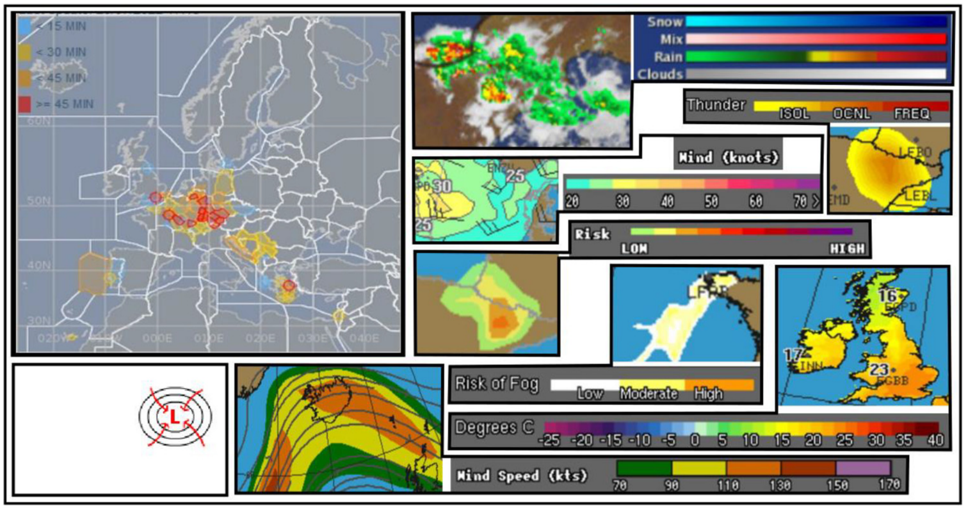
Source: Figure by authors

Figure 3 Outline of the Windy.com network portal



Source: Figure by authors

Figure 4 EUROCONTROL Network Operations Portal overview



Source: Figure by authors

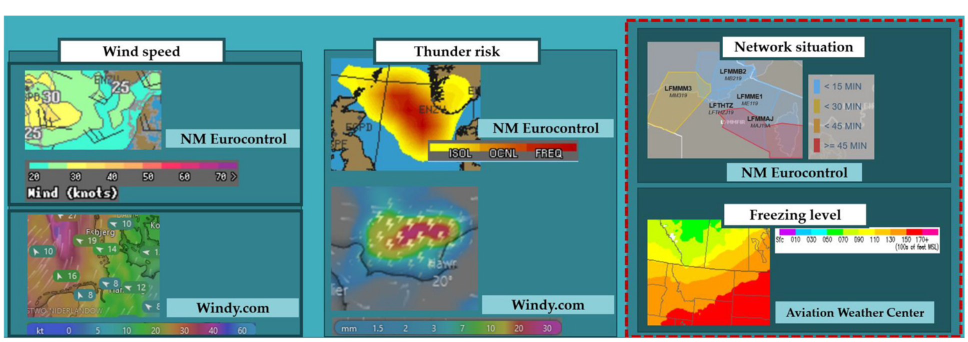
threats or be recognised as a grassy background. It should be noticed that a colour tone, shade or depth has meaning, sometimes allowing for intuitive qualification of a condition's state. The major advantage of this is that the graphical interface makes it explicit when the spectrum delivers intuitive information, although sometimes information has to be enhanced with numbers, as it is not always possible to deduce the entire message (e.g. about the exact altitude at which a threat occurs). However, there are disadvantages as well – mostly when the same information is displayed in different ways depending on services. For instance, wind speed is indicated in different colours and even pictograms (Figure 5). Eurocontrol uses wind barbs, which show wind speed depending on the number of barbs and/or triangles included; Windy.com uses arrows and numbers to denote wind speed.

Pictograms make sense, in that there is no room for disputes about which threat information is displayed because it is a standardised technique for showing multiple pieces of data. When discussing information about thunder risk, as it would seem, it is displayed similarly by those two services – this can be confusing because Windy.com uses pictograms for thunder risk, while the Eurocontrol presents thunder risk by colouring a certain area similarly to the rainfall information provided by Windy.com. Similarly, red indicates delays or freezing levels. The most unclear aspect is that the same network portal displays information whose colour varies – meaning that high intensity is sometimes marked inversely (red is used for marking the high or/and intense phenomena).

3. Methods

This paper presents research on the impact of GUI element design on the IMMS during the flight planning process. The system's assumption is to integrate pilot information related to navigation from multiple sources into one IMMS, displaying different types of information in a universal format on one screen simultaneously. A well-designed interface accelerates the reception of information. The research aims to identify preferred intuitive styles of presenting various types of phenomena. Conducting surveys among pilots is the most reasonable approach to gather information about the preferred data display style, although it must be noted that such surveys, as a tool, may not cover all possibilities.

Figure 5 Examples of the colour ambiguity problem



Source: Figure by authors

3.1 Research assumptions

This study aimed to identify relationships between the presentation of data and the intuitiveness of information reading. These features pertain to selecting the appropriate set of display methods for specific types of information. The preparation stage of the research included preparing a set of graphical elements for the GUI, and the second stage involved preparing a survey targeting respondents. The group of respondents consisted of 50 students specialising in pilotage, who already had some experience with aviation instrument usage. To ensure the credibility of the results, the study adopted a principle comprising the following stages:

- Obtaining preliminary information (questions were grouped into categories and divided into selection tasks: first marking the phenomenon with colour, then grading the colour, including the shape of the pictogram, the degree of transparency and including overlapping colours).
- Verification of the results of the first stage. The data were plotted on the ARN chart, and the task was to choose the most legible way of presenting data plotted on the map.

For better readability, responses were processed using the median. Students, as future aviation professionals, were chosen to capture emerging trends in user interface preferences while effectively managing research costs. The survey, in particular, was considered an efficient research tool before using more advanced methods, such as GUI development and implementation. Although the limitations of using student participants were acknowledged, this approach enabled the validation of the survey tool before it could be introduced to a broader set of respondents in future research.

3.2 Survey construction

The survey contained 21 questions addressing multiple aspects like colour and shape coding of possible hazards or readability of information dependent on the transparency. The colour palette for information markings attempts were prepared in the survey with the possible widest range of colours, tones and shades. Similarly, graphic and symbols based on pictograms that are natural for interpretation were designed.

Based on psychology and bi-neurology, it is shown that colour theory is influenced by societal and behavioural factors. However, it should be noted that some misinterpretations in information understanding can be influenced by the respondent's place of origin. A colour palette [Figure 6(a)] was prepared for research on the assessment of information conveyed by the choice of RGB (red, green, blue) colours. RGB is a theoretical model, and the presentation of colours depends on the device (e.g. monitor). To avoid the impact of monitor settings, templates were provided on paper in printed form.

Determining the level of transparency of the plotted areas may result in overlapping colours. Consequently, colour blending occurs, and if transparency is lower, the higher layer becomes more readable. The background, such as an aeronautical chart [57], may be less legible, especially when combining several colours of different polygons applied on a map [Figure 6(b)]. For this reason, part of the survey addressed the type of background that does not influence colour recognition.

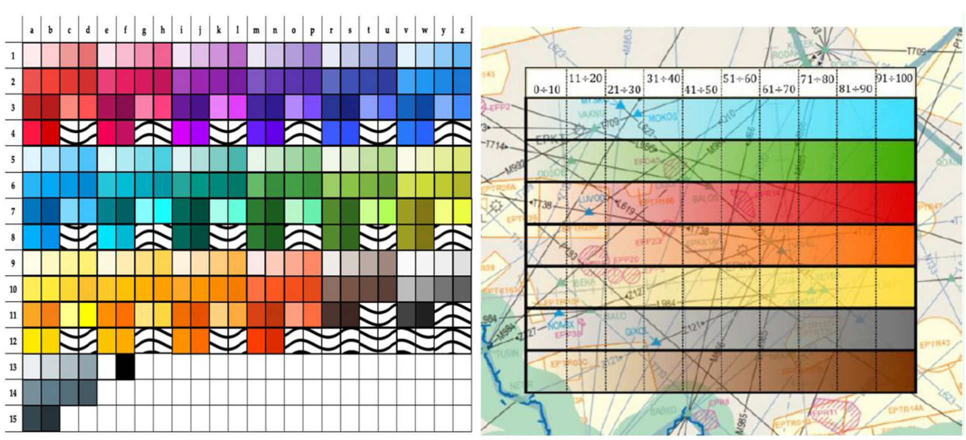
Information in the form of symbols (Figure 7) was prepared to allow for the determination of the type and intensity of the phenomenon (e.g. changing colour or multiplying the pictogram).

3.3 Control group description

The control group consisted of two subgroups with varying levels of flight experience, dependent on the year of study (Figure 8). It was predicted that more experienced pilots may have developed more habits associated with the use of commercial MFDs.

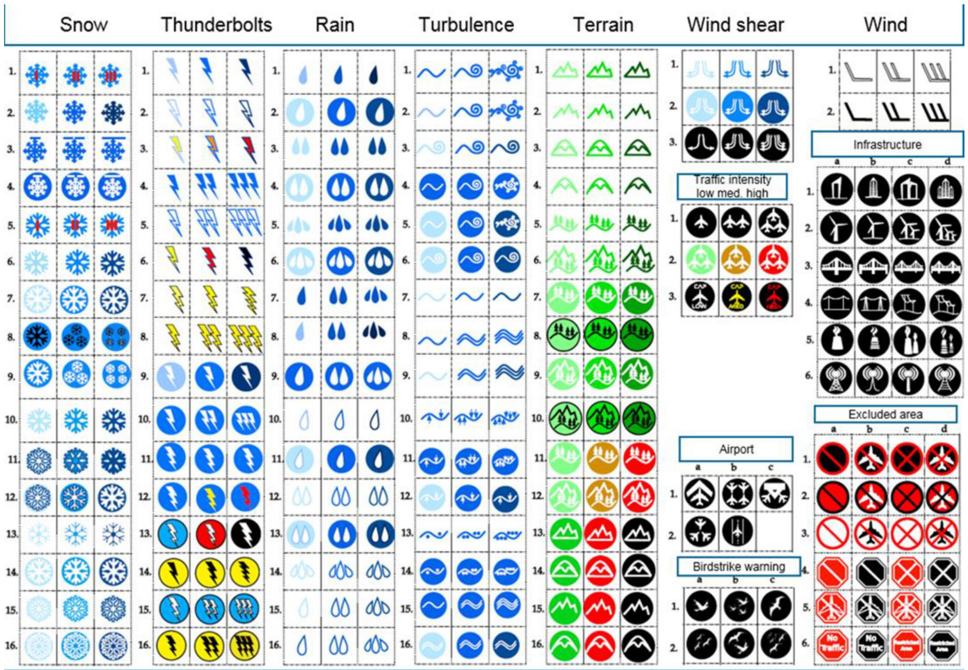
The first group of 25 students (third year), during their PPL training (with an average of 53 h of flight training), was considered as novices, where the influence of modern aviation displays on individual preferences was likely limited. The second group of 25 students (fourth year), during their ATPL training (with an average of 107 h of flight training), was considered more experienced with modern aviation displays. As such, their preferences could potentially be biased by the type of devices they were using.

Figure 6 (a) The RGB model used in the survey. (b) Transparency template used in the survey



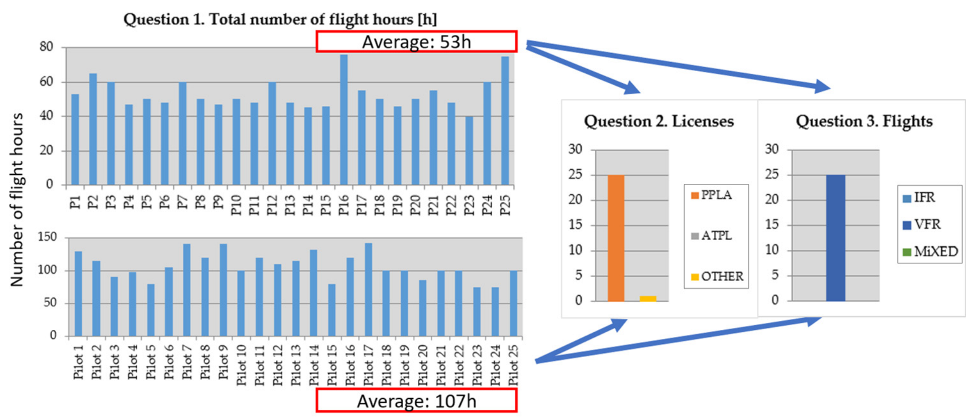
Source: Figure by authors

Figure 7 The set of graphical symbols used in the survey



Source: Figure by authors

Figure 8 Flight experience: Question 1. Total number of flight hours, Question 2. Licenses, Question 3. Flights



Source: Figure by authors

4. Results

This chapter presents results sample got through surveys presented as graphic charts, followed by conclusions.

4.1 Determining the weather information sources

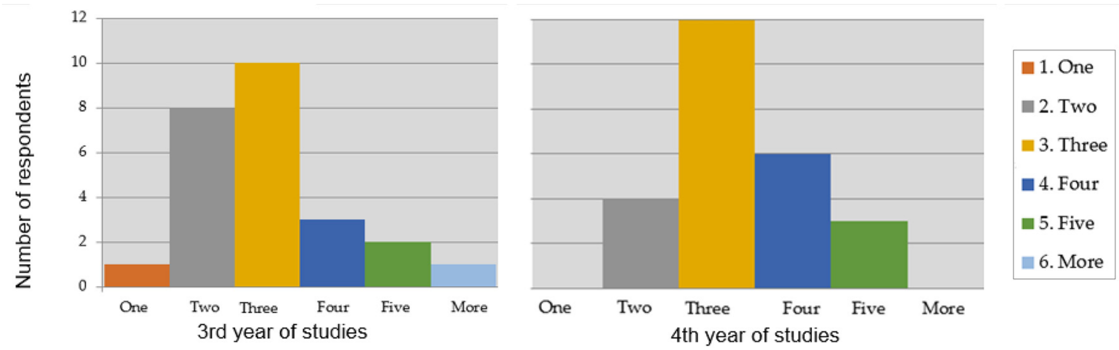
Data gathered showed that in most cases pilots used three sources of weather information (Figure 9). It is worth noticing that from proposed weather portals (domestic and abroad), in most cases, they used domestic portals and international services were not necessarily popular (Figure 10).

According to the results obtained, a clear trend in preferred weather services in the case of both studied subgroups. Given this, it could impact preferred colour schemes used for describing weather hazards.

4.2 Determining the importance of colour

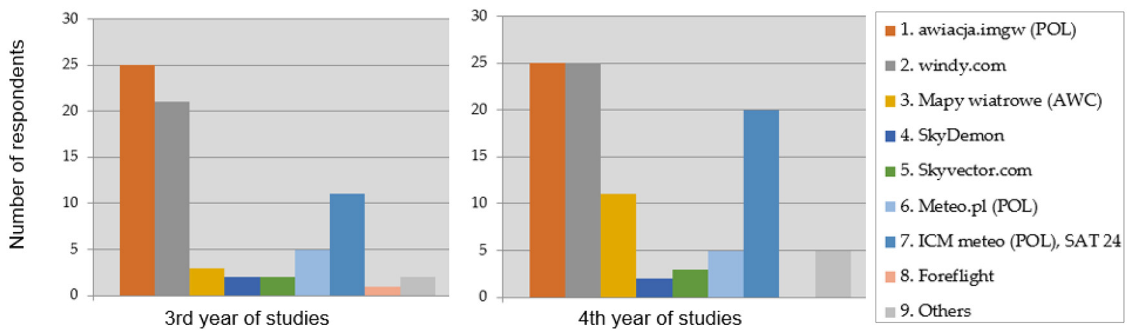
Within the survey, a relationship between colour and subjective information importance was examined. Respondents were asked to sort the related colours by the priority they would assign to the information. Figure 11 shows the relationship between colours, priorities and the number of respondents. Noticeably, for both groups, red colour was referred to as the most important, while white was considered the least important. Orange and yellow were recognised as carrying significant information.

Figure 9 Number of meteorological services in use by surveyed respondents



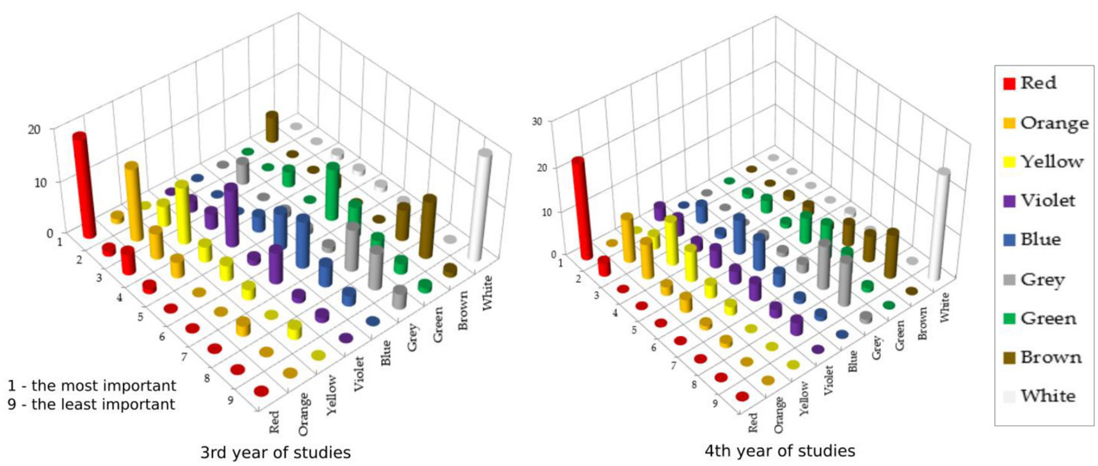
Source: Figure by authors

Figure 10 Meteorological services popularity among respondents



Source: Figure by authors

Figure 11 Assignment of colour priorities

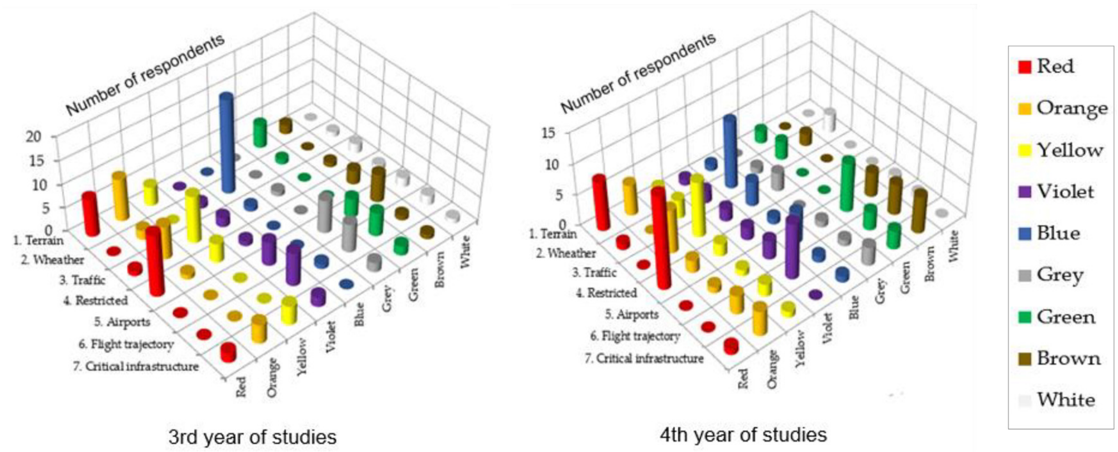


Source: Figure by authors

4.3 Determining the relation of colour and information type

Even though colour can convey information, the next task of respondents was to assign the colour to the corresponding type of information (Figure 12). In the majority, the blue colour is associated with weather, violet with the flight trajectory and yellow with traffic. However, the answers are not that specific. For example, ambiguity in the answer appears within the assignment of the red colour, which has been allocated to terrain and airspace but excluded from traffic. Orange and green have also been assigned to terrain information.

Figure 12 Assigning colour to the information type



Source: Figure by authors

Analysing the plots from Figure 11, respondents chose red as the most important. However, according to the next question (Figure 12), red was assigned to restricted airspace and terrain. Moreover, ambiguity occurs when assigning information to green, as respondents recognise it as preferable for marking trajectory, airports and terrain. Based on Charts 11 and 12, it can be concluded that information about the hazardous area is coloured with a palette indicating the most important information.

The next task was to assign polygon variants on the ARN chart (Figure 13) to the hazard category they represent. The restricted area is mostly associated with the colour red, but other results were highly subjective. For example, terrain hazards seem to pose an ambiguous problem – respondents assigned four different colours to it in similar proportions. Blue and yellow received almost unanimous votes for representing weather and traffic, respectively.

4.4 Determining correlation of the importance of the information with transparency and icons

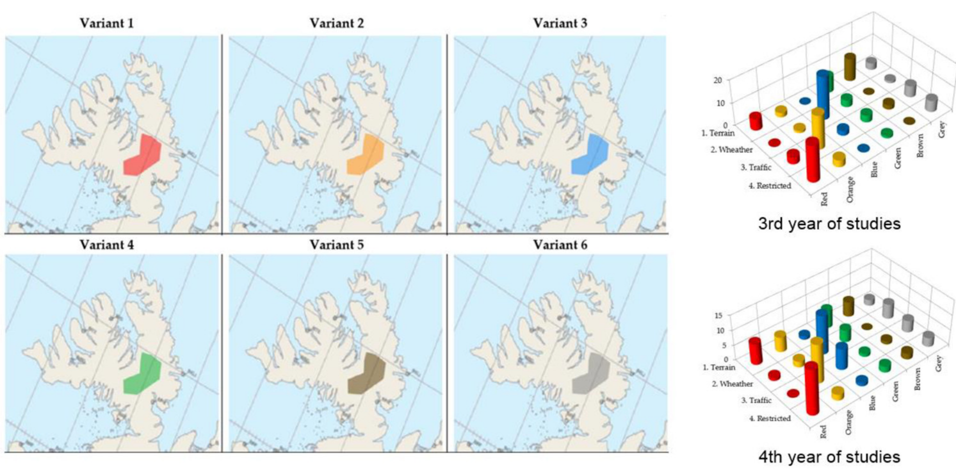
In this part of the study, the task of respondents was to assign the grading of weather information depending on the intensity of the phenomenon (Figure 14).

As expected, most respondents unanimously assigned Variant 1 as the least intense, while Variant 4 as describing the most intense phenomena. The relation between Variant 2 and Variant 3 suggests that for more intense phenomena, an additional icon is preferred, but this conclusion may be driven by responses from respondents with higher pilotage experience.

4.5 Determining the importance of the information correlated with the line style drawing

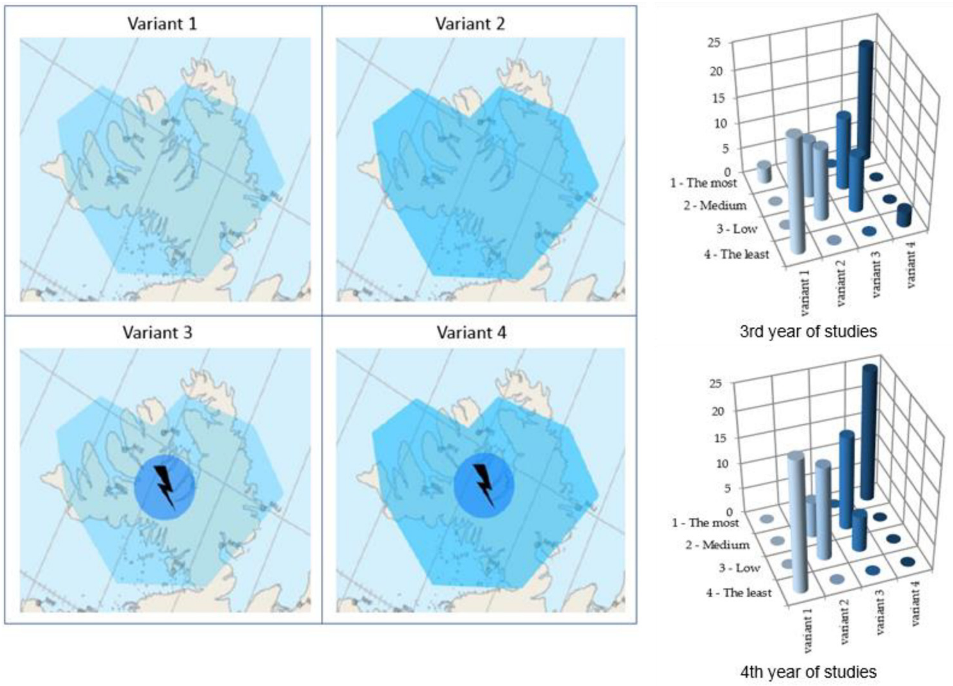
The next task was to sort the graphic variants according to the readability of area presentation (1 – the most, 4 – the least readable). Variants differed by types of boundaries: no boundary,

Figure 13 Assigning colours to hazards category



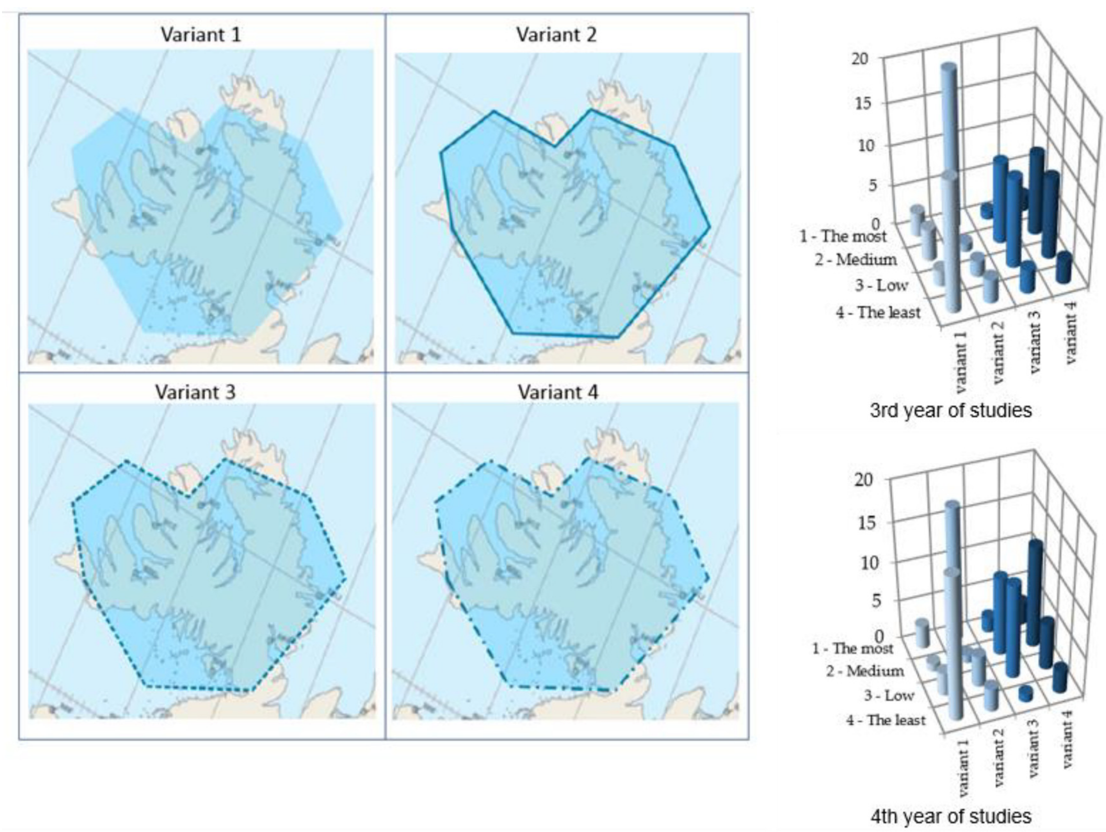
Source: Figure by authors

Figure 14 Phenomena intensity and variant correlation



Source: Figure by authors

Figure 15 The readability of area presentation



Source: Figure by authors

continuous line, dashed line, dash-dot line, as shown in Figure 15.

It can be concluded that a clear outline is important. However, certain types of contours can denote national borders, so they should be chosen judiciously. The thicker the line, the more readable the single object is, and respondents did not find objects without boundaries readable.

Another case concerned the possibility of using drawing with contours in a continuous or intermittent manner, considering different information type.

The test was designed to define readability based on the change in type and colour of the border line. The most readable variant is represented by the third (Figure 16). The least readable was Variant 2. In conclusion, respondents found borders of common colour and continuous line to be the most readable, while those where the line is not continuous and of various colours were not preferred, when areas were not overlaying.

The next example (Figure 17) was designed to be similar to the previous one, but the difference relied on the overlaying of the areas.

Analysing the data, it is not clear which information would be the most readable, with Variants 3 and 4 being preferred by respondents with higher experience, so in this sense, when overlaying polygons are encountered, the preference is not so clear as in previous (Figure 16) example.

4.6 Determining the readability of the object's transparency level

The respondents were also asked about defining the range of preferred polygon transparency based on the chart (Figure 7), as it allows both reading map information underneath and determining the colour of the polygon.

As per Figure 18, respondents preferred the transparency range of 31–50, depending on colours.

In the next question (Figure 19), respondents had to choose the most legible and intuitive phenomena variant outlined on the ERN chart Network portal (Eurocontrol), 2022c. The first variant gained the most votes, so it can be concluded that weather factors that are distinguished by colour, intensity and pictograms were found the most intuitive. Pictograms and variations of boundary colour described the phenomena (Variant 3), was considered the least intuitive.

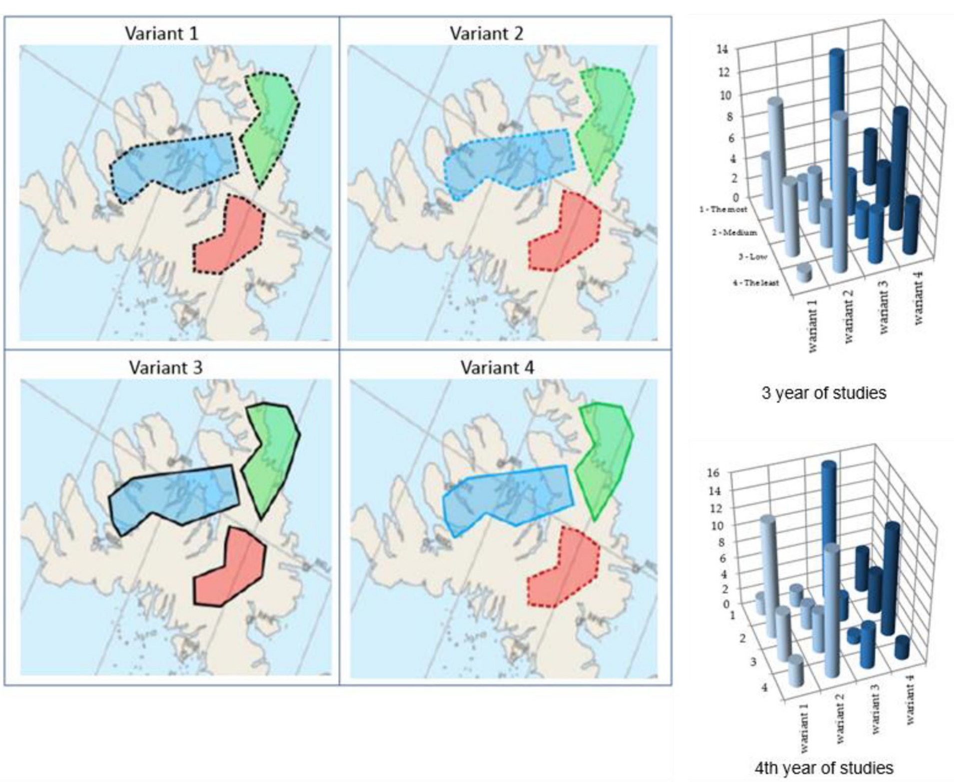
4.7 Combined data in colours processing

In the following part, respondents were asked to assign the border colour of weather phenomena based on their individual preference. As this task is highly subjective and multiple colours could be used, the data for the presentation were processed using the median (Figure 20).

Some trends can be noticed, as phenomena such as hail, rain or snow were associated with shades of blue. Yellow was mostly assigned to thunderbolts, while shades of red were linked to turbulence, icing and wind shear. Noticeably, ambiguities in hazard description using colour occur once again, as air traffic in Figure 12 had the same colour as thunderstorms in this example. These ambiguities can lead to decision-making problems in-flight and should be addressed so that pilots can clearly assess visual clues.

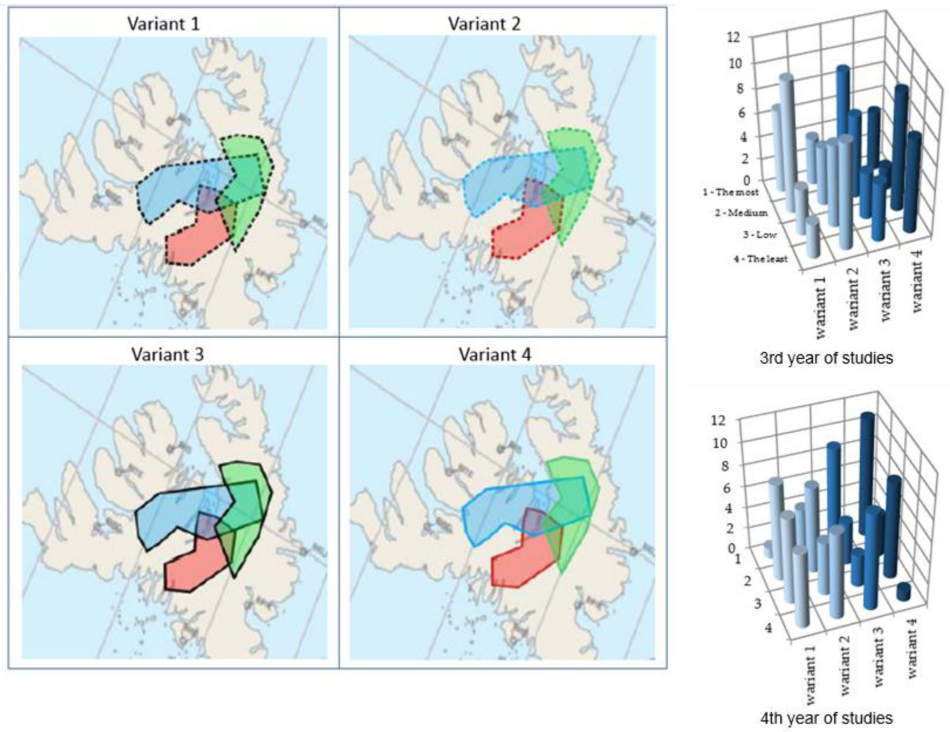
Following task was to match the colour to the type of given information, considering its intensity (e.g. heavy rain). The

Figure 16 Readability of separated areas



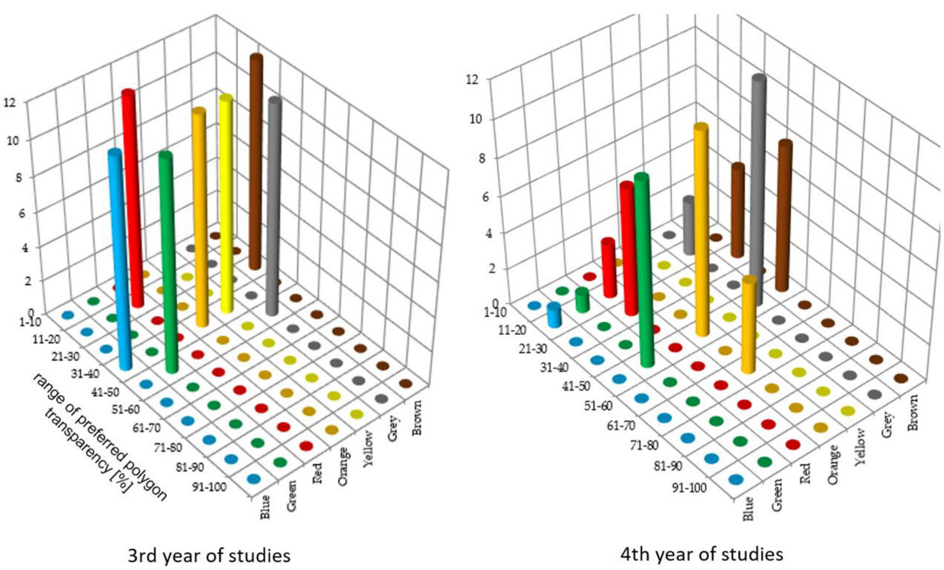
Source: Figure by authors

Figure 17 Readability of overlaying areas



Source: Figure by authors

Figure 18 Readability of information in relation with colours transparency levels

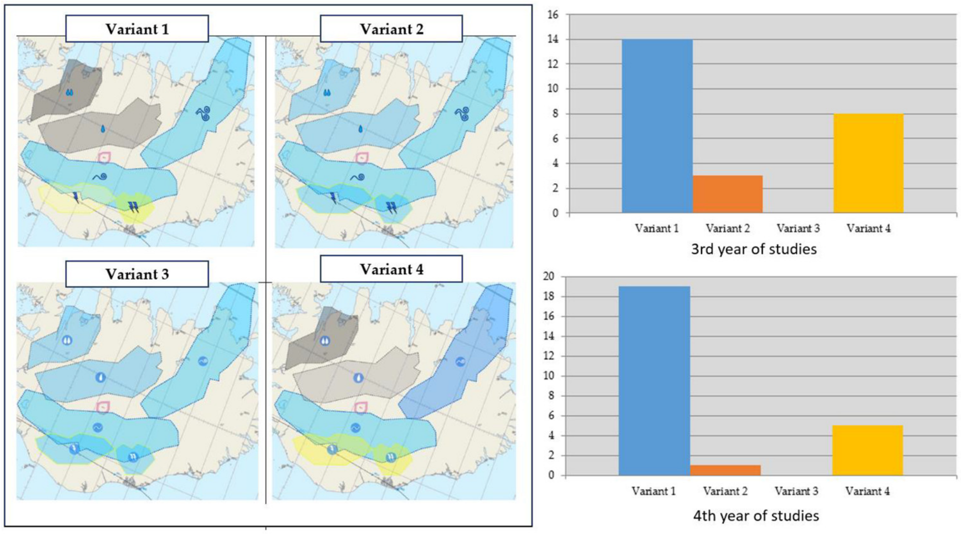


Source: Figure by authors

charts in Figure 21 present the answers regarding the choice of colour from the palette [Figure 6(a)].

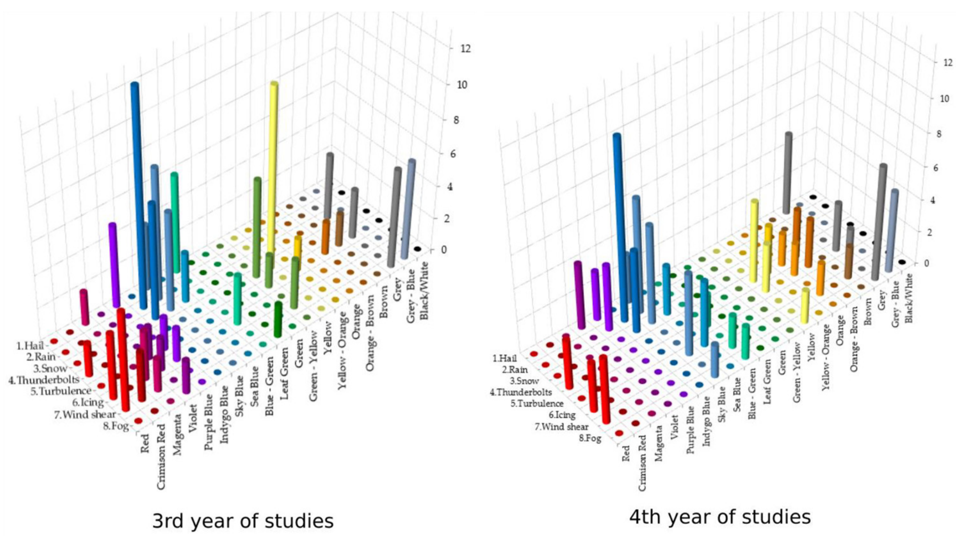
The answers were similar, and despite the proportions changing, the distribution of the votes led to the conclusion that colours are more subdued in inverse proportion to the intensity of the phenomenon (especially noticeable in the turbulence example). Analysing the data provided by respondents, it can be noticed that information marked with lighter shades is associated with lesser threat compared to darker ones.

Figure 19 Combined weather phenomena readability



Source: Figure by authors

Figure 20 The relationship between the colour of contours and individual weather hazards



Source: Figure by authors

4.8 Combined data in symbols processing

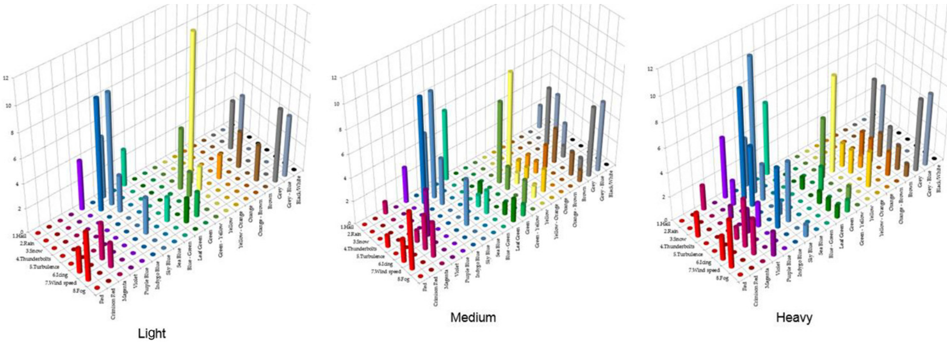
The task was to examine a method of processing and matching symbols, assigning them to specific phenomena or situations. Respondents showed preferences for multiplying pictograms and/or changes in terms of their shade to indicate changes in intensity, as shown in Figure 6. Figure 22 presents the most frequently selected symbols and responses from the survey.

Often, for intensity gradation, respondents preferred to use multiplied symbols. For air traffic and terrain hazards, respondents preferred colour changes to depict gradation.

5. Conclusions

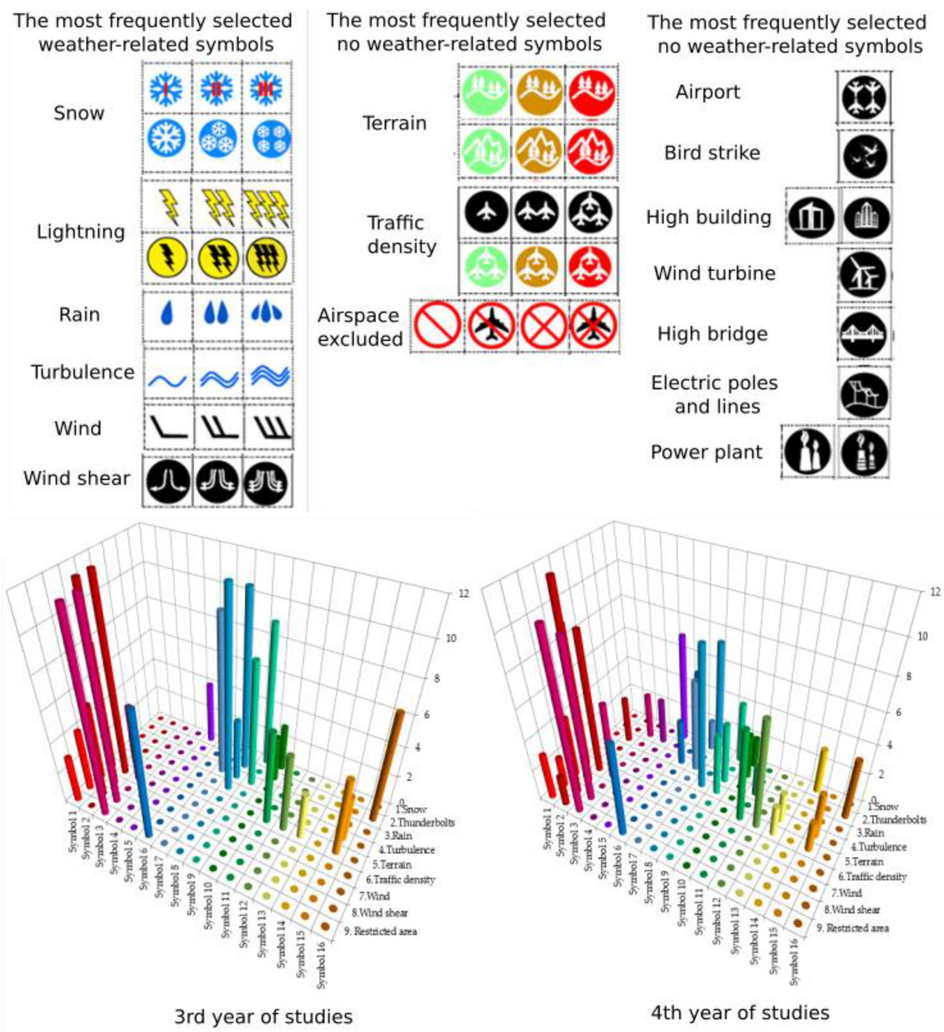
Although it seems that there are numerous aviation standards designed for GUI development, most of them were published by the FAA, ICAO, SAE and RTCA prior to 2020, with the majority dating back to 2015. Given the rapid expansion of technology (particularly tablets since 2010), the latest advancements in this domain may not be fully reflected in the regulations. Based on the research, it can be stated that significant analysis was conducted regarding individual preferences for cockpit visualisation methods, with a focus on

Figure 21 The relationship between the colour of polygon and weather hazards intensity



Source: Figure by authors

Figure 22 Commonly selected symbols describing hazards



Source: Figure by authors

display techniques that consider the possibility of presenting hazards from multiple sources on a single screen, which is not clearly addressed in the regulations. This led to the development of a specific survey as a research tool, which was then used to test a group of pilotage adepts. During the analysis of the results, it was noted that, consistent with EASA guidelines, red colour was perceived as indicating the most significant threats, while white colour was associated with the least important information. Additionally, most obstacles and weather warnings were commonly marked in shades of blue/grey.

An interesting finding is the noticeable discrepancies among individuals, such as ambiguities between preferred coding for hazard groups (global context) and individual hazards (obstacles/restricted subgroup), or in assessing the scale of the intensity of the phenomena.

Some ambiguities and limitations of the results also emerged, including the influence of flight experience on potential answers or cultural background influence. The research does not provide a clear answer on how to display overlapping hazards; it can be noted that the applicability of the proposed visualisation methods and their testing is a particularly interesting topic, especially in light of the results of interface testing in flight as demonstrated in the COAST project as well as limited human capability of hazard perception.

Future research directions should focus on clarifying uncertainties, determining human capacity to distinguish different hazard types, defining the level of detail in the display and investigating hazard severity (e.g. hazard prioritisation).

It is evident from the research that displaying all relevant information on one screen requires the creation of an intuitive system, given the differences in environmental perception. However, ambiguities in the responses indicate that there is currently no universal system for displaying all significant information from various sources. High-level standardisation should be considered, as the ability to interpret hazard types quickly is essential for decision-making, especially during emergencies.

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