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Prerequisites for Statistical Analyses of the Quality of Instrument Flight Procedures

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ABSTRACT

Instrument flight procedures are essential and critical components of the global aviation system. They are designed for all phases of flight, i.e. the standard instrument departures, standard instrument arrivals, instrument approaches and the en-route phase of flight. Instrument flight procedures are designed from various aeronautical data, information, dimensions, etc., which are named instrument flight procedure elements according to this paper. Development of air navigation systems affect design of instrument flight procedures and flexible use of airspace. The design process is carried out within a framework defined by international and national standards, organizational norms and economic aspects. Instrument flight procedure elements are a fundamental part of the process. Deviations of these elements from full compliance with international regulations can significantly and negatively affect air traffic safety. The objective of this paper was to investigate the basic prerequisites for statistical analysis of the design quality of instrument flight procedures, which have not been explored before. Six prerequisites were proposed for acquiring the data and preparing them for further statistical use.

KEYWORDS

instrument flight procedures; prerequisites; statistical quality control.

1. INTRODUCTION

Prerequisites for statistical analysis of the instrument flight procedure (IFP) enable quantitative statistical monitoring of their quality.

IFPs are a set of predefined flight manoeuvres in the standard instrument departure (SID), standard instrument arrival (STAR), instrument approach procedure (IAP) and en-route phases of flight. IFPs must be protected, i.e. the regulations and all known restrictions must be followed. The regulations related to the construction of IFPs are mostly the regulation of the international civil aviation organization (ICAO) with their annexes and documents. The most important is [1], which is periodically amended and supplemented. IFPs are designed concerning aircraft performance, technical characteristics of navigation systems, aerodromes, terrain and obstacles, meteorological phenomena, environmental requirements, airspace and user requirements. All these features, in addition to international and national regulations that prescribe the criteria for the construction and publication of IFPs, are a set of heterogeneous information and data, subject to change and the possible occurrence of defects. Establishing a quality management process for the design and maintenance of the IFP is important to the ICAO. In this sense, the flight procedure design organization (FPDO) is required to define how progress toward the set goals will be measured. Quantitative analyses of the quality of instrument flight procedures have not been implemented worldwide thus far.

According to [2], statistical thinking, quality tools and fact based approaches are necessary for process improvement and to provide practitioners with appropriate data to support decisions. Regarding establishing an efficient measurement system, the measures of that system should be clearly defined, understood [3, 4] and have a meaning [5]. Measures should be practical and have an appropriate scale [6]. To measure a phenomenon, it is possible to use one of the following measurement scales: nominal, ordinal, interval and ratio. In aviation, ordinal scales from one to five are also an instrument for collecting data for statistical analysis to make decisions by research questions [7–9]. According to [10], problems are transformed into statistical ones in the measurement phase. For the obtained data, it is possible to determine whether it is parametric or nonparametric data, and statistical methods can be selected for their testing. After determining the normality of the distribution, the procedure for testing data sample is defined using inferential statistics, i.e. a set of methods that define conclusions about the characteristics of the population [11]. Distributions are largely not subject to the normal distribution, so nonparametric tests are performed as a replacement for parametric tests. Many authors reiterate that only nonparametric tests can give valid results for ordinal data. The authors [12] elaborate how nonphysical phenomena can be measured, i.e. situations when many of the phenomena we encounter are not physical but cognitive and by defining measurement scales, any phenomenon can be quantified. Ordinal measurement scales (such as Likert's) use a set of statements, where each of them is evaluated separately by a scale of attitudes toward the statement and consists of a set of equally spaced numbers followed by approximately equally spaced anchors (e.g. from 1= "Strongly Agree" to 5 = "Strongly Disagree"). Nonparametric tests for ordinal data, such as the chi-square test, Mann–Whitney test and Kruskal–Wallis test, enable verification of data distribution, population affiliation, etc. According to [13], ordinal data are commonly converted into nominal data and analysed using binomial or Poisson models. For process control various tools and methods can be applied. Control charts for process stability [14–17] and metrics such as rolled throughput yield (RTY) to measure overall process performance can be used [18, 19].

With this paper six prerequisites were defined. The first four prerequisites are defined to establish the IFP sample frame, and the last two prerequisites are defined to describe and to propose the tests for the acquired data by using the inferential statistics and to transform the data into the form that will be suitable for analysis with appropriate statistical tools. Finally, we made a test to check and to confirm requirements proposed by this paper.

Previous research in the field of instrument flight procedures is related to the aspects of the implementation and use of the new sensor technologies [20, 21], environmental aspects [22, 23], economic aspects [24], IFP design automation [25], etc. but not related to statistical control of the IFP development process, which makes this paper the first of its kind. Research on the six sigma methodology application is relatively scarce within the aviation industry. Nevertheless, some studies focus on combined Lean management principles and the six sigma methodology. These studies focus on the identification of critical factors and performance indicators (PI) for the airlines [26, 27].

2. METHODOLOGY

The ICAO IFP regulations [1, 28] require states to establish control over the design and maintenance of the IFP development process. IFP implementation is the state's responsibility, which means that the state regulator has the ultimate responsibility for IFPs on its territory. Regulation [1] stipulates that the state must implement quality control measures to design IFP and introduce a quality system for the entire IFP development process. In addition, this system must cover the entire process from data collection to final publication in in the national aeronautical information publication (AIP). The state is ultimately responsible for the IFPs published in the AIP. The role and importance of aeronautical information/data have changed significantly with the introduction of performance based navigation (PBN), i.e. area navigation (RNAV) and required navigation performance (RNP), computerised aeronautical navigation systems and systems for air data connectivity. The tools used with the criteria, the human–machine interface (HMI), the choice of software solution for the IFP design and renewing and upgrading the knowledge of IFP specialists through periodic training are also of significant importance. Within the objectives and description of the process, it is necessary to define input and output elements and other elements that include monitoring the work process and conducting quantified process measurements based on process objectives and values [28]. IFPs are designed from various aeronautical data, information, dimensions, etc. and according to this paper are named IFP elements. The IFP element is the basis for the design and maintenance of the IFP and is subject to systematic errors that affect the quality of the process and thus air traffic safety. By classifying and statistically processing IFP elements and their deviations from full compliance with defined standards and general practice, it is possible to improve the process of design and maintenance of IFPs can be improved. This paper defines the prerequisites for the development of such a method.

2.1 First prerequisite: IFP phases under the quality control

IFPs are classified into conventional and PBN. Conventional IFPs are based on terrestrial navigation aids. At the same time, the PBN IFPs are based on satellite and terrestrial systems (distance measurement equipment, i.e. DME and very high frequency omnidirectional range, i.e. VOR) that can also enable PBN navigation (i.e. DME/DME and VOR/DME). The methodology, tools, regulations and preservation of the quality of the IFP design have changed significantly in the last 20 years with the gradual introduction of the PBN concept. The current and future development of the IFP is based on satellite navigation systems, pseudo satellite navigation systems and automated systems in aircraft. For Europe, the plan is to withdraw all conventional IFPs by 2030. So, this work will be concentrated on developing prerequisites for statistical analysis of the quality of IFPs exclusively for the PBN elements. With this paper, defining the prerequisites for statistical analysis of the IFP quality was based exclusively on the fixed-wing aircraft category A/B/C/D with its speed performance prescribed by [1] and not on helicopters.

According to [1], quality is subject to regular supervision of the civil aviation agency (CAA) for three IFP types, i.e. SID, STAR and IAP as they are defined, prescribed and classified according to the ICAO regulation [1].

2.2 Second prerequisite: Defining the IFP element

The IFP development process involves exchanging heterogeneous aeronautical information and data. This paper considers any aeronautical data, information, criteria and calculation used in designing and implementing the IFP as an IFP element. In the IFP design and implementation, the main sources of the IFP elements are flight procedure design (FPD) service, air traffic control (ATC) service, flight inspection and validation (FIV) service (i.e. pilot opinion), aerodromes (AD), communication-navigation-surveillance (CNS) service, geodesy and cartography (G&C) service, and meteorological (METEO) service. All of them according to their business rules provide various aerodrome data, aeronautical data, obstacle data, survey data, IFP concept and criteria data, airspace data, IFP validation data, navigation aid (NAVAID) data and general information. In addition to the sources mentioned above, other participants in the process are critical to the IFP implementation process, such as government regulators participating in the process as supervisors and approvers of each IFP. In addition, the aeronautical information management (AIM) service is responsible for publishing the IFP through the national AIP. In the flight information region Zagreb (FIR Zagreb), specific data on obstacles (the world geodetic system 1984, i.e. WGS84 coordinates and altitudes/heights), such as mobile antennas, wind turbines and other structures, are also received from the state CAA. Still, any data for use in the IFP design process are subject to prior verification and delivery by the official air navigation service provider (ANSP) geodesy and cartography service.

The number of IFP elements per IFP varies depending on the type of IFP phase of the flight and the complexity of the IFP with environmental conditions such as mountain terrain, proximity to the state border, noise-sensitive areas, NAVAID signal availability, etc. Based on the research conducted by this paper and all defined IFP element types and its sources it was concluded that the most significant percentage of elements in the IFP design process belong to the FPD source (80%). The FPD elements are primarily used in constructing and preparing the IFP for publication. Other IFP elements in the design process account for 20%, the most numerous of which are those related to geodesy and cartography elements, i.e. various types of data related to the coordinates and heights. Despite the smaller number of individual sources of IFP elements in the design process, this does not mean that individual elements are not crucial or that they are less critical for the IFP design process. Thus, for example, the IFP elements obtained from the aerodrome, which relate to the runway thresholds, are highly critical aerodrome data. However, the share of such elements is among the smallest for the IFP design.

According to the IFPs prepared and published thus far in FIR Zagreb, it is estimated that for 410 conventional and PBN IFPs, there are over 30,000 IFP elements. At the same time, for PBN IFP only, which is the subject of this paper, there are over 13,000 elements. Some IFP elements are repeated in several instrument flight procedures, but each is part of a separate IFP and is error prone.

The main steps of the IFP development process according to [28] and the application of relevant sources of IFP elements for each part of the IFP development process are shown in *Figure 1*. Thus, the IFP development process (through which IFP elements pass) starts with the appropriate previous originators. Then adequate IFP elements from various sources are compiled and prepared for further use. This is followed by using the IFP elements in the FPD part of the process to pass the final IFP elements on to the end user through the aeronautical information service (AIS).

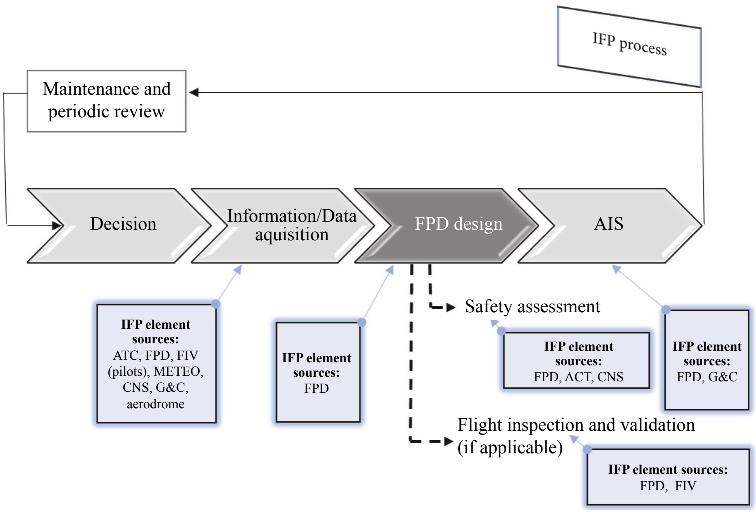

Figure 1 – IFP element sources through the IFP development process

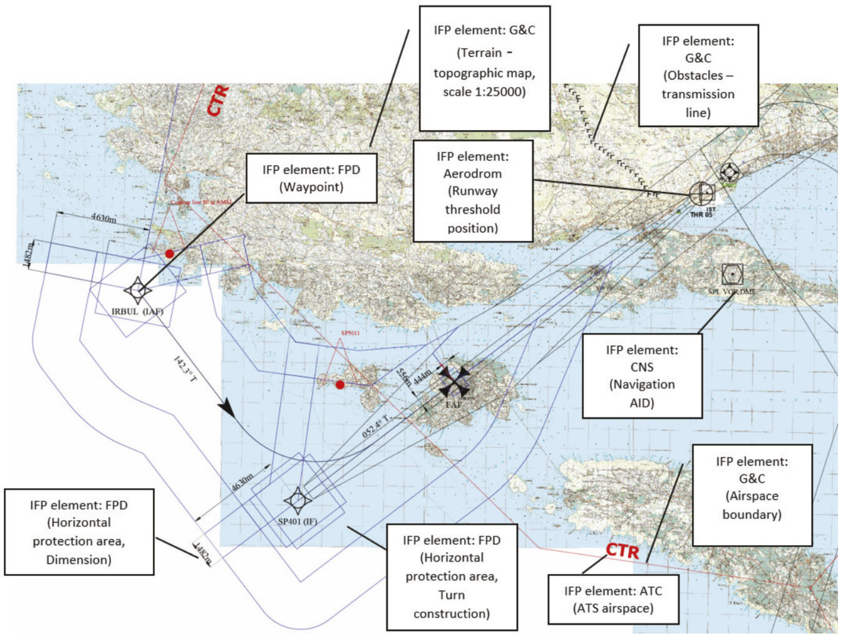

Figure 2 – Example of the IFP elements used for the construction of the IFP PBN approach

The quality of the elements for creating an IFP and its coding, publication and transfer to the aircraft's flight management system (FMS) depends on the input elements. The pilot from the FMS system on the aircraft calls the IFP with the code name assigned to it, which is cleared by the ATC and flies the same with complete confidence for himself/herself and the aircraft in all weather conditions. This highlights the importance of a properly designed IFP and all its elements in the IFP development process chain for security. Applying satellite and pseudo satellite systems in air navigation brings numerous advantages and challenges to IFP designers and users. It is essential to preserve the safety and quality of IFPs. The environment in which IFPs are designed is subject to constant technical and technological changes, the development of new work means, and the fluctuation of people. *Figure 2* shows an example of the IFP construction work and various IFP elements (topographic maps, 3D obstacles, waypoints, dimensions, NAVAID, protection areas, etc.) on initial, intermediate and final approach segments. Each of the IFP elements affects the final product in their way with its criticality for IFP design, from the beginning of the IFP design process to the official publication.

2.3 Third prerequisite: Classification of the IFP element system

As the system is generally a set of technical, mental and other elements, so is the IFP system a set of all aeronautical data and information elements related to the SID, STAR and IAP phases of flight. The system of IFP elements can be decomposed, i.e. divided into subsystems (strata), and the structure of the system of IFP elements can be analysed (a schematic is given in *Figure 3*). According to the vertical distribution, the strata are divided into aspects of the use of IFP elements through the IFP development process, i.e. the strata of input, construction, output and functional elements. The strata best describe the IFP design and maintenance process, i.e. the flow of IFP elements and the environment in which they are defined. Horizontally, the main IFP phases of flight are observed, which are subject to periodic inspection by the FPDO and the state regulator to which they belong, i.e. SID, STAR and IAP phases.

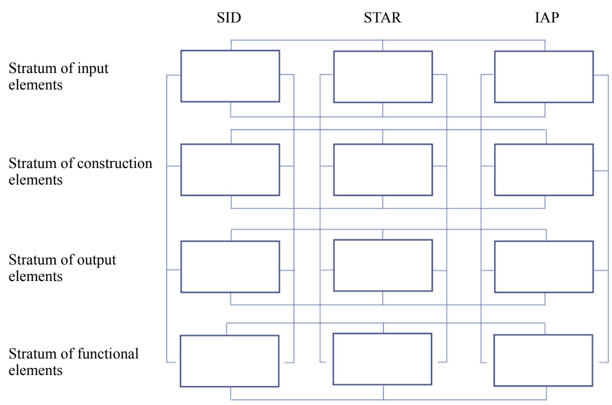

Figure 3 – The schematic structure of the strata of the IFP element system by its vertical and horizontal distribution

According to the previously proposed vertical strata, this paper's entire system of IFP elements is classified into four functional subsystems. Each of them is further divided into variables and related IFP elements (*Figure 4*). For this paper, it was essential to include the most crucial elements that are part of the IFP design and maintenance process based on performance (PBN) and that affect its quality. This analysis of the IFP system provides insight into the functioning of the process. Regarding the IFP development process, the IFP elements in this paper are divided into four subsystems, as follows: input element subsystem (IES), construction element subsystem (CES), output element subsystem (OES) and functional element subsystem (FES).

Within each proposed subsystem, appropriate variables are defined depending on the properties of THE IFP elements to which the IFP elements are similar and according to technical regulations [1, 29, 30, 31, 32] to which compliance with international regulations and general practice are assessed.

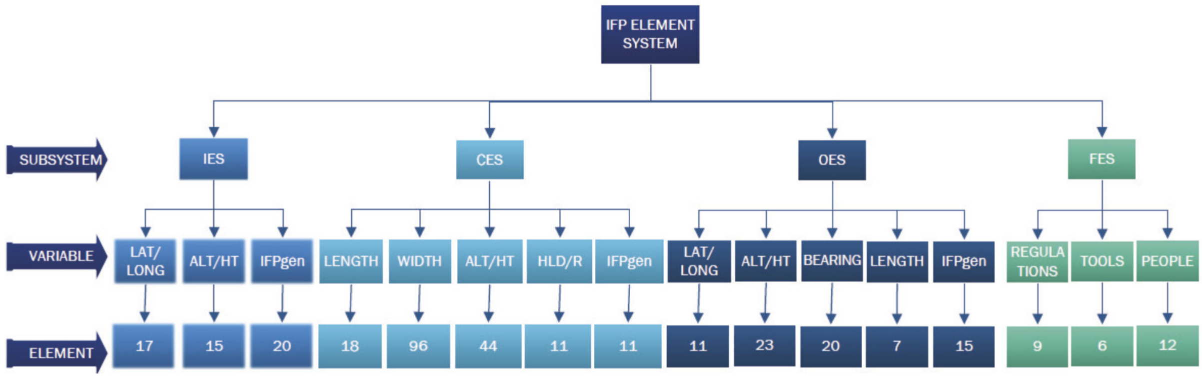

Figure 4 – Classification of the IFP element system

The input elements subsystem (IES). The input information is mainly defined with accuracy and resolutions. The most crucial quality requirement for the design of an IFP is the resolution. According to the above, three variables of input elements were defined:

1) coordinates of positions (latitude/longitude, i.e. LAT/LONG). The variable refers to coordinates that include the positions of runway thresholds, airport reference points, navigation devices, SID/STAR/IAP significant points (waypoints) and obstacle coordinates.
2) absolute and relative heights (altitude/heights, i.e. ALT/HT). The variable refers to the absolute and relative heights of positions, which include runway thresholds (RWY THR) and departure end of the runways (DER), airport reference points (ARP), NAVAIDs, obstacles, transition altitude and reference datum height (RDH) for the approach procedure with vertical guidance (APV) and precision approaches.
3) general data (IFP GEN) are the data that do not have the prescribed mathematical accuracy and resolution by international documents and are essential for the IFP design process. The IFP GEN variable refers to general data and information on approach lights, magnetic variation, meteorological phenomena, barometric pressure readings, controlled areas, airspace classifications, standard temperatures, airport temperatures, NAVAIDs operating time and range, terrain data (topographic maps, digital terrain model), etc.

The construction elements subsystem (CES) arises from constructing an IFP. The FPD is defined as a set of dimensions and turn constructions that define the protection and optimality of aircraft routes, budgetary results and safe separation of aircraft from obstacles. Five variables of construction elements have been defined:

1) permitted segment lengths (LENGTH) concerning the flight phase, according to the document [1]. The LENGTH variable refers to the lengths of the segments. Their optimal and minimum/maximum allowable lengths and minimum stabilization distances.
2) segment widths (WIDTH). The WIDTH variable refers to the 2D spatial dimensions of the IFP protection areas, commonly called widths, which include 2σ fix tolerances, area semi widths, and calculated turn protection surfaces and angular splay of surfaces.
3) permitted minimum obstacle clearances (ALT/HT). The variable refers to the absolute and relative altitude protection of aircraft regarding the designed IFP by applying minimum obstacle clearances margins and budget minimum heights of segments.
4) criteria for defining holding procedures and reversal procedures (holding/reversal, i.e. HLD/R). This variable covers the common IFP elements, keys and characteristics for Holding procedures, Racetrack, Base turn and Procedural turn. This variable includes the correct application of the indicated speeds concerning the aircraft category, horizontal/vertical directions, descent gradients (degrees), the length for the applied procedure, the correct budget definition of lateral protection surfaces, the application of minimum obstacle clearance margins and segment altitude budgets.
5) general information (IFP GEN) relevant to the design of instrument flight procedures. The IFP GEN vari-

able includes IFP elements such as correctly applied indicated speeds for aircraft category, horizontal/vertical directions, vertical gradients (degrees), passing altitudes and coding tables.

The output element subsystem (OES). The IFP approved for official use and are published in the official state AIP. Five variables of the IFP output elements are defined in this subsystem:

1) position coordinates (LAT/LONG). The variable refers to coordinates that include positions: fixes, significant points (waypoints) and positions important for geometric alignment of aircraft in flight (e.g. landing threshold point, LTP; final path alignment point, FPAP).
2) absolute and relative heights (ALT/HT). The variable refers to the absolute and relative minimum altitudes, and individual altitude data for geometric alignment of aircraft in flight (e.g. RDH; threshold crossing height, TCH).
3) navigation directions (BEARING). The variable refers to magnetic and true bearings resolutions for all phases of IFPs and resolutions for vertical angles and gradients.
4) distances (LENGTH). The variable includes IFP elements related to the lengths of the publication segments for all phases of the SID/STAR/IAP IFPs.
5) general qualitative information (IFP GEN), which does not have the prescribed mathematical accuracy and resolution by international documents but should be applied according to the general rules prescribed by the ICAO. The IFP GEN variable includes IFP elements for publication, such as indicated aircraft speeds, IFP text descriptions, notes and warnings, IFP code names and published magnetic variations on instrument charts.

The functional elements subsystem (FES) is defined concerning the IFP design environment. In this subsystem, three variables of functional IFP elements are defined, which relate to the following:

1) available and updated REGULATION. This variable refers to owned and regularly updated international regulations relevant to the IFP development process, i.e. the ICAO procedures for air navigation services – aircraft operations (PANS-OPS) regulations and ICAO annexes and the national rule book on the design and determination of methods, procedures and other conditions for safe take-off and landing.
2) specialist tools (TOOLS) used in the design of instrument flight procedures and their regular upgrades. The TOOLS variable includes various specific tools used in the IFP development process, such as computer-aided design and drafting (CAD) tools, special flight procedure design tools (FPDT) and other IFP design tools taken from the ICAO or EUROCONTROL organizations.
3) training/experience of the IFP specialists and IFP validators (PEOPLE) in the design of instrument flight procedures and their periodic additional training prescribed by domestic and foreign regulations. As such, this information belongs to general information without prescribed restrictions. This research defined the criteria for deviation from full compliance as a combination of international and national regulations and the experience of the authors of this paper.

2.4 Fourth prerequisite: IFP sampling frame

A prerequisite for any statistical analysis is to define a sampling frame. This paper presents a sampling frame for the IFP based on horizontal and vertical strata. The horizontal strata assume three phases of flight under the scope for the quality analysis in terminal control area (TMA). The vertical strata classification of the IFP element system was carried out with defined subsystems and variables up to the level of elements. For each of them an appropriate statement was applied. The statements were listed through a gap checklist adapted to the quality analysis of the design and maintenance of the IFPs. This gap checklist consisted of 335 statements on the compliance of the IFP elements with international regulations and general practice. It should be noted that the defined number of statements does not include all IFP technical standards, criteria, data or information, but only those considered necessary for the analysis of the entire system of design and maintenance of the IFPs related to the officially published IFPs. The statements can be considered as a list of questions that examine the compliance of the IFP system. For all four subsystems of IFP elements, 16 variables were defined, with a total of 335 elements and the same number of statements. The IES subsystem is defined with three variables and 52 statements, i.e. 15% of the total. Five variables were defined for the CES subsystem with a total of 180 statements, i.e. 54% of the total number. For the OES subsystem, five variables were defined with a total of 76 statements, i.e. 23% of the total number, and for the FES subsystem, three variables were defined with a total of 27 statements, i.e. 8% of the total number of statements. A total number of statements represents one sampling frame per airport. As each IFP is complex due to the influence of the environment, i.e. the position of each aerodrome and the distance of the aerodrome from the TMA entry/exit points, the number of IFP elements per sample may vary.

According to [18], the definition of measurement is the assignment of numbers to things to represent facts and conventions about them. A question arises from the rules, if any, according to which numbers are assigned. To collect data on the compliance of IFP elements, it is necessary to conduct a compliance assessment of each IFP element. In this paper, an ordinal measurement scale with levels from one to five was chosen to measure the degree of compliance. Level five indicates full compliance, level four indicates compliance, level three is usually compliant, level two is noncompliant and level one is a fully non-compliant element concerning international regulations and general practice. The criteria for assessing the compliance of each IFP element are also defined. According to the set criteria, out of the total number of statement rankings, 79% of statements refer to those that measured the compliance of the project IFP elements with technical deviations from the standards prescribed by international regulations (on an ordinal scale of 1 to 5), and 21% of all statements refer to general practice (Likert ordinal scale 1 to 5).

In this way, evaluating each IFP element from the statistical set according to the set criteria makes it possible to collect data for further statistical analysis. The collected data are a prerequisite for further statistical analysis, either for inferential data testing or for later application of statistical tools to determine the quality of the IFP development process.

2.5 Fifth prerequisite: Population testing

Establishing a sampling frame enables to collect data from a set of heterogeneous IFP elements. Each collected data is included in the verification related to normality testing (if the data are parametric or non-parametric). For this purpose, the Kolmogorov–Smirnov test was used. After testing for normality, the data were tested for belonging to the same population. Undoubtedly, confirming that there is no difference between the data, i.e. that they belong to the same population, is extremely important so that in later steps, statistical analyses can be performed on data to determine key performance indicators and the stability of the process and to use various other statistical tools for IFP development process quality management. The IFP element system is expected not to have a normal data distribution. The Mann–Whitney (U-test) and Kruskal–Wallis (H-test) tests are usually used to test the data that are not subject to a normal distribution. The Mann–Whitney (U-test) is a nonparametric test (corresponding to the parametric T-test). It is used to test two samples that are not subject to the normal distribution, where the difference between median sets is tested, and samples can have varied sizes. Kruskal–Wallis (H-test) is a nonparametric test for differences between three or more medians, consistent with parametric one-way analysis of variance (ANOVA). In [33], the statistical U-test and H-test are explained. The U-test requires combining and ranking both data samples together and then calculating the sum of the ranks for each sample. The *U* value for each sample was calculated as follows:

$$U_1 = n_1 n_2 + \frac{n_1(n_1+1)}{2} - \sum R_1 \quad (1)$$

$$U_2 = n_1 n_2 + \frac{n_2(n_2+1)}{2} - \sum R_2 \quad (2)$$

where n = number of measurements per sample and R = sum of ranks per sample. The Mann–Whitney (U-test) statistical test selects a smaller value than the calculations obtained for U_1 and U_2.

The procedure for the H-test is carried out by combining all the samples and ranking them together as follows:

$$H = \frac{12}{N(N+1)} \sum \frac{R_i^2}{n_i} - 3(N+1) \quad (3)$$

where N = number of observation data for all samples; n_i = number of observation data from the corresponding sum of ranks; R_i = sum of ranks from a particular sample; and 12 and 3 are constants.

These tests prove that there is no statistically significant difference between the medians (mean values) between the data sets of the analysed samples (Null hypothesis, H0). The main hypothesis and three auxiliary hypotheses are set.

Main hypothesis: There is no statistically significant difference in medians (mean values) between data sets obtained by measuring the compliance of the elements of PBN IFPs on two or more samples.

1) *auxiliary hypothesis*: Data on compliance measurement of IFP elements are not subject to normal distribution; performing nonparametric tests is necessary (K-S test, $p<0.01$).
2) *auxiliary hypothesis:* There is no statistically significant difference in medians (mean values) between samples, i.e. the set of data obtained by measuring the compliance of the IFP elements on one sample corresponds to the set of data obtained by measuring the compliance of the IFP elements on any other sample (U-test, $p>0,01$).
3) *auxiliary hypothesis:* There is no statistically significant difference in medians (mean values) between samples, i.e. data sets obtained by measuring the compliance of the IFP elements on three or more samples do not differ (H-test, $p>0.01$).

2.6 Sixth prerequisite: Transforming the IFP ordinal data

Ordinal data are usually transformed into nominal data and analysed by using binomial or Poisson models [13]. According to [17] defect detection is formulated as a binary classification problem (good versus defective quality):

$$QualityLabel = \begin{cases} 1 \text{ if } i\text{th item is defective } (+) \\ 0 \text{ if } i\text{th item is good } (-) \end{cases} \quad (4)$$

In this formulation, a positive quality label refers to a defective manufactured item, which is otherwise negative.

For example, if an ordinal scale was classified into bad-good-excellent, the quality analyst could only analyse the bad category [13]. This paper proposes transforming the ordinal scale into a nominal one so that all values of the ordinal scale with a result of less than four are analysed as defective, i.e. all data assessed as fully non-compliant, noncompliant and usually compliant were treated as defective elements to define binomial process analyses.

To determine why it is necessary to periodically start the project of statistical analysis of the quality of an IFP, an analysis of the probability of occurrence of defective elements may be made. Suppose the process generates a certain number of defective elements according to the binomial probability distribution. In that case, the probability can be calculated to obtain the exact number of defective elements in the sample, according to [13] as follows:

$$P(x) = C_x^n p^x (1-p)^{n-x} \quad (5)$$

where the value of n indicates the number of elements in the sample, p indicates the probability of occurrence of defective elements concerning previous research and x indicates the number of defective elements for which the probability of occurrence will be calculated.

The prerequisites of statistical analysis of the IFP quality are intended to justify the decision to launch a periodic IFP quality maintenance project at least once every five years. Statistical periodic IFP quality analysis projects within ICAO and national regulators worldwide have not yet been prescribed, so this paper contributes to such an effort.

3. COMPLIANCE ASSESSMENTS AND THE DATA TEST RESULTS

To verify the requirements defined in this paper, gap analysis data was collected for three Croatian airports, i.e. FIR Zagreb (ICAO nationality letters for Croatia are LD). Airports: Zagreb (ICAO location indicator LDZA), Split (ICAO location indicator LDSP) and Dubrovnik (ICAO location indicator LDDU). One sample was taken for each of the mentioned airport. With each sample one PBN SID, one PBN STAR and one PBN IAP in official use was randomly selected. The compliance of their IFP elements with international regulations and general practice was checked using the statements described in this paper through an established gap checklist and according to evaluation criteria. For each PBN IFP, there is technical documentation in written/calculation form with the corresponding technical drawings, from which the elements of the IFP were taken to measure compliance with international regulations and general practice. In total nine technical documentations were taken for collecting the data and testing.

3.1 Descriptive analyses of the data

First, descriptive statistics were used to perform a fundamental analysis of the data collected by sampling, and then the collected data were tested with inferential statistics. *Figure 5* shows the number of collected IFP elements per sample. Each IFP is complex due to the influence of the environment, i.e. the geographical position of each airport, surrounding terrain, populated areas, distance of the airport from TMA entry/exit points, etc.; the number of IFP elements per sample varies.

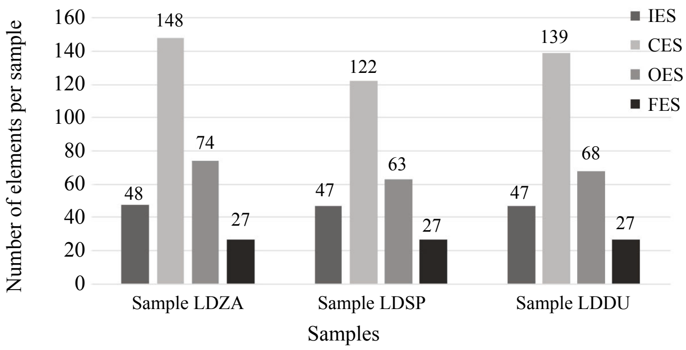

Figure 5 – The number of collected IFP elements per sample

Table 1 lists the nominal values of compliance of IFP elements by sample. For binomial statistical analysis, this paper has previously explained how the transformation of ordinal data implies a transformation so that data rated as fully non-compliant, noncompliant and usually compliant are *Defective*. At the same time, data rated as compliant and fully compliant are considered correct data (Not defective). The ordinal measurement scale data were collected according to the given criteria, where most of the IFP elements were fully compliant (94.1%), followed by compliant elements (5.4%) and noncompliant elements (0.5%). In contrast, there were no usually compliant and fully non-compliant elements.

The essence of this paper was not to enter the nature of the errors found and to analyse them with various statistical tools specific to attribute data, such as p-control charts, process stability tools, yield metrics, Pugh matrices, etc. but to define and propose prerequisites for such analyses.

Table 1 – Compliance of the IFP elements by sample

Ordinal scale	Defectiveness – binomial	Sample LDZA	Sample LDSP	Sample LDDU
1	Defective	0	0	0
2	Defective	2	1	1
3	Defective	0	0	0
4	Not defective	19	11	15
5	Not defective	276	247	265

3.2 Inferential analyses of the data

The results of inferential testing of the acquired IFP data aimed to test the set null hypothesis, the main hypothesis and the auxiliary hypotheses defined by this paper. The results of testing the samples are necessary to confirm the thesis of the data that do not differ from each other, i.e. the data that belong to the same population. This is one of the fundamental prerequisites for conducting further statistical analyses of the quality of the IFP design and maintenance. First, the data were tested to check normality and whether it was necessary to perform nonparametric tests.

Using IBM SPSS tools, the collected data were tested by the K-S test according to previously defined variables for combinations with two LD AD samples (see *Table 2*). The results *p* from *Table 2* and for all three LD AD samples are 0.000 across the variables, which does not mean that there are no values behind zero. This leads to the conclusion that the first auxiliary hypothesis for the studied cases is confirmed, the data are not distributed according to the normal distribution ($p<0.01$) and nonparametric tests are needed.

Table 2 – K-S test for combinations with two LD AD samples

IFP subsystem	Variable	Samples LDZA-LDSP (*p*)	Samples LDZA-LDDU (*p*)	Samples LDSP-LDDU (*p*)
IES	Lat/Long	0.000	0.000	0.000
IES	Alt/Ht	0.000	0.000	0.000
IES	IFP Gen	0.000	0.000	0.000
CES	Length	0.000	0.000	0.000
CES	Width	0.000	0.000	0.000
CES	Alt/Ht	0.000	0.000	0.000
CES	HLD/R	0.000	0.000	0.000
CES	IFP Gen	0.000	0.000	0.000
OES	Lat/Long	0.000	0.000	0.000
OES	Alt/Ht	0.000	0.000	0.000
OES	Bearing	0.000	0.000	0.000
OES	Length	0.000	0.000	0.000
OES	IFP Gen	0.000	0.000	0.000
FES	Regulation	0.000	0.000	0.000
FES	Tool	0.000	0.000	0.000
FES	People	0.000	0.000	0.000

Table 3 shows the *p* values obtained using the Mann–Whitney test (U-test) for combinations with two LD AD samples each. The results *p* from *Table 3* ranged between 0.172 and 1.000. The result *p* for the U-test collectively, without division into variables, ranged between 0.221 and 0.574 for the cases studied, leading to the conclusion that the second auxiliary hypothesis in this paper is confirmed (U-test, $p>0.01$). This means that there is no statistically significant difference in medians (mean values) between samples and that set of data obtained by measuring the compliance of the IFP elements on one sample corresponds to the set of data obtained by measuring the compliance of the IFP elements on any other sample.

Table 4 shows the *p* values obtained using the Kruskal–Wallis test (H-test) for all three LD AD samples. The results *p* ranged between 0.581 and 1.000. The result *p* for H-test collectively, without division into variables, was 0.463 for the cases being studied, leading to the conclusion that the third auxiliary hypothesis in this paper is confirmed (H-test, $p>0.01$). Accordingly, this confirms that there is no statistically significant difference in medians (mean values) between samples and that data sets obtained by measuring the compliance of the elements of IFPs on three or more samples do not differ (H-test, $p>0.01$). This further means that the data sets belong to the same population as the previous auxiliary hypothesis.

Table 3 – U-tests between two IFP samples by variables

IFP subsystem	Variable	Samples LDZA-LDSP (*p*)	Samples LDZA-LDDU (*p*)	Samples LDSP-LDDU (*p*)
IES	Lat/Long	0.763	1.000	0.763
IES	Alt/Ht	0.172	0.210	0.949
IES	IFP Gen	1.000	1.000	1.000
CES	Length	1.000	1.000	1.000
CES	Width	0.322	0.620	0.593
CES	Alt/Ht	1.000	1.000	1.000
CES	HLD/R	1.000	1.000	1.000
CES	IFP Gen	1.000	1.000	1.000
OES	Lat/Long	0.973	0.748	0.809
OES	Alt/Ht	0.537	0.498	1.000
OES	Bearing	1.000	0.792	0.792
OES	Length	0.699	0.699	1.000
OES	IFP Gen	1.000	0.983	0.983
FES	Regulation	1.000	1.000	1.000
FES	Tool	1.000	1.000	1.000
FES	People	1.000	1.000	1.000

Table 4 – H-tests for three IFP samples by variables

IFP subsystem	Variable	Samples LDZA-LDSP-LDDU (*p*)
IES	Lat/Long	0.581
IES	Alt/Ht	0.177
IES	IFP Gen	1.000
CES	Length	1.000
CES	Width	0.606
CES	Alt/Ht	1.000
CES	HLD/R	1.000
CES	IFP Gen	1.000
OES	Lat/Long	0.809
OES	Alt/Ht	1.000
OES	Bearing	0.349
OES	Length	0.809
OES	IFP Gen	0.998
FES	Regulation	1.000
FES	Tool	1.000
FES	People	1.000

A total of 132 tests (Kolmogorov–Smirnov, Mann–Whitney and Kruskal–Wallis) were conducted using the IBM SPSS Statistics version 26. The paper confirms that the null hypothesis is true, i.e. there is no difference between the values tested.

3.3 The results on the occurrence of defects

Previous research showed a defectiveness in the IFP elements of 0.8%, which can be rounded to 1% of defects. In this paper, according to the sample frame containing 335 IFP elements and with the determined percentage of defects, it was decided to determine the probability of the occurrence of defective elements in the samples. Two possibilities were analysed – one for zero defective elements and the other for their cumulative occurrence. Using the Minitab tool, the calculation showed that the probability of finding any defective element in the sampling is 96.5%.

Then, the cumulative probability of occurrence of defective elements was calculated. With this analysis, the aim was to define the number of defective elements that could appear per sample. Using the Minitab tool, it was found that it could be claimed with 99.8% probability (the result is 0.997702 or 99.8%) that nine or fewer defective elements would appear in the sample.

Based on the binomial distribution, the results showed that it is possible to expect errors during the IFP design process. It is important to note that workflow defects may not be significant to flight safety but may indicate workflow anomalies, which can lead to safety hazards (e.g. inadequate training and refresher of procedure designers, etc.).

4. DISCUSSION

The originality of this work lies in its discussion of a unique, unexplored application, namely, the quantitative, statistical analysis of IFP quality. No significant literature can be associated with the area studied in this paper. Still, the ICAO pressure states to find a way to monitor the quality of IFPs statistically. Therefore, the methodology presented in this paper is based on six prerequisites.

From the paper it was concluded that established methodology and test results prove the possibility of statistical analysis of the IFP quality.

Regarding the implication of this paper, it can be used for State Agency supervision or for FPDO improvements on its own. This study is on the path to make improvements to explore the possibility of moving from periodically qualitative to periodically quantitative statistical analysis of the IFP design. Periodic verification of each officially published IFP takes considerable time, sometimes even years, spent verifying hundreds of IFPs. In contrast, statistical projects based on the prerequisites proposed in this paper will take several months with precise quantitative results of the current level of the process quality and its shortcomings. Thus, this can save much energy and time for the FPDO, make room for improvements and leave the time for other FPDO activities during the five years.

This work was limited to analysing the global navigation satellite system (GNSS) PBN IFPs prescribed by the ICAO Doc 8168-OPS/611 Volume II. The PBN DME/DME IFPs are not covered with the statements, as they are not currently applied in Croatian FIR Zagreb airspace. However, if necessary, it is possible to expand the number of statements for this type of backup navigation.

5. CONCLUSION

The objective of this paper was to define prerequisites on which the IFP statistical quality control can be based. The six prerequisites were proposed for acquiring the data and preparing them for further statistical use. From the first to the sixth prerequisite described in this paper, it was elaborated how to best comprehend and statistically process all the important IFP elements for periodical maintenance of the IFP quality. As part of the process, it was important to define the proper instrument flight phases that need to be quality checked regularly. Huge effort was made to define and classify the system of IFP elements. Furthermore, it was important to define the statements that best describe and question the quality of every element. Data were collected for further testing by establishing the sample frame, evaluating elements with the established criteria and by using an ordinal measurement scale. Inferential statistics were used to check the data distribution, which is a prerequisite for applying proper further tests. As it was confirmed that the data were not normally distributed, nonparametric tests for two (U-test) and three samples (H-tests) were used, which showed no difference between the analysed data, i.e. the data belonged to the same population. Since the tests applied determined that the data were not normally distributed, the statistical tools that can be used for analysing the quality of the IFP development process are the attribute statistical tools. For further statistical application, ordinal data were appropriately transformed into nominal data. In addition, binomial analyses were conducted on the occurrence of defects, which showed that there is a possibility of the occurrence of defects for the analysed IFP development process (FIR Zagreb), and this paper showed that it is justified and possible to conduct an IFP quality control in a quantified statistical manner.

A few defects are to be expected in the design of an IFP, but each FPDO is obliged to carry out maintenance and five-year periodic quality control of each IFP under their authority. For the moment, the process is globally qualitative, but this paper has considered that it is possible to periodically control the quality of the IFP in a quantitative manner. This paper shows that heterogeneous IFP elements can be brought under statistical control.

The essence of this paper was not to go into the nature of errors and analyse them with various statistical tools specific to attribute data (*p*-control chart for process stability, yield metrics, Pareto, Pugh matrices, etc.) or analyse their hazards with risk matrices but to define and propose prerequisites for such an analysis.

Further research is foreseen in establishing a periodic project of maintenance of IFPs based on the Six Sigma DMAIC method and developing a specialised computer expert system that substitutes the IFP experts' opinions in analysing the quality of the IFP design. It is presumed that such IFP expert system can be based on combined firm rules and fuzzy logic.

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Preduvjeti za statističku analizu kvalitete instrumentalnih letnih procedura

Sažetak

Instrumentalne letne procedure osnovna su i kritična komponenta svjetskog zrakoplovnog sustava. Oblikovane su za sve faze leta, tj. standardne instrumentalne odlaske, standardne instrumentalne dolaske, instrumentalna prilaženja i rutnu fazu leta. Instrumentalne letne procedure oblikovane su iz različitih zrakoplovnih podataka, informacija, dimenzija, itd., a koji su prema ovom radu nazvani elementima zrakoplovnih informacija. Razvoj zrakoplovnih navigacijskih sustava utječe na oblikovanje instrumentalnih letnih procedura i fleksibilnu uporabu zračnog prostora. Proces oblikovanja se provodi unutar okvira kojeg definiraju međunarodni i nacionalni standardi, organizacijske norme i ekonomski aspekti. Elementi zrakoplovnih informacija su temeljni dio procesa. Odstupanja ovih elemenata od potpune sukladnosti s međunarodnom propisima može značajno i negativno utjecati na sigurnost zračnog prometa.

Cilj ovoga rada bio je istražiti osnovne preduvjete za statističku analizu kvalitete oblikovanja instrumentalnih letnih procedura, koje do sada nisu istražene. Predloženo je šest preduvjeta za prikupljanje podataka i njihovu statističku uporabu.

Ključne riječi

instrumentalne letne procedure; preduvjeti; statistička kontrola kvalitete.