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Preliminary Identification and Analysis of Encoding Errors in GA Pilot Weather Reports (PIREPs)

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ABSTRACT

Pilot Weather Reports (PIREPs) are one way that pilots may provide actual weather conditions to other pilots, air traffic control (ATC), flight service, and the national weather service. These pilot reports provide firsthand real-time information about the weather conditions that pilots encounter. PIREPs communicate weather information that is difficult to obtain otherwise such as icing aloft, turbulence, sky cover, and low-level wind shear. This firsthand information provided through PIREPs is critical to aviation safety and weather forecasting. For General Aviation (GA) pilots, PIREPs are of special importance because they may not have on-board weather radar or access to a dispatch service that is commonly used by the airlines. Additionally, many of these pilots may be operating smaller and lighter aircraft compared to those operated by the airlines. For an immediate radio PIREP to occur, the pertinent weather condition encountered is: 1) recognized by the pilot, 2) communicated via radio, 3) written by receivers, 4) encoded into PIREP codes, and 5) disseminated.

There are potential errors that may result in PIREPs that are untimely, misleading, erroneous, or never get disseminated. Assuming that the weather information submitted by the pilot was complete and error-free, this study aims to identify the types of coding errors, frequency by PIREP text element indicators (TEIs. e.g., /SK, /TP, /IC), and their proportions. Statistical and graphical analyses were used.

In this study, PIREPs obtained from the Iowa State University Iowa Environmental Mesonet (IEM) PIREPs database are analyzed. A spring/summer time frame is desirable to capture a variety of GA PIREPs. The 06/01/2019 to 07/31/2019 timeframe was selected for the study, and aircraft types were limited. A total of 3,654 PIREPs were obtained from Cessna 172, Mooney Acclaim, and Piper Cub aircraft over this time frame. From this pool, 50 PIREPs from each of these three aircraft types were randomly selected and analyzed. The encoded PIREPs were compared to the encoding guidelines found in federal documents such as FAA Order JO 7110. U, *Aeronautical Information Manual (AIM), Federal Meteorological Handbook No. 12,* and the PIREP Form FAA Form 7110-2.

From this study, a better understanding of PIREP coding errors may lead to the development of training to address submission and disseminating errors, and also provide requirements for automated systems. Better coding of PIREPs could lead to more PIREPS getting disseminated, and more informed and consistent analysis for weather forecasting. More accurate PIREPs have the potential to improve aviation safety.

INTRODUCTION AND BACKGROUND

During a flight, pilots may encounter changes in weather conditions. When pilots report actual weather conditions they encountered, it is called a Pilot Weather Report (PIREP). PIREPs are firsthand reports made by pilots concerning the weather conditions they face during flight [1]. PIREPs are one way that pilots may provide local weather information that is difficult or impossible to detect otherwise. PIREPs provide firsthand real-time information about the weather conditions that pilots face. This weather information is disseminated to other pilots, weather forecasters, air traffic controllers, and flight briefing personnel among others in the national airspace system. This firsthand information is critical to aviation safety and weather forecasting. For General Aviation (GA) pilots, PIREPs are of special importance because they may not have on-board weather radar, access to dispatch, or a company, and maybe in smaller, lighter aircraft than commercial transport category aircraft. In addition, icing, turbulence, and low-level wind shear are difficult if not impossible to detect using ground-based or satellite weather sensors. Therefore, PIREPS may be the only source of weather information available to GA pilots or air traffic controllers [2]. The Federal Aviation Administration (FAA) recommends pilots submit at least one PIREP on each flight, regardless of whether the encountered weather is good, bad, or match weather forecasts [3]. The weather information reported should be accurate and timely to increase its usefulness.

PIREP Codes: PIREPs are disseminated to other pilots using a coded language that compresses the weather information reported into short phrases. For example, urgent PIREP at 2010 Zulu (time) was reported by a DC-10 flying at 37,000 feet about 75 nautical miles southwest (240 degrees) of Anchorage, Alaska, and noted that Mt. Augustine erupted with volcanic ash 40 nautical miles south and moving south-southeast. This PIREP might be coded as: *UUA /OV PANC240075 /TM 2010 /FL370/TP DC10 /WX VA /RM VOLCANIC ERUPTION 2008Z MT AUGUSTINE ASH 40S MOV SSE SO2* [4]. These phrases, divided by forward slashes (/), are the specific PIREP categories referred to as Text Element Indicators (TEIs) on the PIREP form (FAA Form 7110-2) [5]. There are five required categories of PIREP – Message Type, Location, Time, Flight Level, and Aircraft Type – and seven weather-related categories – Turbulence, Icing, Sky Cover, Flight Visibility, and Weather, Temperature, Wind, and Remarks [3][6].

PIREP Submission: Pilots may submit a PIREP using a web-based application or may communicate weather information to controllers over the radio. In both cases, pilots do not submit PIREPs as codes. Instead, they communicate conversationally with controllers over the radio or via a touch or drop-down option list on web applications. Typically, for an immediate radio PIREP to occur, the pertinent weather condition encountered in the air is – 1) recognized by the pilot, 2) communicated by the pilot via radio, 3) written by receivers/controllers, 4) encoded to PIREP codes, and 5) disseminated.

PIREP Errors: During each of the five steps, there are potential errors that may result in PIREPs becoming untimely, misleading, erroneous, or never being disseminated. Pilots may make errors in identifying and reporting the weather they encountered. For example, pilots may report Moderate Turbulence as Medium or Intermediate Turbulence, or make errors in providing mandatory information such as their location, altitude, and aircraft type. Receivers/Controllers may make errors in receiving and encoding the weather information. For example, coding Moderate Turbulence as /TB MDT instead of /TB MOD, or missing on coding required fields such as time and flight level.

In this study, a sample of PIREPs available in the Iowa State University Iowa Environmental Mesonet (IEM) PIREPs database [7] were examined for coding errors. This database contains PIREPs that were disseminated across the United Stated and have made into the National Airspace System. In this paper, it was assumed that pilots reported the weather information accurately and without errors. Therefore, the errors in the PIREPs correspond to the coding errors generated at the receiver and disseminator end. A total of 150 PIREPs were analyzed for counts, frequencies, and types of encoding errors in PIREPs. Statistical and graphical analyses were used to describe the data. A better understanding of PIREP coding errors may lead to the development of training to address submission and disseminating errors, and also provide requirements for automated systems. Improved coding of PIREPs could lead to more PIREPS getting disseminated, and more informed and consistent analysis for weather forecasting. More accurate PIREPs have the potential to improve aviation safety.

METHODOLOGY

This section discusses the data sources, collection, and analysis procedures used in this study.

Data Sources and Collection: For this study, coded PIREPs were obtained from the Iowa State University Iowa Environmental Mesonet (IEM) PIREP database [7]. This database contains PIREPs that were reported from across the United States and had made into the National Airspace System. A spring/summer time frame of 06/01/2019 to 07/31/2019 was selected to capture a variety of GA PIREPs. To limit the scope of the study, aircraft types were limited to three common GA aircraft – Cessna 172 (C172), Mooney Acclaim (M20T), and Piper Cub (PA28). A total of 3,654 disseminated PIREPs were obtained from these three aircraft types over this time frame. From the selected pool of 3,654 PIREPs, 50 PIREPs from each of the three aircraft types were randomly selected for analysis. The PIREP sample is 150 total (3 x 50 = 150).

Data Analysis: Each of the 150 PIREPs was manually analyzed for coding errors. In this study, it was assumed that the weather information submitted by pilots was complete and error-free. Under this assumption, each PIREP was analyzed for errors in PIREP codes. The codes in the encoded PIREPs were compared to the PIREP encoding guidelines found in federal documents such as FAA Order JO 7110 [4], *Aeronautical Information Manual (AIM)* [8], *Federal Meteorological Handbook No. 12* [6], and the PIREP Form FAA Form 7110-2 [9].

PIREPs are divided into 12 categories known as the Text Element Indicators (TEIs). The federal documents provide guidelines to code weather information corresponding to each TEI. To identify coding errors in PIREPs, codes in each of the PIREP TEIs were compared to the formats and guidelines in the federal documents. A TEI code was counted as an error if it did not follow the guidelines strictly. Table 1 shows examples of some of the codes that were counted as errors. If a TEI code had any error, it was counted as *TEI with error.* The overall errors in PIREPs and all TEIs were graphed for the 50 PIREPs from each of the three aircraft, and for the combined sample of 150 PIREPs. The distribution of errors by TEIs was graphed for the combined sample.

Table 1. Examples of errors in PIREP TEIs codes

PIREP codes in the data sample	PIREP codes according to guidelines
/TB LGT TURB	/TB LGT
/FL30	/FL030 or /FL300
/TB LIGHT-MODERATE CHOP	/TB LGT-MOD CHOP
/SK BASES OVC035	/SK OVC035-TOPUNKN
/WX LGT RA	/WX –RA
/SK BKNUNKN/TOP025	/SK BKN-TOP025

Since the Remarks (/RM) category is open-ended, any type of information may be coded in this field and formats may be ignored. Therefore, the Remarks category was counted as a *TEI with error*, if and only if the information reported in Remarks should have been coded in another category of the PIREP. For example, /RM BKN050 code in the Remarks was counted as an error since the information belongs in the Sky Cover /SK category.

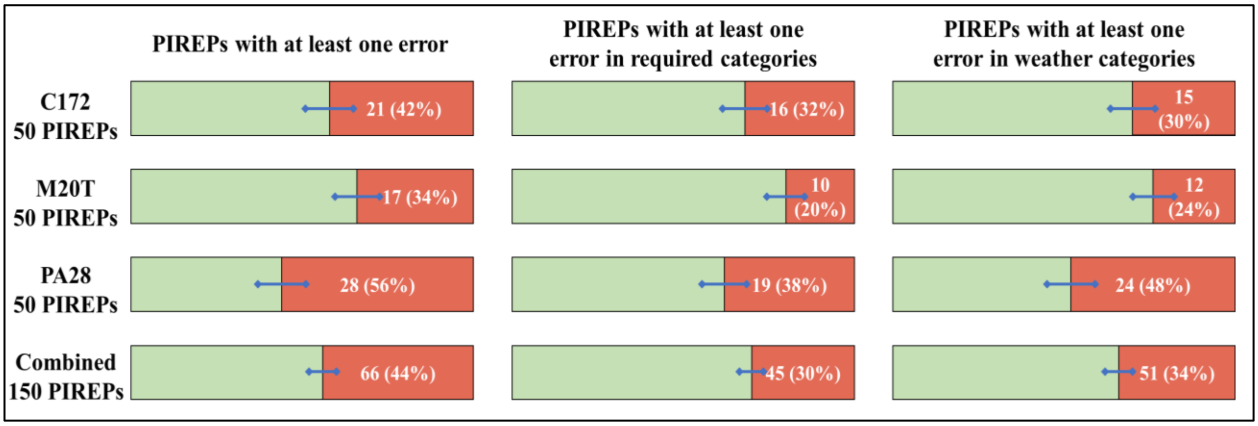
While some of the codes that vary from guidelines may have errors may still be discernable by humans. The purpose of coding is a consistent, compressed, and rapid form of communication of weather information. In this study, strict comparison with the guidelines was followed, and any variation from documented guidelines was counted as an error. The errors are essentially binary response variables – error present (1) or not (0). Therefore, proportions were used as point estimates and 95% confidence intervals were calculated using the normal approximation method for binomial data. The statistics are reported both in tables and in graphs, when appropriate.

RESULTS

This section details the results of the coding errors in PIREPs. The results are described in four major sections – overall errors, errors in TEIs, errors by PIREP categories, and types of errors. It is important to note that errors and confidence interval widths are reported in percentage points. Therefore, as an example, 30% (± 7%) essentially means that the point estimate of proportion is 0.30 with a width of ± 0.07, resulting in the 95% confidence interval of 0.23 to 0.37 or 23% to 37%. *The error estimates, sample sizes, and 95% confidence intervals for each of the errors reported in this section are summarized in Table 2.*

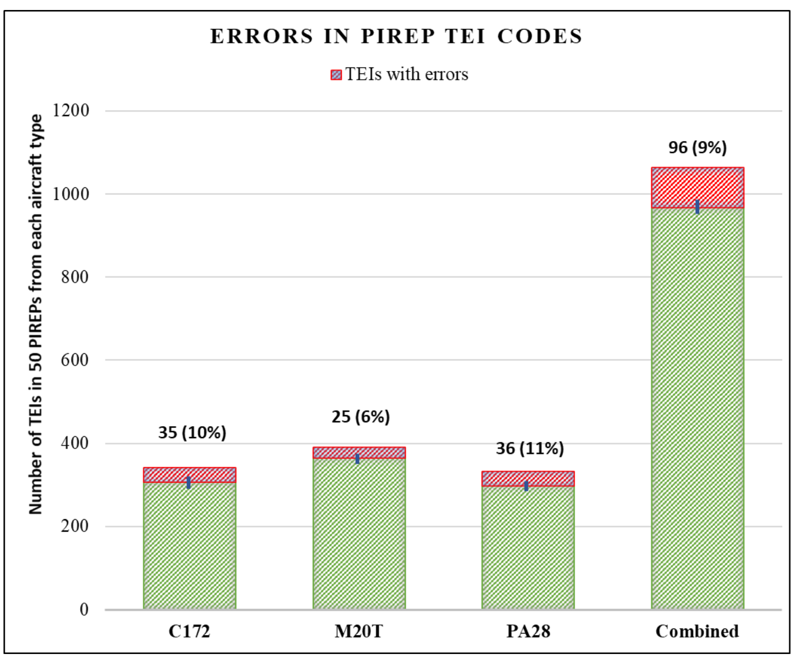
Overall Errors: From the 50 PIREPs for each of the three aircraft types, PIREPs with at least one error, PIREPs with at least one error in required categories, and PIREPs with at least one error in weather categories were identified and counted. Figure 1 shows results for each of the aircraft types as well as for the combined sample of 150 PIREPs. From the combined sample, 44% (± 8%) of the PIREPs had at least one error, 30% (± 7%) of the PIREPs had at least one error in the four required categories, and 34% (± 8%) PIREPs had at least one error in the weather categories. Note that the errors are calculated using the normal approximation method for binomial confidence intervals, sample size and proportions for each estimate, and an alpha of 0.05. Therefore, the standard error is given by $\pm Z_{\alpha/2}\sqrt{\frac{p(1-p)}{n}}$.

Figure 1. Overall results of errors in PIREPs.



Errors in TEIs: From each PIREP, the total number of TEIs present and TEIs with errors were counted. The 50 PIREPs from C172 contained a total of 341 TEIs; PIREPs from M20T contained 390 TEIs, and PIREPs from PA28 contained 333 TEIs. In total, the 150 PIREPs contained 1062 TEIs. Figure 2 shows the number (%) of TEIs with errors for each aircraft type and for the combined data sample of 150 PIREPs. A total of 96 (9% ± 2%) of TEIs had errors in the combined sample. Proportions of TEIs with errors were found for each PIREP. Figure 2 shows the lowest, mean, and highest proportions of TEI errors in PIREPs from three aircraft and from the combined sample. In the combined sample, a highest of 43% of the TEIs in a PIREP had errors, whereas there were PIREPs with no TEI errors at all, resulting in a 0% lowest error level. On average, 10% of the TEIs had errors in the combined sample of 150 PIREPs.

Figure 2. Number (%) of TEIs with errors and Lowest, Mean, and Highest proportions of *TEIs with errors* in PIREPs

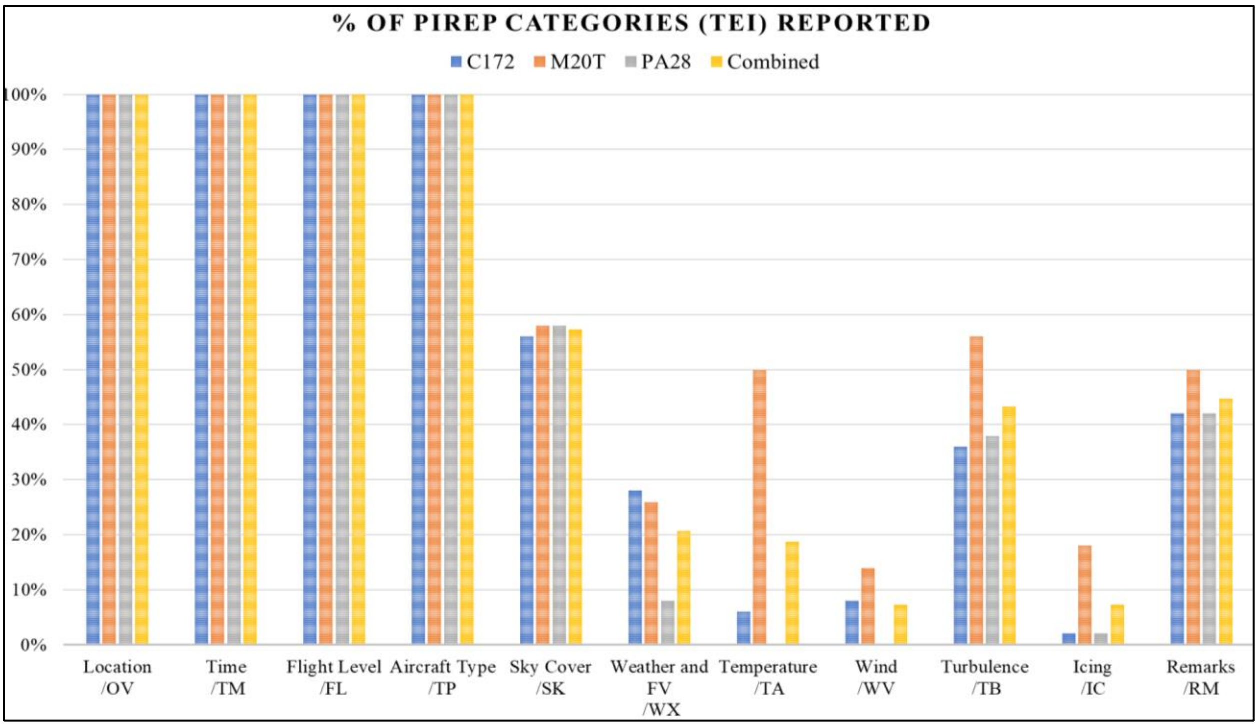


Proportions of TEI codes with errors in each PIREP			
	Lowest	Mean	Highest
C172	0%	11%	43%
M20T	0%	7%	43%
PA28	0%	11%	38%
Combined	0%	10%	43%

Interpretation of the table: In the combined sample, a highest of 43% of the TEIs in a PIREP had errors, whereas there were PIREPs with no TEI errors at all, resulting in a 0% lowest error level. On average, 10% of the TEIs had errors in the combined sample of 150 PIREPs.

Errors by PIREP Categories: Each of the PIREP categories was not reported in each PIREP. Figure 3 shows the percentage of each category present in PIREPs from C172, M20T, PA28, and the combined sample. The four required categories were reported in all PIREPs sampled. Sky Cover was reported in more than 50% of the PIREPs from each aircraft type. Temperature and Wind were not reported in any of the PA28 PIREPs. Since the PIREPs were selected from a summer time frame and most GA flights are at a relatively low altitude compared to summertime freezing altitudes, there were very few Icing PIREPs in the sample.

Figure 3. Proportions of PIREPs that reported the 12 PIREP categories (TEIs)



To find the errors corresponding to each PIREP category, errors were manually identified, segregated into respective categories, and counts were noted for the combined sample of 150 PIREPs. Figure 4 shows the category-wise distribution of coding errors. Time, Aircraft Type, and Icing categories had no errors in the codes. Sky cover codes had the highest error level of 35% (± 10%), followed by Location codes with 17% (± 6%) errors in codes. Sky Cover codes were inaccurate because of incorrect formatting of cloud cover, bases, and tops information. In the Remarks category, 15% (± 9%) of the codes were incorrect. Since the Remarks section is an open-ended field, any type of information may be coded within it. Therefore, a code in the Remarks section was counted as incorrect if it belonged to another PIREP category and was incorrectly placed in Remarks. Note that the errors are calculated using the normal approximation method for binomial confidence intervals, sample size and proportions for each estimate, and an alpha of 0.05. Therefore, the standard error is given by $\pm Z_{\alpha/2}\sqrt{\frac{p(1-p)}{n}}$.

Figure 4. Proportions of errors in each PIREP category (Combined Sample)

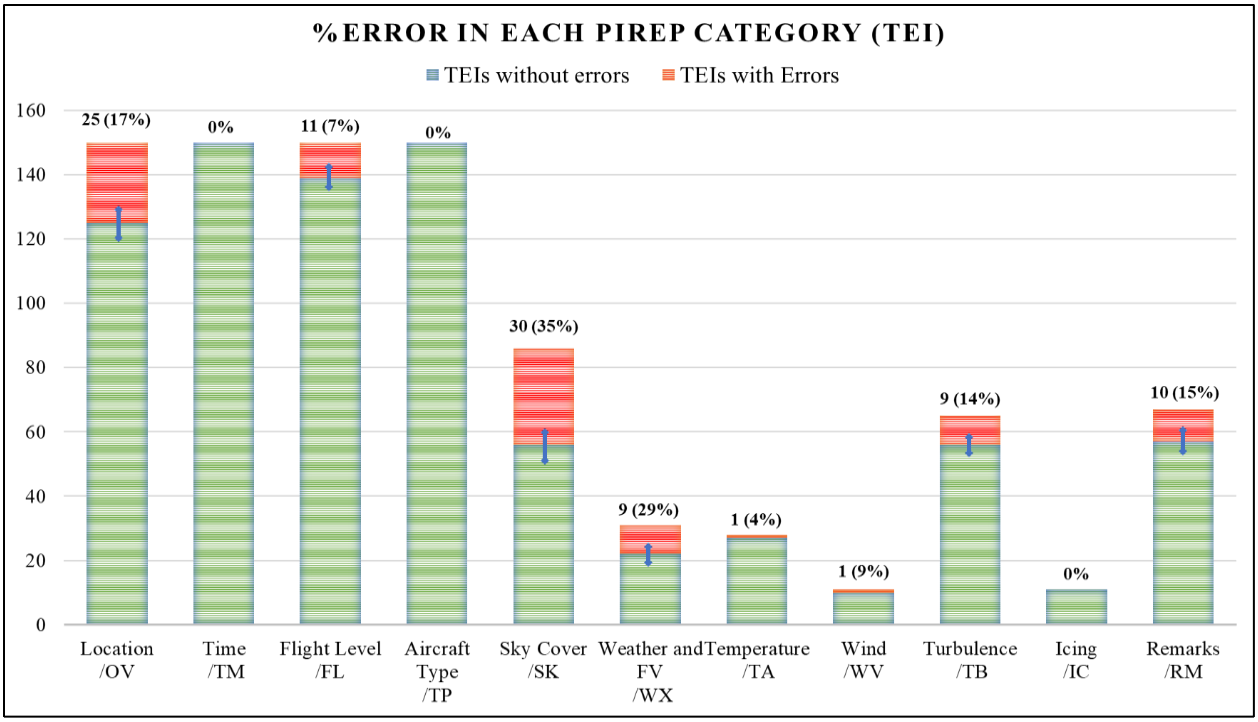


Table 2. Summary of error estimates and 95% confidence intervals for each of the errors

Errors	Sample size (n)	Proportion Point Estimate (p)	Std. Dev. $\sqrt{np(1-p}$	95% CI $Z_{\alpha/2}$ = 1.96		
				Std. Error $\pm Z_{\alpha/2}\sqrt{\frac{p(1-p)}{n}}$	Lower 95% CI	Upper 95% CI
At least one error in PIREPs	150	44%	6.0795	8%	36%	52%
At least one Error in Required Categories	150	30%	5.6145	7%	23%	37%
At least one Error in Weather Categories	150	34%	5.8017	8%	26%	42%
Errors in TEIs	1064	9%	9.3443	2%	7%	11%
Location /OV	150	17%	4.5644	6%	11%	23%
Flight Level /FL	150	7%	3.1927	4%	3%	12%
Sky Cover /SK	86	35%	4.4198	10%	25%	45%
Flight Visibility /WX	31	29%	2.5273	16%	13%	45%
Temperature /TA	28	4%	0.9820	7%	0%	10%
Wind /WV	11	9%	0.9535	17%	0%	26%
Turbulence /TB	65	14%	2.7846	8%	5%	22%
Icing /IC	11	0%	0.0000	0%	0%	0%
Remarks /RM	67	15%	2.9168	9%	6%	23%

Types of Errors in PIREP codes: The errors in PIREP codes were grouped into six types. Table 2 shows the six types of errors, examples, and frequency for each type of error. Formatting errors were the dominant errors in the PIREPs and included deviations from the published coding guidelines. There were 65 instances of formatting errors in 150 PIREPs. Next, there were seven instances where information was coded in a wrong PIREP category and four instances where critical elements of TEIs were missing. According to the *Federal Meteorological Handbook No.* 12, a valid PIREP must contain the five required elements of the PIREP and at least one weather-related element [6]. However, there were five instances where no weather information was provided in the PIREPs. Reporting no weather information is not the same as reporting good weather conditions. For instance, if no turbulence or icing is present, then the PIREP codes /TB NEG or /IC NEG must be present in the PIREP.

Some errors were easy to detect due to the practical limits of altitudes for these aircraft types, or codes entered as an abbreviation with no known meaning. For example, Flight Level code /FL1600 literally translates to a flight level of 160,000 feet, which is not possible for these three aircraft types. Similarly, /FL30 is an invalid code as it is impossible to determine whether the flight level is 030 (3,000 feet) or 300 (30,000 feet). There were four instances where the code contraction was unknown. Table 3 has examples of the errors.

Table 3. Examples of types of errors in PIREP codes

Types of Errors	Examples	Frequency
Formatting Errors	/OV 32 N CSG; /OV2NM FINAL RWY06 /TB SMOOTH; /TB LIGHT-MODERATE, /TA -2; /SK 005-007 SCT; /WX 5SM	65
Information coded in the wrong TEI	/RM LGT RAIN; /RM BKN050	7
No weather information reported	/OV FINAL R7 /TM 2048 /FL004 /TP M20T	5
Elements of TEI missing	/SK TOP125; /TB	4
Unknown code contraction	/WX UNLIMITED; /SK CLEAR; /FLARVL	5
Other obvious errors	/FL1600; /FL30; /SK OVC1500	8

DISCUSSION

GA pilots provide actual weather conditions aloft that are used by other pilots, weather briefers, and controllers to aid pilots in avoiding potentially hazardous weather conditions. This information is also used by meteorologists to improve current weather forecasts and forecasting models. For this information to be useful, it must be timely and accurate. In the 150 PIREPs sampled in this study, the overall error rate was high with 44% (± 8%) of PIREPs having at least one error. Errors were found in both the required sections of the PIREP (30% ± 7%) and the weather information sections (34% ± 8%). Errors in location and flight level are particularly troublesome as this information locates the weather being observed in three dimensions. Errors in weather conditions prevent the information from being accurate and potentially useful. Weather information such as sky cover, visibility, turbulence, and icing are crucial for other pilots and forecasters, however, errors were found in these PIREP codes. Commercial transport companies typically use aircraft dispatchers and/or automated texting systems to aid in reporting weather; GA pilots typically do not have these systems.

Need for training: Since PIREPs may be the only way for GA pilots to communicate real-time weather information to other pilots, ATCs, and forecasters, improving PIREP accuracy is critical for aviation safety. In this paper, the researchers focused on the errors in the PIREP codes and, therefore, assumed that the information provided by the pilots was error-free. Under this assumption, the researcher found that 44% of the PIREPs had at least one error. This is a high error rate considering the criticality of information conveyed through PIREPs in general aviation. This emphasizes the need for special training for the personnel receiving and encoding PIREP information. It has been highlighted by several pilots, controllers, and FAA experts that there is little training provided to accurately code PIREP information, and that the receivers must learn it on their own.

While many errors can be rectified manually, many of the errors are ambiguous. For example, /FL30 is not correct, but worse is that it is unclear. /FL30 could mean flight level of 30 feet, 3000 feet, or 30,000 feet. The standard form is to use /FL in hundreds of feet expressed as three digits. For example, 30,000 feet would be /FL300 while 3000 feet would be /FL030. There are numerous examples of this type of problem in other TEIs as well. While automation efforts may be adversely affected by these types of errors, training may decrease these errors.

It is important to note that the major assumption of this study is that the weather information provided by the pilots was error-free. This assumption was necessary within the scope of this study to focus on the coding errors. However, this assumption is not true in reality. A large proportion of errors in the PIREP codes may have propagated from the incorrect or errored information provided by GA pilots. Research on this may be pursued in future. During training, pilots are taught how to read PIREPs but are not always trained on how to submit one. This is a major source of errors in PIREPs. Therefore, there is an opportunity to develop training for pilots to accurately submit PIREPs, both ab initio and recurring. The combination of training pilots to accurately submit PIREPs and training controllers to accurately code PIREPs can significantly reduce the errors in PIREPs, and therefore, improve the quality of PIREPs and overall general aviation safety.

Opportunity for automation: Formatting errors are a large part of the high error-rate in manually coding the PIREP information. There are multiple chances of errors during the process of listening to a spoken PIREP, noting the details, and accurately converting them to codes. In addition, hands-on communication increases pilot workload. In times of adverse weather conditions, a pilot's priorities are aviate, navigate, communicate. Delayed communication may lead to inaccurate or late PIREPs which may appear to provide false weather information to other pilots in the region [2]. A potential solution to achieve higher accuracy, timeliness, and usefulness of PIREPs is to automate the PIREP submission and coding process, thereby, reducing the need for hands-on communication and manual coding [10] [11]. Researchers have been developing an automated PIREP system using a trained speech-to-text transcriber, a trained Named Entity Recognition (NER) model for information extraction, and a deterministic encoder [12] [13].

CONCLUSION

Weather conditions may contribute to fatal and non-fatal GA accidents and incidents. One way to improve aviation safety is to improve the reporting of accurate, timely, and useful weather information. Weather conditions aloft such as visibility, icing, wind shear, and turbulence are difficult if not impossible to detect using known and deployed technologies.

In this study, a sample of 150 PIREPs were selected as a stratified random sample over the spring/summer time frame of 06/01/2019 to 07/31/2019. Three common GA aircraft types comprised the strata: Cessna 172, Mooney Acclaim, and Piper Cub aircraft. A sample of 50 PIREPs from each of these three aircraft types were randomly selected and analyzed. The encoded PIREPs were compared to the encoding guidelines found in federal documents such as FAA Order JO 7110. U, *Aeronautical Information Manual (AIM), Federal Meteorological Handbook No. 12*, and the PIREP Form FAA Form 7110-2. From the combined sample of 150 PIREPs in the study, the major results obtained were:

1. 44% (± 8%) of the PIREPs had at least one error,
2. 30% (± 7%) of the PIREPs had at least one error in the four required categories,
3. 34% (± 8%) PIREPs had at least one error in the weather categories,
4. 9% (± 2%) of the Text Element Indicators had errors,
5. 35% (± 10%) of the Sky Cover codes had errors
6. 17% (± 6%) of the Location codes had errors
7. Six types of errors were identified – Formatting errors, information coded in the wrong TEI, no weather information reported, elements of TEI missing, unknown code contractions, and other obvious errors.

From this study, a better understanding of PIREP coding errors may lead to overall improved PIREPs. This information may be used to develop training and recurrent training for pilots and controllers on how to speak PIREPs and how to accurately code PIREPs, respectively. By reinforcing training and recurrent training, it is possible to expect high quality PIREPs to be available for forecasting and for navigating away from known adverse weather conditions. A better understanding of sources of errors in the current PIREP submission and dissemination process also helps in developing and improving automated systems. Better coding of PIREPs could lead to more PIREPS getting disseminated, and more informed and consistent analysis for weather forecasting. More accurate PIREPs have the potential to improve aviation safety.

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