Influence of time pressure on aircraft maintenance errors

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Introduction

Even though proper maintenance is crucial for aviation safety, tracing the effect that human error in maintenance operations has on accidents and incidents remains a difficult task. According to a UK Civil Aviation Authority study (2003), maintenance and inspection deficiencies ranked fourth (12%) as a factor in aviation accidents overall. Other studies have described that as technology has improved, aviation accidents attributed to mechanical failures alone have decreased, yet those attributed to human error have not shown the same reduction (Wiegmann & Shappell, 2003). Aircraft maintenance requires high reliability and is an important concern in the human factors realm for several reasons. On the one hand, automation, which has reduced flight crew workload, does not apply in maintenance operations (Reason & Hobbs, 2003). On the other hand, maintenance tasks generally access critical areas where human errors lead to serious consequences (Reason, 1997).

From a human factors perspective, in the current competitive environment of commercial aviation, occupational opportunities relating to aircraft maintenance technicians (AMTs) are declining. While oil prices soar, fares remain low due to competition (Bond, 2008). Employing fewer technicians and making turnaround at the airport gate shorter are two of the various ways airlines have sought to improve financial efficiency. These strategies often result in an increase of time pressure on technicians. Increased airport congestion has also intensified time pressure on AMTs as on-time performance is measured by regulatory agencies and consumers alike. The negative effects of time pressure on human performance have been reported in various studies (McDaniel, 1990; Lin & Su, 1998; Kellog, Hopko, & Ashcraft, 1999; Braun, 2000). Zakey (1993) argued that under time pressure, performance degradation occurred in complex tasks due to the shortage of cognitive resources, thus leading to the adoption of simple strategies and increased performance errors. Therefore, further studies regarding the effect of time pressure on human errors are indispensable to achieving higher levels of safety in aviation.

As a model of accident causation in complex systems, Reason (1990) proposed a human error production model based on a chain of causality. Contributing factors, such as psychological precursors, line management deficiencies, and fallible decisions, precede unsafe acts. Unsafe acts, which are direct causes of accidents, consist of skill-based errors (e.g. slip and lapse), rule-based errors (e.g. applying wrong rules), knowledge-based errors (e.g. misdiagnosis), and violations. Wiegmann and Shappell (2003) developed Reason's (1990) model and established the Human Factor Analysis and Classification System (HFACS) to investigate aviation incidents and accidents. HFACS describes four layers of failure: organizational influences, unsafe supervision, preconditions for unsafe acts, and unsafe acts.

The National Aeronautics and Space Administration's Aviation Safety Report System (NASA ASRS) collects voluntarily submitted information regarding unsafe aviation events, or incidents (NASA, 2000). The system, which is designed as a confidential and non-punitive incident reporting system, allows aviation professionals to submit reports regarding problems or errors so that the information may be used to assuage system deficiencies in the future. Along with capturing demographic information, the ASRS form instructs reporters to describe the chain of events leading to the unsafe situation in free-format narratives. Although the data contained in the ASRS database may be considered biased to some extent, due to the nature of voluntary reporting systems and the infinite sample size that could be represented, its narratives are a valuable source of information relating to the actual safety issues aviation professionals face each day. The purpose of this study, therefore, was to classify incidents in the ASRS narratives through focusing on unsafe acts and their contributing factors and to identify the unsafe acts and other contributing factors related to time pressure.

Methods

Procedure

Human factors researchers and a subject matter expert in commercial airline aircraft maintenance operations at the University of Illinois analyzed maintenance-related incident reports downloaded from the ASRS database. ASRS data was searched using two filters: reports relating to Federal Aviation Regulation (FAR) Part 121 scheduled commercial operations and maintenance related reports. These parameters were chosen since scheduled commercial flights would best represent high tempo operations, thus a set of events related to time pressure should be evident in the data. This initial search resulted in a set of 3534 reports. We further reduced this to 992 reports by focusing on the most recent 2-year period (From August 2004 to July 2006). One of the human factors researcher and the subject matter expert read and analyzed the set of the 992 ASRS reports for instances of unsafe acts and undesirable outcomes along with their associated contributing factors.

Coding unsafe acts

Unsafe acts in this study were coded using a modified Human Factor Analysis and Classification System (HFACS) (Wiegmann & Shappell, 2003), which is based on Reason's (1990) model. Unsafe acts consist of *skill-based errors, decision making errors, routine violations, exceptional violations*, and *process*. Skill-based errors consist of slips, lapses, and perceptual errors. For instance, inadvertently forgetting to close an inspection panel is an example of a skill-based error. Decision making errors include rule-based errors (e.g. applying wrong rules) and knowledge-based errors (e.g. misdiagnosis). For example, a decision error occurs when an AMT judges that an alarm sensor needs to be fixed without noticing that the mechanical system itself is broken. Routine violations represent habitual violations such as bending procedures and not using checklists. Installing a part without referring to documents is an example of a routine violation. Exceptional violations are willful violations such as falsifying data or blatantly forcing a technician to sign off on work he didn't perform. We introduced a category *process* to refer to a situation where a human error was reported, but the information in the report was not enough to specify the exact nature of the unsafe act.

Coding contributing factors

Contributing factors were also modified from HFACS. Although we originally coded 22 categories when the initial classification was conducted, these were integrated into 13 categories during the analysis phase, based on the similarity of the factors. The 13 resulting categories consist of *lack of vigilance, inappropriate attitude, time pressure, distraction/interruption, physical state, coordination, lack of experience, environment, equipment and parts, document and procedure, design, previous deviation, and organization*. Lack of vigilance represents carelessness to notice any signs of danger or required procedures. Inadequate attitude consists of complacency and overconfidence. Time pressure is a pressure to hastily complete a task as indicated by an approaching deadline. Distraction/interruption takes people's attention away from the task at hand. Physical state consists of physical fatigue, circadian dysrhythmia, physiological state, and physical limitation. Coordination includes issues within the maintenance group and between the maintenance group and other departments. Lack of experience involves insufficient job experience and training. Environment refers to situations arising from external occurrences such as cold and stormy weather, dark workspace, noisy surroundings and confined places that are difficult to access. Equipment and parts refers to situations wherein required equipment, tools, and parts are not available. Document and procedure illustrates when procedures are not well established or explained in the documents, such as the maintenance manuals, minimum equipment list, standard operation procedures of each company, and job cards of each task. Design refers to situations wherein the manufacturer's aircraft/component design does not aid in the prevention of human errors in maintenance. Previous deviation refers to previous technician errors that in turn induce another error on behalf of the receiving technician. Organization is a factor related to supervision and management.

Reliability and validity

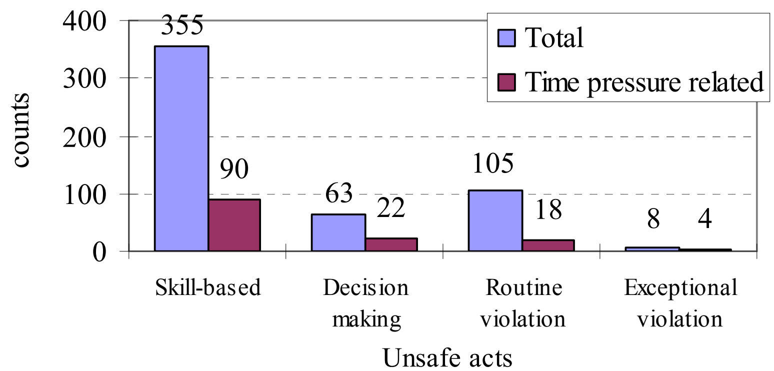
When the two raters did not come to agreement regarding a classification, a third rater would independently code the report and settle the categorization conflict. In order to ensure that the classification system in this study was valid, the independent coding results were tested for inter-rater reliability (Fleiss, Levin & Paik, 2003). The values of kappa for unsafe acts were mostly between 0.4 and 0.5, and those values for contributing factors were between 0.5 and 0.6. Based on the criteria introduced by Fleiss, Levin, and Paik, the raters achieved fair to good agreements beyond chance. It was expected that the value of agreement would improve as the raters read forward; however, the value did not improve drastically. This is partly because the narratives in the ASRS have various styles, depending on reporters and reported situations. This also represents the conundrum of incomplete "investigation." Thus this information can be interpreted differently, depending upon the reader's bias. Even with researchers who were focused on the issue of time pressure in maintenance operations, the reports still resonated differently according to expertise and academic background.

Results and Discussions

Among the 992 ASRS maintenance reports, 678 instances of human error were found. Four hundred and fifty four errors were self-reported by the person who committed the error.

Frequency of unsafe acts

Frequencies of unsafe acts are shown in Figure 1. Half of the errors in this study (n=355) were related to skill-based errors (52.4%). We were unable to determine the specific trigger events for 147 of the incidents in this study, thus these unsafe acts fell into the category *process* (21.7%). Routine violations (n=105, 15.5%) and decision making errors (n=63, 9.3%) followed. Few decision making errors were found most likely because aircraft maintenance is routinely performed based on instructions in documents; hence, there are fewer opportunities to make decisions. Few exceptional violations were reported (n=8) and this may be due to the voluntary nature of the ASRS; those who commit exceptional violations are perhaps loathe to disclose such proclivities. Each of the 8 exceptional violations in this study was not self-reported. In terms of time pressure related errors, skill-based errors (n=90, 62.1%) were predominant among the total distribution. Decision making errors (n=22, 15.2%) and routine violations (n=18, 12.4%) produced nearly the same frequencies.

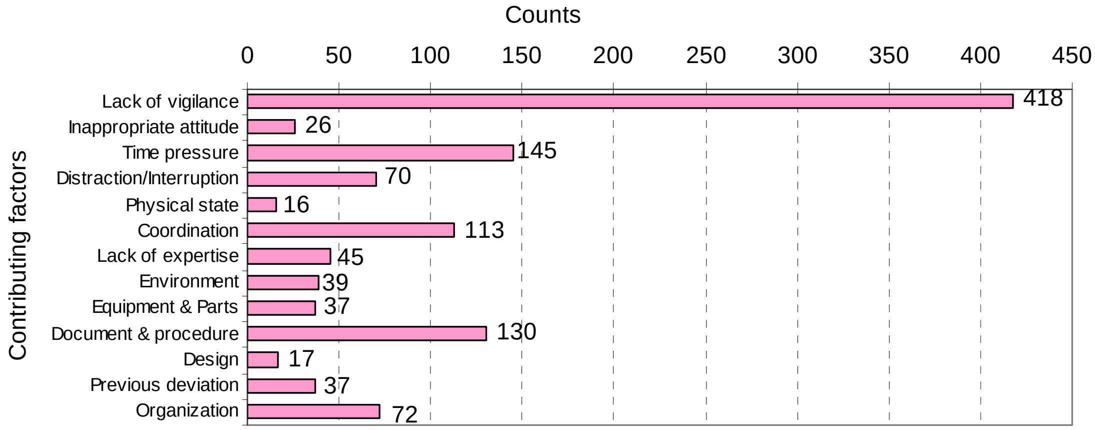


Frequency of unsafe acts

Figure 1

Frequency of contributing factors

The frequency of contributing factors is shown in Figure 2. Among the 678 errors, we determined that 151 error reports did not include enough information to allow thorough investigation of contributing factors. In the remaining 527 reports, lack of vigilance surfaced predominately in the contributing factors classifications (n=418, 79.3%). Time pressure was the next largest factor (n=145, 27.5%), followed by



Identified contributing factors

Figure 2.

documentation and procedure (n=130, 24.7%), coordination (n=113, 21.4%), organization (n=72, 13.7%), and distraction/interruption (n=70, 13.3%).

Lack of vigilance, e.g. carelessness to notice signs of hazard or perform required procedures, was identified as the largest factor among contributing errors. AMTs self-reported that they did not pay attention when they missed a task, or were not aware of the task altogether. Inappropriate attitude, consisting of overconfidence and complacency, can be seen in the narratives. When an AMT pointed out a problem with an aircraft in ACN 641974 (c.f. ACN represents document numbers.), a lead mechanic told an AMT to dispatch an aircraft because "it was just making a round trip." A complacent attitude was also observed in ACN 635595 in which an AMT had conducted a bird strike inspection without using the printed inspection instructions because the AMT could not print out the maintenance manual. Various events can disrupt/interrupt regular maintenance. An AMT forgot to document a bird strike inspection as a result of muddle after a fellow AMT was injured (ACN 635737). Supervisors also may interrupt AMTs' work with instructions for them to help on other tasks. New malfunction discoveries, by flight crews and other AMTs, were also reported as contributing to distraction/interruption. These interruptions inevitably occur in aircraft maintenance since one AMT must routinely cope with various tasks.

Physical state, consisting of physical fatigue, circadian dysrhythmia, physiological state, and physical limitations, was not frequently found in the narratives analyzed for this study. This may reflect that fatigue was not a frequent factor, but it may also suggest that AMTs tend to put less focus on their fatigue when reporting their errors, and in fact may see fatigue as the cost of doing business.

Time pressure was coded when the reporter claimed (1) that they were under time pressure or when (2) the raters determined that time pressure existed in consideration of the situation. Examples of time pressure situations include gate return, approaching departure time, and inbound flight delays. For instance, after mistakenly separating the wrong connecters, an AMT reported that the "main contributing factor was hurried atmosphere of flight operations" (ACN 635304). Time pressure was also often related to the Minimum Equipment List (MEL), which allows an aircraft to be released for flight when the MEL items are inoperative under the condition that the aircraft meets certain airworthiness requirements. Time pressure in a situation where an MEL is first applied can be tacit, as the MEL is usually first applied just prior to departure. When applying the MEL, AMTs need a thorough understanding of the complex instructions and equipment interactions, under time pressure, to conform to the airworthiness regulations. In addition, the MEL application requires an additional level of coordination between technicians, flight crews, and maintenance control, which brings another set of factors to bear on the situation.

There were two types of coordination factors assessed in the narratives: (1) intra-department coordination (coded as *coordination inside*) within maintenance and (2) inter-department coordination (coded as *coordination outside*), such as between maintenance and the flight crews. In terms of intra-department coordination, lack of communication was reported during maintenance tasks that needed multiple AMTs' cooperation. AMTs must communicate with each other to accomplish their tasks safely and successfully; this is especially true when working on a large aircraft. As an example, an aircraft was damaged because of a misassumption when an AMT moved a flap after looking at the lead mechanic whom he thought was giving him a “thumbs up” (ACN 657986). In addition, AMTs conducting remote maintenance operations occasionally had to contact maintenance controllers in their maintenance base. This organizational process made communication complicated, and opened the opportunity to induce more errors. Coordination problems outside of the maintenance group mainly took place between flight crews and maintenance staff. Decision making was the predominant unsafe act among the cases with “coordination outside” problems as a contributing factor. For example, a flight crew’s failure to directly provide the correct information about a malfunction resulted in a wrong repair task conducted by AMTs. Once the failure report was received, the AMTs were fixated on the original information and remain so even when updated information percolated in. AMTs sometimes did not acknowledge the flight crews’ opinions when it came to issues of airworthiness. Although this problem may be a consequence of maintenance’s presumption of a lack of specific system or maintenance knowledge from the flight crews’ perspective, AMTs should be able to persuade flight crews that the problematic aircraft is able to fly safely and legally. However, in some cases where coordination probes were causal to an event, when traced back to origin by the reporting AMT, it was revealed that the flight crews’ understanding was correct. The ASRS reports also revealed that AMT’s reported lack of adequate systems training or on-the-job experience as contributory to their unsafe acts. As noted by one AMT when pointing out that it was the first time for both assigned AMTs to work on the landing gear, “some of the contributing factors were no training” (ACN 656612).

Environment refers to situations such as poor weather, dark workspace, noisy surroundings, and confined places that are difficult to access. AMTs reported that working under severe weather conditions served as contributory when they made errors. More than 95% of the cases with environmental factors noted as contributory were related to skill-based errors. In ACN 679705, a lead mechanic reported that he did not see a part interfered with a door seal in a cold and dark night. Equipment and parts refers to the absence or inferior quality of required equipment, tools, and parts. In these situations, AMTs tended report finding a substitute. Although such behaviors may reflect good personal qualities in our daily life, they are not always appropriate in aircraft maintenance that demands high reliability. In ACN 657973, an AMT reported that he used rag for screw cleaning because a required thread cleaning tool was not available. Similar to tools and equipment problems, parts availability also had an effect on proper maintenance tasks. In ACN 653455, a parts stock deficiency required an MEL application, during which an AMT made an error.

Although AMTs cannot completely fault their errors on documents and procedures, it is true that unclear or insufficient document structures and descriptions contribute to human errors. In this study, this category only included errors due to problematic documents, not inadvertent misunderstanding by AMTs. Twenty five percent of all the errors were possibly related to this issue. After failing to conduct an inspection, a reporter of ACN 653738 argued that required inspection items should be flagged in the documents.

Design is selected when manufacturer’s aircraft/component design does not consider enough to prevent human errors in maintenance. There were some cases that the raters sensed that poor design might have induced human errors. In ACN 645261, a reporter raised an issue that a safety pin was not visible from outside, making it difficult to check from outside whether a safety pin was left or removed.

Previous deviations by other AMTs, flight crews, and other related personnel made it hard for AMTs to correct the error. For example, an AMT installed the wrong part without verifying its part number, which was incorrectly ordered by his colleague (ACN 661804). AMTs sometimes installed a part that had the same part number as the removed part even when this part was incorrect (ACN 633047). AMTs seemed to have a tendency to believe that current conditions were correct.

Organization focuses on company-wide problems, including problematic supervision. Supervisors on occasion, failed to manage maintenance tasks, resulting in incompletion of the required tasks. When the reporters argued that there was a lack of manpower, this was also coded as a supervisory problem. Inadequate organizational culture was also an influential factor. If more than one person or whole maintenance group agreed with an illegal maintenance action, it was also seen as a problem in the organization. As an example, an AMT mentioned that he was in a hurry because the company did not allow overtime (pay/hours) (ACN 632193). This was an example of how the company’s policy played a contributory role in aircraft maintenance safety.

Association between contributing factors

According to the Chi-square analysis, time pressure was associated with lack of vigilance ($\chi^2(1,527)=16.8$, $p< .01$), distraction/interruption ($\chi^2(1,527)=15.6$, $p< .01$), design ($\chi^2(1,527)=6.7$, $p= .01$), and organization ($\chi^2(1,527)=5.4$, $p= .02$). Lack of vigilance was related with time pressure, coordination ($\chi^2(1,527)=12.8$, $p< .01$), document and procedure($\chi^2(1,527)=14.2$, $p< .01$), and organization ($\chi^2(1,527)=28.7$, $p< .01$). Inappropriate attitude was related to coordination ($\chi^2(1,527)=4.7$, $p= .03$). Physical state was related to environment ($\chi^2(1,527)=7.5$, $p< .01$).

Under time pressure, AMTs may lower attention to each task in order to cope with various tasks simultaneously. This tendency probably increased lack of vigilance. We suppose that time pressure was associated with distraction/interruption partly because AMTs have to conduct multiple tasks at a time under time pressure. Since assigning too few AMTs would increase time pressure, the organization factor was associated with time pressure. It is useful to know that these factors often exist together when errors occur. For example, in order to reduce the risk of time pressure, attention should be paid to lack of vigilance, distraction/interruption, design, and organization.

Association between unsafe acts and contributing factors

The multinominal logistic model was applied to errors categorized as skill-based errors, decision making errors, and routine violations and whose contributing factors were identified in order to investigate associations between unsafe acts and contributing factors (n=482). All contributing factors were included in the multinominal logistics analysis (Table 1) unless the count of a factor was zero.

Skill-based errors. Lack of vigilance (Odds ratio=4.3, $p< .01$), distraction/interruption (Odds ratio=2.5, $p= .02$), and environment (Odds ratio=14.1, $p= .01$) were positively associated with skill-based errors, whereas inappropriate attitude (Odds ratio=0.2, $p< .01$), coordination (Odds ratio=0.4, $p< .01$), and previous deviation (Odds ratio=0.1, $p< .01$) were negatively associated. The high odds ratio association with environment corresponds to the study by Hobbs and Kanki (2003), which found that skill-based errors and perception errors were closely related to the environmental factors. Hobbs and Williamson (2003) found in their questionnaire survey to AMTs that fatigue, pressure, and environment were closely associated with skill-based errors. The fatigue and pressure factors were not significantly associated with skill-based errors in our study.

Table 1

Association between unsafe acts and contributing factors by Multinominal Logistic Regression Analysis

	Skill-based errors				Decision making errors				Routine violation			
	Beta	SE	P	OR	Beta	SE	P	OR	Beta	SE	P	OR
Lack of vigilance	1.46	0.30	0.00 **	4.30	-1.03	0.36	0.00 **	0.36	-1.10	0.34	0.00 **	0.33
Inappropriate attitude	-1.75	0.52	0.00 **	0.18	0.52	0.66	0.43	1.69	1.58	0.50	0.00 **	4.83
Time pressure	0.03	0.28	0.91	1.03	0.80	0.35	0.02 *	2.23	-0.70	0.34	0.04 *	0.50
Distraction/Interruption	0.95	0.41	0.02 *	2.57	-0.68	0.56	0.23	0.51	-0.75	0.49	0.12	0.47
Physical state	0.57	0.82	0.49	1.76	-0.36	1.07	0.73	0.70	-0.66	1.10	0.55	0.52
Coordination	-0.87	0.27	0.00 **	0.42	1.32	0.34	0.00 **	3.75	0.04	0.32	0.90	1.04
Lack of expertise	-0.34	0.38	0.37	0.71	1.70	0.41	0.00 **	5.45	-1.52	0.64	0.02 *	0.22
Environment	2.65	1.04	0.01 *	14.12					-1.85	1.04	0.08	0.16
Equipment & Parts	-0.29	0.43	0.50	0.75	0.35	0.53	0.51	1.42	0.17	0.47	0.71	1.19
Document & procedure	-0.35	0.26	0.18	0.71	0.37	0.35	0.29	1.45	0.27	0.30	0.37	1.30
Design	1.03	0.84	0.22	2.81	-0.17	1.09	0.88	0.84	-1.28	1.09	0.24	0.28
Previous deviation	-2.06	0.42	0.00 **	0.13	-0.28	0.67	0.68	0.76	2.26	0.40	0.00 **	9.57
Organization	-0.46	0.36	0.20	0.63	0.04	0.45	0.93	1.04	0.48	0.40	0.23	1.61

1. ** 99% level of significance, * 95% level of significance
2. SE = Standard Error, OR = Odds Ratio

Positive associations of skill-based errors with lack of vigilance and distraction/interruption make sense because these factors are considered to cause unintended, careless errors. On the other hand, a negative association with inappropriate attitude may derive from the characteristic of the factor. Since inappropriate attitudes (i.e. overconfidence and complacency) accompany conscious thoughts, it is probably does not correlate to skill-based errors. Other negatively associated factors, such as coordination and previous deviation, imply that skill-based errors are caused mainly by individual factors, not coordination or other people's errors. Time pressure, which was the focus of this study, was not significantly associated with skill-based errors.

Decision making errors. Time pressure (Odds ratio=2.2, $p = .02$), coordination (Odds ratio=3.7, $p < .01$), and lack of expertise (Odds ratio=5.4, $p < .01$) were positively associated with decision making errors, whereas lack of vigilance (Odds ratio=0.4, $p < .01$) was negatively associated. Although it was not a high odds ratio (i.e. 2.2), time pressure was associated with decision making errors. It needs to be noted that the 95% confidence interval for the odds ratio was between 1.1 and 4.5. It might be a weak association. Positive associations with coordination imply the importance of communication to prevent decision making errors. Lack of expertise would preclude making the right decision. Lack of vigilance was negatively associated with decision errors. This is most likely because AMTs necessarily pay a certain level of attention to making a decision, even if the decision is a poor choice. Hobbs and Kanki (2003) argued that rule-based errors were closely associated with coordination, and knowledge-based errors were related to procedures and training/qualification. Hobbs and Williamson (2003) found a linkage between rule-based errors and procedures, and between knowledge-based errors and training. In our study, decision making errors included rule-based errors and knowledge-based errors. Overall, trends found by Hobbs and Williamson are consistent with those of the current study.

Routine violations. Routine violations were positively associated with inappropriate attitude (Odds ratio=4.8, $p < .01$) and previous deviation (Odds ratio=9.6, $p < .01$), whereas lack of vigilance (Odds ratio=0.3, $p < .01$), time pressure (Odds ratio=0.5, $p = 0.04$) and lack of expertise (Odds ratio=0.2, $p = .02$) had significantly low odds ratios. It is reasonable to consider that inappropriate attitude may play a role in inducing routine violations as this type of attitude would lower the concerns on conformity. A high association with previous deviation may show AMTs' tendency to rely on other people, although they are supposed to be responsible for their every maintenance action.

Hobbs and Kanki (2003) found that management and supervision, and norms were closely associated with violations. In the study by Hobbs and Williamson (2003), violations were most closely associated with pressure as opposed to our result. This difference might derive from the difference in definition. Hobbs and Williamson (2003) used the category *pressure*, not *time pressure*. In addition, the data collection methods might have affected the result. Hobbs and Williamson (2003) conducted a questionnaire survey while our study used incident reports in a voluntary reporting system.

McDonald, Corrigan, Daly, and Cromie's (2000) study found that 34% of routine maintenance tasks at airlines include procedure violations. Hobbs and Williamson (2003) argued that these inconsistent results might derive from the fact that they focused on different subsets of violations. In this study, drawing a fine line between unintentional errors and routine violations was a challenging task for the raters because AMTs' intentions were not always explained clearly in the ASRS reports. Hesitation to report their own or colleagues' violations may have made the reports vague.

Conclusion

A set of unsafe acts and contributing factors in aircraft maintenance events were identified in maintenance related error reported to the Aviation Safety Report System. Among unsafe acts, more than 50% were identified as skill-based errors. Time pressure was one of the predominant contributing factors along with lack of vigilance. Time pressure was positively associated with decision making errors and negatively associated with routine violations. In relation to other contributing factors, time pressure was associated with lack of vigilance, distraction/interruption, poor design, and organizational factors. The results provide beneficial ideas toward reducing human errors that can be attributed to time pressure. Further studies are necessary to investigate how time pressure influences AMTs' safety behaviors.

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