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The Activated Failures of Human-Automation Interactions on the Flight Deck [*]

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ABSTRACT

Cockpit automation has been developed to reduce pilots' workload and increase pilots' performance. However, previous studies have demonstrated that failures of automated systems have significantly impaired pilots' situational awareness. The increased application of automation and the trend of pilots to rely on automation have changed pilot's role from an operator to a supervisor in the cockpit. Based on the analysis of 257 ASRS reports, the result demonstrated that pilots represent the last line of defense during automation failures, though sometimes pilots did commit active failures combined with automation-induced human errors. Current research found that automation breakdown has direct associated with 4 categories of precondition of unsafe acts, including 'adverse mental states', 'CRM', 'personal readiness', and 'technology environment'. Furthermore, the presence of 'CRM' almost 3.6 times, 12.7 times, 2.9 times, and 4 times more likely to occur concomitant failures in the categories of 'decision-errors', 'skill-based error', 'perceptual errors', and 'violations'. Therefore, CRM is the most critical category for developing intervention of Human-Automation Interaction (HAI) issues to improve aviation safety. The study of human factors in automated cockpit is critical to understand how incidents/accidents had developed and how they could be prevented. Future HAI research should continue to increase the reliability of automation on the flight deck, develop backup systems for the occasional failures of cockpit automation, and train flight crews with competence of CRM skills in response to automation breakdowns.

Keywords: Accident Investigation, Automation Surprises, Cockpit Design, Decision Aids, Human-Automation Interaction, Human Factors

I. INTRODUCTION

The development of advanced technologies in computer sciences have made mass applications of automation on the flight deck, and also introducing all aspects of Human-Automation Interaction (HAI) issues in flight operations. Given these technical capabilities, which systems should be automated and to what extent on the flight deck have to be further examined for improving aviation safety. Parasuraman, et al. [1] outlined a model for types and levels of automation that provides a framework and an objective basis for making appropriate adoptions. It is important to understand that automations may change human cognitive activities and can impose new coordination demands on the pilots. Despite considerable effort by human factors experts, HAI breakdowns in the cockpit are still a key safety concern in aviation [2, 3]. Through the coordination of the best features of human and computer, automated systems provided effectiveness in flight operations, such as auto-throttles which are efficient in terms of fuel consumption and energy management, and the Integrated navigational systems which are able to autonomously fly

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the aircraft with remarkable precision in both vertical and horizontal, and enable aircraft landing in almost zero visibility.

Nomenclature

ASRS	Aviation Safety Reporting System
CFIT	Control Flight Into Terrain
CRM	crew resource management
EGPWS	Enhanced Ground Proximity Warning Systems
FMA	Flight Mode Annunciator
FMS	Flight Management Systems
HAI	Human-Automation Interaction
HFACS	Human Factors Analysis and Classification System
ILS	Instrument Landing System
INS	Inertial Navigation System
MCP	Mode Control Panel
NASA	National Aeronautics and Space Administration
PFD	Primary Flight Display
SEREC	Science and Engineering Research Ethics Committee

The evolution of advanced technology in the cockpit is only a part of the solution to overall safety improvements for flight operations. The analysis of accident investigation reports has consistently shown that human factors involved in 70-80% of incidents and accidents, and this figure has remained constantly over decades, with no sign of decreasing [4, 5]. In a worldwide survey of causal factors of accidents in commercial aviation, it was found that in 88% of the cases the crew was identified as a causal factor; in 76% of instances the crew were implicated as the primary causal factor (European Aviation Safety Agency, 2012). Therefore, the study of the human-automation interaction in automated cockpit is critical to understand how incidents/accidents had developed and how they could be prevented..

II. COCKPIT AUTOMATION CREATED HAI ISSUES ON THE FLIGHT DECK

Automated aids on the flight deck are designed specifically to decrease pilots' workload by performing many complex tasks simultaneously including information processing, system monitoring, diagnosing potential risks/cautions, and controlling the aircraft. Wiener and Curry [7] proposed that automation systems have superior information processing abilities, and are able to deal with large amounts of information whilst concurrently maintaining precise control. The invention of Flight Management Systems was designed not only to keep the aircraft on course, but also to manage many aspects of the flight such as calculating fuel-efficient routes, navigation, detecting and diagnosing system failures. An inevitable impact of this high level of automation is that it has changed the way pilots perform tasks and make decisions [8].

Human-centred design of automation has been cited as a desirable goal which should focus on supporting the human operator of the systems matching the hardware, software and operating environments. This design philosophy provides guidelines to direct decisions concerning the interaction of the flight crew with the aircraft systems, such as allocation of functions between pilots and automated systems, levels of automation, and information formatting [9]. In addition, the use of a high degree of automation decreases the likelihood of pilots expending the mental effort to process all the available information in cognitively complex ways. While advanced automation technology may solve some problems, it often introduces others. In aviation, new technology can be part of a solution, but it is important to remember that it will bring new issues that may not have been anticipated and must be considered in a larger context, such as philosophy of interfaces design, training, systems integration, and operational characteristics of human operators [10, 11].

III. THE RISK OF HUMAN-AUTOMATION BREAKDOWN ON THE FLIGHT DECK

Cockpit automation has been developed to reduce pilots' workload and increase pilots' performance. However, previous studies have demonstrated that failures of automation have significantly impaired pilots' situational awareness. European Aviation Safety Agency conducted a cockpit automation survey which confirmed that the most common factors relating to the peaks of stress and workload generated by unanticipated situations requiring manual override of automation, are those which are difficult to understand and manage, and this could subsequently create effects of automation surprise (European Aviation Safety Agency, 2012). Flight crews may spend too much time trying to understand the original conditions which may in turn distract them from other priority tasks and flying the aircraft. Mode confusion of automation presents a difficult situation in modern cockpits which erodes the safety barriers and places additional workload onto the pilots. Human factors issues were involved in 70-80% of incidents and accidents, based on the analysis of accidents investigation reports around the world. This figure has remained constant over several decades. Previous research applied the Human Factors Analysis and Classification System (HFACS) which based upon empirical evidence of how actions and decisions at higher managerial levels in the operation of commercial aircraft linked to errors on the flight deck and subsequent accidents [2, 5].

Automation system generally are reliable and consistent in applying repetitive actions and monitoring small status changes precisely, not easily detectable by crews. However, automation must be applied prudentially, as new generation of pilots may lack basic flying skills if the automation disconnects or fails. Parasuraman and Riley [13] described the tendency of HAI issues on the flight deck including automation abuse, automation disuse and automation misuse. The use of a high degree of automation decreases the likelihood that pilots will make the cognitive effort to process all the available information in cognitively complex ways. An inevitable facet of this high level of automation has changed the way pilots perform tasks and make decisions. The evidence of automation-induced commission errors was produced by full-mission simulations in the National Aeronautics and Space Administration (NASA) Ames Advanced Concepts Flight Simulator [14]. Automation commission errors are errors made when decision makers inappropriately follow automated information. Tenney, et al. [15] suggested that breakdown of human-automation interactions could generate unexpected crew behaviour which could lead to adverse consequences.

The failure path of human factors in aviation is associated with the active failures performed by front-line operators and latent failures generated in upper levels and which are normally dormant in the system [16, 17]. Combined with other contributory factors, these failures might be able to break the system's defence leading to major accidents. Automation issues are mainly related to active failures and have continually been reported to the NASA Aviation Safety Reporting System (ASRS). The analysis of accident/incident reports should be just one aspect of a continuous safety auditing process. The approach of reactive analysis accidents alone is insufficient to ensure aviation safety and should be supplemented by a proactive approach of identifying the paths of hazards before they evolve into an accident. Therefore, the objectives of current research are to examine pilots' active failures related to flight deck automation; to identify the paths of breakdown between human and automation interactions; and to develop the guidelines for increasing the effectiveness of human-automation interactions in order to improve aviation safety.

IV. METHOD

4.1 Data collection

NASA's Aviation Safety Reporting System (ASRS) is the largest voluntary confidential reporting system in the world. Pilots submitted reports concerning safety of flight operations are reviewed before being made available on the database. Each submitted report outlines an occurrence in which the submitter considered safety to be compromised. Occurrence reporting aims to elicit information from near-miss events that may not be visible under the normal conditions during most flights. The data of current research was obtained taking into account Commercial Flights (Federal Aviation Administration part 121) that involved automation-related incidents in the landing phase. The ASRS Database is coded by NASA analysts with a specific taxonomy used to classify types of incident.

To focus on human-automation Interaction issues raised on the flight deck, current research used incident reports by selected by the following criteria: 1. Automation problem: automation failure which affects the operation of a component, part or element such that it can no longer function as intended; automation fault which is exhibition of an item or system that may function partially with potential of leading to failure; and automation confusion in which systems are functioning normally but pilots were confusion by loss of situation awareness and commit human errors by misinterpretation the automation systems. The components of automation systems involved in these occurrences including Approach coupler, Auto-flight system, Auto-throttle/Speed control, Instrument Landing System (ILS), Auto-land, Flight Control Computer, Radio Altimeter, Enhanced Ground Proximity Warning Systems (EGPWS), Alt hold/capture, Database, INS/NAV system, Primary Flight Display (PFD), Mode Control Panel (MCP), Air Data Computer, Flight Director, Flight Mode Annunciator (FMA); 2. Flight phases: Descent, Initial Approach, Final Approach, Landing; 3. Incident types: Altitude Cross Restriction not met, Altitude Overshot, Excursion from assigned Altitude, Track/Heading, Speed, Unstable Approach, Loss of Control, Encounter Control Flight Into Terrain (CFIT), Uneventful Procedure Deviation and Airborne Conflict. There are 257 confidential reports derived from the ASRS in total. Current research did not involve collecting information directly from subjects, conducting experiments, taking samples, or any other invasive approaches. Therefore, a low risk ethics proposal was approved by the Science and Engineering Research Ethics Committee of Cranfield University, United Kingdom.

4.2 Research design

The data analysis will utilise the active failures of Human Factors Analysis and Classification System (HFACS) as a framework to categorise the human-automation interactions issues on the flight deck. Such taxonomic systems are suited to analysis of the factors that precipitate an event [18]. Based on Reason's 1990 'Swiss cheese model', HFACS was developed to enable an understanding of human factors issues, and provide a systematic, data-driven approach to investment and interventions [2]. This human error taxonomy spans across four primary tiers then contains causal sub-categories to describe the contributory factors of active failures and latent failures. However, current research only focuses on automation and active failures on the flight deck, so the research framework was adapted to address pilots' unsafe acts, including 4 categories of decision-error, skill-based error, perceptual error and violation; and the pre-condition of unsafe acts including 7 categories of adverse mental states; adverse physiological states; physical/mental limitations; crew resource management; personal readiness; physical environment, and technological environment. Those 11 categories of active failures of pilots may have interacted with automation systems directly and involved in the occurrence of safety concerns.

4.3 Coding process

Content analysis is the technique that uses a set of procedures to make valid inferences from description or reports. It includes large amounts of textual information and systematic identification of the properties, such as the frequencies of terminology. The data was coded separately using content analysis into the 11 categories of active failures including unsafe acts of the operators and preconditions for unsafe acts, by an aviation human factors specialist and a pilot. Each report was classified into a framework structured to accommodate information provided by ASRS query and the 11 categories of active failures. The presence or absence of each category was assessed in each narrative respectively with 1 or 0. To avoid over representation, each category was counted a maximum of once per report and the count acted as an indication of the presence or absence of each active failure category. Prior to undertaking the present study these analysts also undertook the analysis of 523 aviation accident reports [5].

4.4 Statistical analysis

A chi-square test was applied in order to determine whether there is a relationship between automation problems and categories of active failures. Since there is no dependent or independent variable in Chi-square tests, this was complemented with further analyses using Goodman and Kruskal's tau. The value of tau has the advantage of being a directional statistic. The lower level categories of unsafe acts of pilots were designated as being dependent upon the categories at the higher level of precondition of unsafe acts in the framework, which is congruent with the framework's underlying theoretical assumptions. Finally, odds ratios were also calculated to quantify the likelihood of the presence of a contributory factor in one category being associated with the concomitant presence of a factor in another category. However, it must be noted that odds ratios are an asymmetric measure and so are only theoretically meaningful when associated with a non-zero value of tau (Li, Harris and Yu, 2008).

V. RESULTS

A total of 257 Commercial Aviation ASRS reports associated with automation related safety concerns were analysed. The samples consisted of seven different aircraft manufacturers with 99 Boeing (38%), 52 Airbus (20%), 24 McDonnell Douglas (9%), 20 Bombardier (8%), 15 Embraer (6%), 3 Dash 8 (1%), and 1 Citation X (0.4%). Because of the confidential nature of reports, the type of aircraft was not available for 43 cases (16%). The highest frequency phase involving incidents was initial approach with 108 (41%), followed by descent with 92 (36%), final approach with 48 (19%) and Landing with 9 (4%). The ASRS reports have been summarized to 10 different types of incidents related to HAI issues presented in table 1. The majority of automation issues are automation mode confusion and component fault including flight management system, followed by auto-pilot, instrument landing system (ILS), approach coupler, auto-thrust, auto-land, alt/hold capture, mode control panel, radar altimeter and flight management computer. Furthermore, not only components on aircraft failed but also a number of unserviceable ILS facilities at the approaching airport. The frequencies and percentage of automation issues related to pilots' active failures are shown in table 2.

Table 1 Types of ASRS events (N = 257)

Types of Incidents	Frequency	Percentage
01. Altitude Cross Restriction not met	52	20.23%
02. Altitude Overshot	17	6.61%
03. Excursion from assigned Altitude	21	8.17%
04. Track / Heading	57	22.18%
Speed	12	4.67%
05. Unstable Approach	22	8.56%
06. LOC-I	13	5.06%
07. Encounter CFIT	10	3.89%
08. Uneventful	46	17.90%
09. Procedure Deviation	5	1.95%
10. Airborne Conflict	2	0.78%

5.1 The association of automation breakdown and pilots' active failures

The analysis of 257 confidential reports found that automation fault is the highest frequency (137); followed by automation mode confusion (90), and the lowest frequency is automation failed (30) on the flight deck. Automation failure can be a difficult situation for pilots to understand the situation and may create a startle in the cockpit, as pilots may take too much time trying to understand the ambiguous information, which may distract them from priority tasks and caused adverse outcomes. By analysing ASRS reports, it can be found that the highest occurrence of pilots' active failures is 'technology environment' (67.3%), followed by 'crew

Table 2 Automation problems and human factors issues on the flight deck

Contributing Factors		**Frequency**	**Percentage**
Automation Problems	Failed	30	11.7%
	Malfunction	137	53.3%
	Confused	90	35.0%
Taxonomy Framework of HFACS	Technology environment	173	67.3%
	Physical environment	34	13.2%
	Personal readiness	58	22.6%
	Crew resource management	156	60.7%
	Physical/mental limitation	13	5.1%
	Adverse physiological state	10	3.9%
	Adverse mental states	122	47.5%
	Violations	32	12.5%
	Perceptual errors	26	10.1%
	Skilled-based errors	101	39.3%
	Decision errors	127	49.5%

Table 3 Chi-square, Goodman and Kruskal's tau, and odds ratio of significant association between Automation breakdown and pilots' active failures (N=257)

Automation breakdown association with human factors	χ^2	*p*	τ	*p*	Odds ratio
Automation Confused * Decision-errors	7.58	**	.03	**	2.07
Automation Confused * Technology environment	161.48	***	.63	***	.11
Automation Confused * Adverse Mental State	8.72	**	.03	**	2.18
Automation Confused * CRM	29.74	***	.11	**	5.31
Automation Confused * Personal Readiness	13.37	***	.05	***	2.99
Automation Malfunction * Violations	5.06	*	.072	*	2.48
Automation Malfunction *Technology environment	96.11	***	.374	***	27.85
Automation Malfunction * CRM	8.16	**	.032	**	.47
Automation Malfunction * Personal Readiness	10.66	***	.041	**	.36
Automation Failed * Decision-errors	5.12	*	.020	*	.39
Automation Failed * Technology environment	13.29	***	.052	***	16.71
Automation Failed * Adverse Mental State	7.93	**	.031	**	.30
Automation Failed * CRM	13.42	***	.052	***	.23

Automation breakdown association with human factors	χ^2	*p*	τ	*p*	Odds ratio
Technology environment * Decision-errors	19.23	***	.08	***	.29
Adverse mental State * Decision-errors	7.16	**	.03	**	1.96
Crew resource management * Decision-errors	23.34	***	.09	***	3.61
Technology environment * Skill-based errors	4.73	*	.02	*	.56
Adverse mental State * Skill-based errors	31.81	***	.12	***	4.52
Crew resource management * Skill-based errors	60.28	***	.24	***	12.74
Adverse mental State * Perceptual errors	5.49	*	.02	*	2.75
Crew resource management * Perceptual errors	4.88	*	.02	*	2.98
Adverse mental State * Violations	6.64	**	.03	**	2.75
Crew resource management * Violations	8.58	**	.03	**	4.02
Personal readiness * Violations	4.66	*	.02	*	2.34

Note: χ^2: Chi-square, τ: Goodman & Kruskal's tau

Table 4 Chi-square, Goodman and Kruskal's tau, and odds ratio of significant association between precondition of unsafe acts and unsafe acts of pilots (N=257)

Note: χ^2: Chi-square, τ: Goodman & Kruskal's tau

resource management (CRM)' (60.7%), 'decision-errors' (49.5%), 'adverse mental states' (47.5%), and 'skill-based errors' (39.3%). Automation failure presents a difficult situation in modern cockpits which erodes the safety barriers and places additional workload onto the pilot, and it has created the precondition of unsafe acts for pilots to commit unsafe acts. The chi-square, Goodman and Kruskal's tau, and odds ratio are used to examine the association between automation problems (failed, fault, and confused automation) and pilot's active failures shown in table 3. It is the evidence of automation breakdown directly associated with pilots' active failures in the cockpit.

5.2 The association of precondition of unsafe acts and pilots' unsafe acts

Automation breakdown has direct impact on pilots' cognitive processes, and has significant association with 4 categories of HFACS level-2 including adverse mental state, technology environment, personal readiness, and CRM. Furthermore, it has indirect impact on 4 categories of unsafe acts of pilots (HFACS level-1). The application of chi-square, Goodman and Kruskal's tau, and odds ratio enable to test the association between precondition of unsafe acts (level-2) and unsafe acts of pilots (level-1) shown in table 4.

VI. DISCUSSION

This study is focused on HAI issues which are the interaction between pilots and automations in the cockpit. It is suitable to confine the research scope to the landing phase of flight, as this phase of flight is associated with an increase in crew's workload as they are manoeuvring the aircraft and monitoring the automation systems simultaneously. Automation Surprise is a common phenomenon of HAI breakdowns, and was defined as "situations where crews are surprised by actions taken (or not taken) by the auto-flight system" [19]. The term of 'surprise' is adopted since pilots are not aware of the automation's status or the aircraft's status, until some events eventually trigger pilots' attention. These situations may occur as a consequence of undetected faults or in a fully operational system affected by inappropriate inputs or "autonomous" operations, all of these 'precondition of unsafe acts' were caused by pilot-automation breakdowns, and could evolve to disaster. The HAI issues raised safety concerns had included loss of control, unstable approaches and uneventful occurrences during the landing phase, and associated with confusion by the mode control panel, faults of radio altimeter, and faults of the flight management system. Serious safety concerns were raised regarding the effects of automation reliability. However, automation complacency occurs under conditions of multiple-task load, when manual tasks compete with automated tasks for pilots' attention. While pilots' decision aid provided by automation systems is imperfect on the flight deck, it will have contributed to those incidents involving automation-induced human errors including both omission and commission errors [20].

6.1 The paths of HAI breakdown initiated by automation

The complexity of automation has challenged flight crews in normal operations and become a serious risk when faults or failures have occurred which generate unexpected situations leading to adverse consequences [15]. The bold-arrow lines of figure 1 show direct impacts of automation breakdown on unsafe acts of pilots based on table 3. The automation failure is significantly associated with pilots' active failures such as 'adverse mental states' comprising task saturation, over confidence, tunnel vision and distractions; 'CRM' including lack of teamwork, failure to cross-check crew actions, and lack of leadership; and 'technology environment' encompassing inappropriate design of equipment and controls, display/interface characteristics, and checklist layouts; and 'decision-errors' consisting of over reliance on automation, improper use of automation, inadequate knowledge of system and inappropriate procedure connected to task-related issues. Automation fault has significantly associated with 'CRM', 'technology environment', and 'personal readiness' including failure to prepare physically or mentally for duty, failures to adhere crew rest requirements, overexertion when off-duty, self-medicating, and inadequate training; and 'violations' including routine or exceptional violated SOP or technical manuals.

Automation confusion has significantly associated with 'adverse mental states', 'CRM', 'personal readiness', 'technology environment', and 'decision-errors'. All of these 3 categories of automation issues have significantly associated with 8 categories of pilots' active failures shown as the straight lines in figure 1. Further analysis of the strength of association between the 3 categories of automation issues and 7 categories of 'pre-conditions for unsafe acts' indicated 21 (3*7) pairs of statistical associations in which 13 pairs of associations were significant ($p < 0.05$). All of these 13 pairs of significant associations were high odds ratios values and with non-zero values of tau (τ). The values of odds ratios (table 3) indicate that the presentence of 'automation failure' will be 16 times more likely to occur pilot's active failure of a concomitant active failures of 'technology environment'; and the presence of 'automation fault' almost 2.5 times more likely to occur a concomitant active failure of 'violations'. Furthermore, the odds ratios suggested that the presence of 'automation confusion' is almost 5 times more likely to occur concomitant active failure of 'CRM' problem on the flight deck.

6.2 The indirect impacts of automation failures to pilots' performance

Technological evolution has provided automation with an increasing level of "decision" and "autonomy" inducing the HAI problems. Systems are able to compensate automatically for unanticipated aircraft states like asymmetric thrust, turbulences or auto-trim [13]. In other cases, automation provide silent protection for the flight envelope (stall, over-speed, bank angle) without giving explicit notification of what is doing. This out-of-the-loop situation can be worsened by a lack of physical feedback, such as side-stick and auto-throttle not moving accordingly to the autopilot commands, making it less obvious to pilots the task of tracking and monitoring automated actions [9, 21]. The dotted lines of figure 1 illustrated indirect impacted of automation breakdowns on pilots' unsafe acts based on table 4.

Current research finds that automation breakdowns have direct associated with 4 categories of precondition of unsafe acts, including 'adverse mental states', 'CRM', 'personal readiness', and 'technology environment'. According to the theoretical framework of HFACS, it has demonstrated that those 4 categories in the upper levels have further impacts on the downward level of unsafe acts of operators, including 'decision-errors' such as over reliance on automation, improper use of automation, 'skill-based errors' including failure to prioritize attention, loss of mode awareness, and inadvertent operation; 'perceptual errors' such as misjudgement of the aircraft's altitude, attitude, or airspeed, and spatial disorientation; and 'violations' such as deviated SOPs of automation systems. Further analysis of the strength of association between categories of 'pre-conditions for unsafe acts' and 'unsafe acts of operators' demonstrated that 28 (7*4) pairs of statistical associations in which 11 pairs of associations were significant ($p < 0.05$). All of these 11 pairs of significant associations were high odds ratios values and with non-zero values of tau (τ). The values of odds ratios indicate that the presentence of 'CRM' is almost 3.6 times, 12.7 times, 3 times, and 4 times more likely to occur concomitant active failures of 'decision-errors', 'skill-based error', 'perceptual errors', and 'violations'; the presence of 'adverse mental states' almost 4.5 times more likely to occur a concomitant active failure of 'skill-based errors' (table 4 and figure 1).

6.3 The prioritized functions between Automation and flight crew

Current study find that automation is less likely, and the flight crews were most likely, to be involved as a precursor to events involving both skill-based and decision errors, as pilots were more likely to make decision errors where they were unaware of the source of the problem. An important feature of the difference between automation and human operators is the capability to maintain constant manoeuvre over long period of time without suffering from fatigue. Furthermore, flight crews may be aware of the problem, but their ability to intervene and resolve the problem may be inhibited by their lack of understanding the complexity of aircraft systems – the autonomy authority, complexity, coupling, and observability [22]. The accidents of Asiana-214 and Air France-447, demonstrated that HAI breakdown of impoverished awareness of the underlying functionality of automation systems, and the relinquishing of authority by the automation back to the pilots, are not problems of the past of traditional cockpit but affects are still present in an advanced cockpit. The designers of automations have to be aware of the natural limitation of human being's cognitive processes in order to create a human-centered system which is able to process all necessary information to meet the needs of pilots [23].

HAI is an important characteristic of many modern operational situations and understanding the relationship between human factors and automation issues would help designers of flight deck automations to develop human-centred systems. Reason [17] has suggested that there is a 'many to one' mapping of precondition of unsafe acts and pilots' unsafe acts, making it difficult to predict which actual errors will occur as a result of which preconditions. The results of current study support this assertion. Figure 1 demonstrated that "CRM" is the most critical category for developing safety mechanism for accident prevention, as "CRM" is not only associated with automation failure, automation fault and automation confusion, but also has impacted to 'decision-errors', 'skill-based errors', 'perceptual errors' and 'violations' on the unsafe acts of pilots (figure 1). Pilots confronted by automation failure might be confused by information displayed on interfaces which related to a failure to 'monitor' the status of flight mode control panel, or auto-throttle system could potentially lead to accident. However, it is the pilots' actions and decisions which ensure the aircraft landing safely during automation breakdowns. Therefore, good practice of CRM did demonstrate the effectiveness of intervention for aviation safety, and it can be supported by the example of United Airlines-232 which had a crash landing in Sioux City.

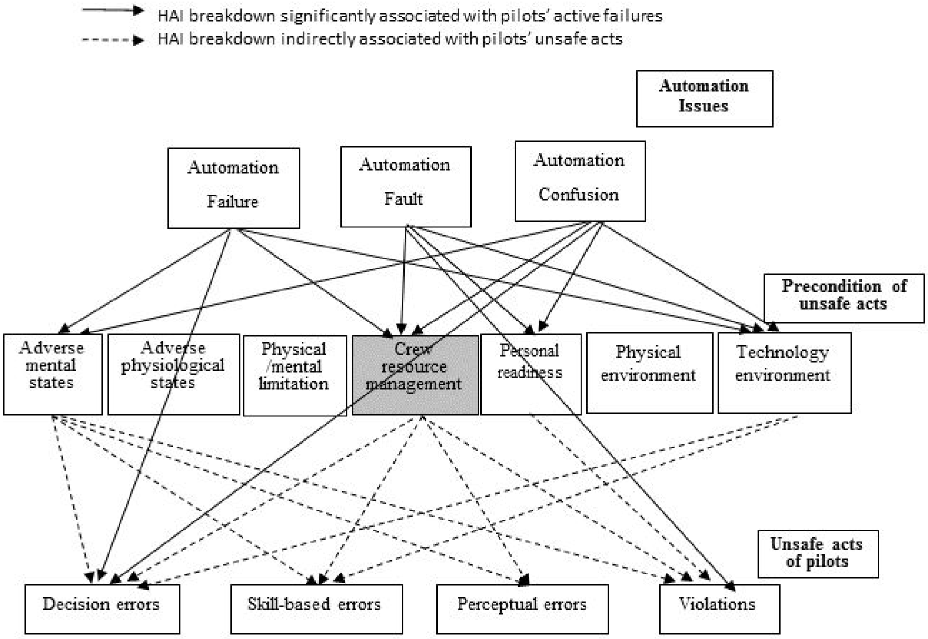

Figure 1 The paths of pilots' active failures associated with automation issues on the flight deck

Pilots have to monitor automated systems to rapidly processing complex and dynamic situations, and most of the time the processes of automated systems are based on complex rules and SOPs that are difficult for human operators to follow. Over-reliance on automated systems can degrade pilots' situation awareness and decision-making. When the automation systems failed or pilots confused by automation, the lack of awareness of the state of the systems can inhibit the crew's ability to recover the situation [24]. These are automation-induced errors which precipitate an event and can adversely disturb the crew and their situation awareness of the underlying causes. Where the attribution of a fault is not clear the crew's ability to predict the path and identify the correct course of action is very limited. Analysis of accident and incident reports suggested that monitoring failures are often responsible for breakdowns in pilot-automation coordination resulted in decision errors or violations [19]. There are lots of automation systems integrated with the flight deck and they might have affected among each other, such as auto-pilot, auto-throttle, auto-land, auto-trim, integrated navigation system, flight management system/computer, flight mode annunciator, mode control panel, and ground proximity warning system. The failures of those automation systems may create potential risks of altitude cross restriction not being met, altitude overshooting, track/heading, speed, unstable approach, encounter CFIT, and airborne conflict. It is an important aspect in determining how a new piece of automation is designed to intervene in one dimension without affecting other dimensions as well [22].

VII. CONCLUSION

The findings based on ASRS reports show that in general pilots represent the last line of defence during automation failures, though sometimes pilots did commit active failures that combined with automation-induced human errors. Current research identifies “CRM” as the most critical category for developing intervention of HAI to improve aviation safety. For automation breakdowns, pilots can still manually control the aircraft using problem-solving skill by applying CRM skills to operate the aircraft. In summary, there are thousands reports of ASRS safety concern regarding HAI issues. However, it is unknowable how often instances within the various active failures of human errors occur in day-to-day flight operations that have not resulted in accidents. The analysis of confidential reports related to automation breakdowns allows pilots to share experiences without being involved incidents or accidents. The credit must be rewarded to those pilots who were able to save the aircraft without adverse outcomes that might have damaged aircraft or passengers. Variations in flight deck automation should be evaluated to identify the standards of a pilot’s minimum safe performance in order to maintain safety of flight operations. Future HAI research should continue to increase the reliability of automation on the flight deck, develop backup system for the occasional failures of cockpit automation, and train flight crews with competence in response to automation breakdowns.

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