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Surface Accident and Incident Taxonomy and Mitigation Strategies

TECHNICAL REPORT

NASA Contract NAS1-02057
Task Order No. 7003

Prepared for

National Aeronautics and Space Administration
Langley Research Center
Hampton, VA 23681-0001

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Surface Accident and Incident Taxonomy and Mitigation Strategies

By

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RTI International

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1.0 INTRODUCTION

This document describes work done under NASA Contract NAS1-02057, Task Order 7003, titled "Planning, Requirements Definition, Research, and Technical Development of the Strategic Operations Component of the Synthetic/Enhanced Vision System." Specifically, this document is intended to satisfy Deliverable 1 of the Statement of Work titled "Surface Accidents and Incidents Taxonomy and Mitigation Strategies." This document describes some of the existing databases that describe surface accidents and incidents and provides a review of relevant entries from them. It proposes a categorization scheme for the data and presents the results of the database reviews in terms of this categorization. Finally, the characteristics of the accidents/incidents categories are related to the information/procedural requirements for and the intended functionality of the Synthetic/Enhanced Vision System in order to identify strategies for mitigating each accident/incident category.

1.1 Background

In 1997 the White House Commission on Aviation Safety and Security, chaired by then Vice-President Al Gore, set a goal to reduce the fatal aviation accident rate by 80% within ten years. In response, the FAA formed a number of joint safety analysis teams (JSATs) composed of representatives from FAA, industry, and NASA. Through the Aviation Safety Program, NASA also took up the challenge to conduct research that will address the Commission's goal and result in airspace/airplane system improvements that will contribute to a five-fold reduction in aviation accidents by the year 2007, and a ten-fold reduction in aviation accidents by 2017. The Crew Systems Branches (CVIB and CSOB) at NASA, Langley Research Center are leading and performing research efforts to increase aviation safety by focusing on the pilot/vehicle components of the airspace system. Target research areas of this effort include: Synthetic Vision Systems (SVS), enhancing the flight crew's awareness of not only the position of their aircraft in the airspace but also the position of potential obstacles/hazards relative to their aircraft; crew/vehicle interfaces; flight deck design; human performance assessment; and the application and certification of advanced technology.

For air operations, Approach and Landing accidents and CFIT remain top priorities for improved safety. Data from many safety studies indicate that approximately 56 percent of the jet-fleet accidents happen during the approach and landing phases of flight while these phases comprise only 16 percent of the flight duration.[1] The Flight Safety Foundation studied 287 fatal approach and landing accidents occurring between 1980 and 1996 and identified the primary accident causes.[2] However, while the rate of accidents in air operations has remained relatively constant since 1985, runway incursions and other surface incidents have steadily increased. Both runway incursions and surface operations incidents are significant threats to aviation safety and operational efficiency. The FAA (November, 1999) defines a runway incursion as "any occurrence at an airport involving an aircraft, vehicle, person, or object on the ground that creates a collision hazard or results in loss of separation with an aircraft taking off, intending to take off, landing, or intending to land."[3] The FAA goes on to clarify the definition saying that:

> "Runway incursions include problems on the runway but not on taxiways or the ramps (in this case, the runway is considered that area intended for landing and take off between the runway holding positions markings). The definition applies only to airports with operating control towers, since events at non-towered airports are not likely to be reported. In order for an event to be a runway incursion, at least one aircraft, vehicle, pedestrian, or object must be on the ground.
>
> Runway incursions should not include aircraft, vehicles, pedestrians, or objects on the runway without permission when there is no collision hazard or loss of separation; nor should they include animals on the runway. (Although these and other similar or unapproved movements occur, they are called surface incidents, not runway incursions.)
>
> A runway incursion occurs when a pilot or controller takes an unplanned or evasive action to avoid a collision hazard. Pilot actions might include unplanned deceleration (ground or air), accelerated rotation during takeoff, evasive change in heading or altitude, initiated go-around or aborted landing, aborted takeoff. Controller action might be a canceled landing or takeoff clearance."

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1 Boeing Commercial Airplanes Group, Statistical Summary of Commercial Jet Aircraft Accidents, Worldwide Operations, 1959-1996, Seattle, Washington, 1997
2 Khatwa, R., and Helmreich, R., Flight Safety Foundation Approach-and-landing Accident Reduction Task Force Analysis of Critical Factors During Approach and Landing in Accidents and Normal Flight: Data Acquisition and Analysis Working Group Final Report, Society of Automotive Engineers, Report No. 1999-01-5587, October, 1999.
3 Federal Aviation Administration's Air Traffic Resource Management Program Planning, Information and Analysis (ATX-400), Aviation Safety Statistical Handbook. Volume 7, No. 11, U.S. Department of Transportation, Federal Aviation Administration, November, 1999.

In the same reference, a surface incident is also defined as “any event where unauthorized or unapproved movement occurs within the movement area or an occurrence in the movement area associated with the operation of an aircraft that affects or could affect the safety of flight.” For the purpose of this report, the definition of incident will also include events that affect the efficiency of the surface operation, for example making a wrong turn and getting lost on the airport surface without affecting the safety of the flight. Runway incursions and surface operations incidents/accidents are a serious problem according to the FAA. Incursions are up dramatically doubling since 1994 to an all-time high of over 400 incursions last year.

January 22, 2001, two airplanes loaded with passengers came within “yards” of each other on the active runway at Seattle Tacoma International Airport. An American Airlines passenger aircraft (63 passengers) which had landed on runway 16 Right turned onto a taxiway and crossed runway 16 Left as a TWA passenger aircraft (103 passengers) took off from that runway. The TWA jet passed directly over the American Airlines aircraft. It was dark and visibility was officially about 1300 feet with patchy fog. This incident happened even though Seattle Tacoma International Airport has the most advanced marking, lighting, and signage system available and is one of the few airports in the world that is certified for Category IIIb operation.

Aircraft operations that require the most stringent separations (sometimes less than 200 feet) are those that occur while the aircraft are moving on the airport surface. In today’s environment, flight crews maintain awareness of hazards on the airport surface as well as their current position by way of frequent visual scans and in some cases radio communications. This method is usually adequate during VMC except for rare runway/taxiway geometries (obtuse-angled intersections) and during high workload. However, in reduced visibility conditions (IMC), at night, and during high workload, maintaining position and hazard awareness on the surface can become difficult. In these situations, uncertainties that can arise can affect operations by at best reducing the flow rates and in the worst case increasing the probability of a runway incursion and/or a surface accident. A taxonomy of surface operations incidents is needed to identify the types of incidents/accidents that are occurring and to develop a mitigation strategy that will address all of the incident categories. The mission of the Synthetic/Enhanced Vision System (SVS/EVS) is to enhance safety and enable consistent gate-to-gate aircraft operations in normal and low visibility. In order to accomplish this mission, the objective is to increase the situation awareness of flight crews by presenting information about their surroundings that may be denied them by adverse visibility conditions. It is conceived to be a system of sensors, databases, computers, displays, and controls that will present visual representations of the environment. This mission is consistent with the proposal made by the International Civil Aviation Organization (ICAO) to develop a modular system to support safe, orderly, and expeditious movement of aircraft and vehicles on the airport surface under all circumstances, including low visibility (Hooey et al. 1999).[4] ICAO has called their system concept the Advanced Surface Movement Guidance and Control System (A-SMGCS) and has developed a set of technology-independent development guidelines for the system. They have stated that in order to support safe and efficient gate-to-gate operations, A-SMGCS must provide the following basic functional requirements:

- Surveillance: Capture identification and positional information on aircraft, vehicles, and objects.
- Routing: Plan and assign routes to individual aircraft and vehicles to provide safe, expeditious, and efficient movement.
- Guidance: Provide necessary advisory information in a continuous unambiguous manner, such that pilots can follow their assigned route while maintaining an appropriate speed.
- Control: Measures to prevent collisions, runway incursions, and ensure safe, expeditious, and efficient movement on the airport surface.[5]

Although Young and Andre (1998) were focused on a Cockpit Display of Traffic Information (CDTI) for surface operations, their arguments concerning traffic awareness can be expanded to include the flight crew's spatial awareness on the airport surface as well. Access to a surface operations display can provide the flight crew with increased awareness of traffic and their position with respect to airport features and obstacles while decreasing uncertainties associated with available visual cues and radio communications. They state that "this increased awareness can:

4 Hooey, B. L., Schwirzke, M.F.J., McCauley, M.E., Renfroe, D., Purcell, K., Andre, A.D., Issues in the Procedural Implementation of Low-Visibility Surface Operations Displays, in R.S. Jensen (Ed.), Proceedings of the Tenth International Symposium on Aviation Psychology, Columbus: Ohio, 1999.
5 International Civil Aviation Organization (ICAO), Draft Manual of Advanced Surface Movement Guidance and Control System (A-SMGCS), 16th Meeting of the International Civil Aviation Organization's All Weather Operations Panel, Montreal, Canada, 1997.

1. Reduce the likelihood of runway incursions and surface accidents,
2. Reduce the likelihood of navigation errors on the surface,
3. Enable tighter separations on the surface and higher taxi speeds,
4. Enable strategic planning to avoid departure queues,
5. Enable strategic planning by choosing a runway exit that will allow minimum taxi-in,
6. Reduce the amount of radio communication required during surface operations, and
7. Provide pilots with a "rear-view mirror" to reduce jet blast effects on trailing aircraft."[6]

1.2 Goal

The purpose of this document is to relate informational and procedural requirements to categories of accidents and incidents in such a way as to provide rationale for display element down-select choices and develop test plans to evaluate these choices. In accomplishing this goal it should be possible to represent the candidate strategic surface operations display concepts in terms of intended function, display elements, and accident/incident mitigation benefits, as well as describe some of the issues related to selection of information elements and procedural modification.

This document is intended to be a description of the causal factors associated with surface operations accidents and incidents and an attempt to formulate a categorization scheme that depicts the causal relationships. Mitigation strategies are presented to address each of the accident/incident categories from the aspect of information and/or procedural modification.

1.3 Accident and Incident Data Sources

A number of data sources were utilized to develop this document. The National Aviation Safety Data Analysis Center (NASDAC) provided data from the FAA's Accident/Incident Data System (AIDS). The AIDS database contains incidents data records for all categories of civil aviation (general aviation and commercial air carrier) since 1978. The NASDAC database for AIDS contains incidents only. Incidents are events that do not meet the aircraft damage or personal injury thresholds contained in the National Transportation Safety Board (NTSB) definition of an

6 Young, S.D., Andre, A.D., CDTI Requirements for Airport Surface Operations, National Aeronautics and Space Administration internal document, June 1998.

accident. NASDAC uses the National Transportation Safety Board (NTSB) accident database as the primary source for accident information. The information contained in AIDS is gathered from several sources including incident reports from FAA Flight Standards Service Personnel who investigate the incidents, pilots, controllers,and supervisors. This information consists primarily of a description of the incident (e.g., location, time, aircraft involved, and type of incident) and statements from controllers and supervisors about what they did or observed relative to the incident. The difficulty with this database is that the pilots provide little, if any, information on the details of what led to the incident because they know that any information they provide can be used by the FAA in subsequent enforcement action against them. Therefore, it is often difficult to obtain information that is detailed enough to identify the factors causing the pilot errors.

The Aviation Safety Reporting System (ASRS) is a voluntary, confidential, and anonymous incident reporting system. It is a cooperative program established under FAA Advisory Circular No. 00-46D, funded by the FAA, and administered by NASA. Information collected by the ASRS is used to identify hazards and safety discrepancies in the National Airspace System. It is also used to formulate policy and to strengthen the foundation of aviation human factors safety research. The ASRS receives, processes, and analyzes reports of unsafe occurrences and hazardous situations that are voluntarily submitted by pilots, air traffic controllers, and others. Pilots, air traffic controllers, flight attendants, mechanics, ground personnel, and others involved in aviation operations can submit reports to the ASRS when they are involved in, or observe an incident or situation in which they believe aviation safety was compromised. Pilots are more forthcoming in the information that they provide to the ASRS, since they are guaranteed anonymity for the reports that they submit. By agreement, the FAA may not seek and NASA may not release to the FAA any information that might reveal the identity of any party involved. Thus there is more detail in the ASRS reports that is augmented by “call back” information when it is available. Some caution should be used in applying this data, because the voluntary reporting process does have the tendency toward producing a reporting bias where only those incidents that will be or have been observed are reported in order to take advantage of the limited immunity from regulatory enforcement action provided through the use of the system. Therefore, many of the incidents reported to the ASRS contain descriptions of events that are or come close to being reportable pilot deviations.

In 1994, the FAA's Office of System Safety (ASY-1) asked the MITRE Corporation's Center for Advanced Aviation System Development (CAASD) to assist the FAA in addressing ways to reduce runway incursions and related surface incidents.[7,8] Adam et al. state that they were "tasked to identify factors relevant to the causes and prevention of human error in surface operations, with emphasis on factors that have the potential to cause what is often classified as 'pilot error'." The study report is published in two parts and documents the results from a survey of airline pilots concerning their perception of situations and conditions encountered during operations on airport surfaces. The results are extensive and identify factors that leave pilots vulnerable to error.

Although the study of controller and pilot errors in airport operations (Cardosi et al. 2000)[9] was heavily weighted toward tower operations, there was data reported from the review of 100 of the most recent (at that time) runway transgressions. The term "runway transgressions" included both runway incursions and surface operations incidents. The report identifies factors associated with these incidents and potential remedies and complements the above review of ASRS data.

7 Adam, G.L., Kelley, D.R., and Steinbacher, J.G., Reports by Airline Pilots on Airport Surface Operations: Part 1 Identified Problems and Proposed Solutions for Surface Navigation and Communication MITRE Report No. MTR 94W0000060, May 1994.
8 Adam, G.L., and Kelley, D.R, Reports by Airline Pilots on Airport Surface Operations: Part 2 Identified Problems and Proposed Solutions for Surface Operational Procedures and Factors Affecting Pilot Performance, MITRE Report No. MTR 94W0000060.v2, March, 1996.
9 Cardosi, Kim and Yost, Alan, Controller and Pilot Error in Airport Operations: A Review of Previous Research and Analysis of Safety Data U.S. Department of Transportation, Federal Aviation Administration, Report DOT/FAA/AR-00/51, January, 2001.

2.0 ACCIDENT AND INCIDENT DATA

The following sections present a description of the data gathered from each of the data sources.

2.1 FAA Accident Incident Data System

The data from the FAA Accident Incident Data System that was provided by the National Aviation Safety Analysis Data Center was heavily biased toward minor "accident" type of surface operations incidents. There were 78,606 data records available in the system spanning a time frame from 1978 to 2002. The search of the data was limited to commercial operations and used the word "taxi" as the key search parameter. The search with these parameters resulted in 466 "hits." These 466 records were reviewed and screened. When mechanical failures and reports concerning in-flight incidents (for example "the taxi out was normal but the crew failed to level out at the assigned altitude" would not be considered a surface operations incident) were eliminated, 248 records remained for further analysis.

2.2 Aviation Safety Reporting System

The ASRS database is massive containing 258,763 records spanning a time frame from 1988 to 2002. The search of the data was limited to air carrier reports containing the word "taxi" as the keyword parameter. The result of this search was 5,174 data "hits." Due to resource limitations, it was not practical to review a data set this extensive. Therefore, a decision was made to limit the search to the time frame from January 2001 to February 2002. The search with these limiting parameters produced 473 "hits." These 473 records were reviewed using the same screening process that was employed for the AIDS data. The result of this screening was the identification of 228 records which were relevant to the current study and were retained for further analysis. In order to validate the results, these data were compared to data reported by Hubener in a 1995 dissertation from the Technical University of Berlin.[10]

2.3 Department of Transportation Study

The Department of Transportation (Cardosi et al. 2001) study looked at the previous research on runway incursions and surface operations incidents. It summarized data and results of studies as far back as 1978. These studies report on data from at least 683 accidents/incidents occurring during surface operations. Cardosi then goes on to examine the 100 most recent (at that time)

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10 Hubener, S., Safety of Airport Surface Movement, Technischen Universitat Berlin, September, 1995.

ASRS reports of runway incursion and surface operations incidents. Nineteen of these reports were excluded from further analysis because of one of the following reasons: 1) the event occurred at an uncontrolled field or at a foreign airport; 2) the event was unrelated to pilot error (e.g., mechanical failure); or 3) the report was a safety concern peculiar to that specific airport. Additionally, five reports did not fit into any analytic category. Thus 76 incident reports were analyzed and the results documented.

2.4 MITRE Survey

The approach taken in the MITRE studies (Adam et al. 1994, 1996) was to investigate all of the factors that may contribute to pilot errors on the airport surface. Pilots from two major U.S. airlines were surveyed to obtain detailed information about the causes and prevention of runway incursions and related surface operations incidents. The purpose of the survey was to obtain detailed information on surface operations strictly from a pilot's point of view. One thousand nine hundred and nine (1,909) pilots responded to the questionnaires. Of those that responded, 954 were captains, 840 were first officers, and 115 were second officers. Some of the survey results will be presented in sections below.

3.0 ACCIDENT AND INCIDENT CATEGORIZATION RESULTS

The FAA's 1998 Airport Surface Operations Safety Action Plan states, "Nearly all runway incursions are caused by human error. While it is fortunate that very few runway incursions result in accidents, the lapses of discipline or procedure that create these errors point to a potentially serious problem that must be addressed at all levels…" (FAA 1998).[11] Cardosi (2001) points out that while the opportunities for equipment malfunctions to cause the surface accidents and incidents are relatively rare; the opportunities for human error are abundant. The proximity and number of aircraft in the terminal environment, combined with the complexity of operations and the requirement for extremely accurate timing, conspire to make the airport surface and proximal airspace extremely unforgiving of pilot and controller errors. Abbott (1999)[12] observes, "the aviation community focuses on continuous safety improvements – one reason for the excellent safety record that currently exists. However, improvements in the accident rate have not been uniformly evident over the past few years." She goes on to state "human error, especially flight crew error, continues to be cited as a primary factor in a majority of aviation accidents (Boeing 1996[13] and FAA 1996[14]) and is a recurring theme." Therefore, the taxonomy of accidents and incidents presented below will focus on the human error causal component.

3.1 Error Categories

Two categorization schemes emerged as a result of the data review. The first taxonomy is based on an FAA-defined type of classification which addresses the source of the error. The four categories of accidents/incidents in this scheme include:

1) Operational Errors that are occurrences attributable to an element of the ATC system, which result in:

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11 Federal Aviation Administration's Runway Incursion Program Office (ATO-102), 1998 Airport Surface Operations Safety Action Plan to Prevent Runway Incursions and Improve Operations U.S. Department of Transportation, Federal Aviation Administration, 1998.
12 Abbott, K.H., Human Error and Aviation Safety Management, Flight Safety Foundation's 52nd International Air Safety Seminar, November, 1999.
13 Boeing Commercial Airplane Group, Statistical Summary of Commercial Jet Aircraft Accidents, World Wide Operations 1959-1995, April, 1996.
14 Federal Aviation Administration, Human Factors Team Report on: The Interfaces Between Flightcrews and Modern Flight Deck Systems, July, 1996.

a) less than applicable separation minima between two or more aircraft, or between an aircraft and obstacles. Obstacles include vehicles/equipment/personnel on movement surfaces, or

b) an aircraft landing or departing on a runway closed to aircraft operations after receiving air traffic authorization

2) Pilot Deviations, which are actions of a pilot that result in a violation of a Federal Aviation Regulation. For example, a pilot fails to obey air traffic control instructions to not cross an active runway when following the authorized route to an airport gate.

3) Vehicle/Pedestrian Deviations which are vehicle or pedestrian incursions resulting from a vehicle operator, non-pilot operator of an aircraft, or pedestrian who interferes with aircraft operations by deviating onto the movement area (including the runway) without ATC authorization.

4) Ground Handling Deviations which are accidents or incidents resulting from the pilot following the directions of ground handling personnel.

The second classification scheme focuses on the pilot deviations and is based on modeling human error. Abbott (1999) cites work by Reason (1990)[15] and Hudson et al. (1998)[16] which formulate two basic categories of error, which are: 1) those in which the intention is correct, but the action is incorrect (including slips and lapses); and 2) those in which the intention is wrong (including mistakes and violations). Abbott defines the four subcategories as follows:

Slips are performing one or more incorrect actions, such as a substitution or insertion of an inappropriate action into a sequence that was otherwise good. For example, setting the wrong altitude into a mode selector panel when the correct altitude is known and intended.

Lapses are the omission of one or more steps in a sequence. For example, missing one or more items in a checklist that has been interrupted by another flight deck activity.

Mistakes are errors where the human did what he or she intended, but the planned action was incorrect. Usually mistakes are the result of an incorrect diagnosis of a problem or a failure to understand the exact nature of the current situation. The plan of action thus

15 Reason, J.T., Human Error, New York: Cambridge University Press, 1990.

derived may contain very inappropriate behaviors and may also totally fail. For example, a mistake would be when a pilot formulated and verbalized an erroneous taxi plan.

Violations are the failure to follow established procedures or performance of actions that are generally forbidden. Violations are generally deliberate, though an argument can be made that some violation cases can be inadvertent. For example, a violation would be pressing on with a landing even when sight minima have not been met, or taking off without a takeoff clearance. It should be mentioned that a "violation" error might not necessarily be in violation of a regulation or other legal requirement.

Hooey and Foyle (2001)[17] also used the Reason model to relate errors to the flight crew activities of planning, decision making, and execution. They postulated that planning errors and decision errors are errors in which the intention was wrong and thus could be classified as mistakes. Correct intention and incorrect action (lapses and slips) are represented by execution errors. They define their error categories as follows:

Planning errors are errors in which the pilot formulated an erroneous plan or intention but carried out the plan correctly. In these instances the pilots formulated and verbalized an erroneous taxi plan, or inadvertently modified a taxi plan, and then made navigation decisions based on the incorrect plan. Two contributing factors for these errors have been identified as miscommunication and expectation/confirmation bias.

Decision errors occurred when the route had been properly received and communicated; however, the pilot made an erroneous choice at a decision point along the route. Most often this can be seen as a turn in the wrong direction at a choice point. The pilots formulated and verbalized, the correct intentions, but failed to execute the correct action.. Two major contributing factors to this type of error are excessive operational/procedural demands and inadequate navigational awareness.

Execution errors are those in which the clearance was correctly communicated, the pilot identified the correct intersection and direction of turn, but made an error in carrying out

16 Hudson, P.T.W., van der Graaf, G.C., and Verschuur, W.L.G., Perceptions of Procedures by Operators and Supervisors, Paper SPE 46760. HSE Conference of the Society of Petroleum Engineers, Caracas, 1998.
17 Hooey, B.L. and Foyle, D.C., A Post Hoc Analysis of Navigation Errors During Surface Operations: Identification of Contributing Factors and Mitigating Solutions, Proceedings of the Eleventh International Symposium on Aviation Psychology, Columbus, Ohio, 2001.

the maneuver. Factors contributing to this type of error are complex taxiway geometry, confusing/missing signage, and adverse and disorienting visibility.

The operational data also show that some errors may fall into the violation class of errors where procedures are violated. Although a number of errors in the above categories result in a violation of clearances (e.g. failure to hold short), the flight crew was following procedure. Violations occur when the crew does not follow procedure, for example, the pilot taxis or takes off without receiving the proper clearance. Factors contributing to violation type errors include miscommunication (the flight crew thought they had clearance), excessive operational demands, expectation and confirmation bias, and pilot attitude. Figure 3.1-1 presents an error categorization scheme based on both the FAA and the human error categories.

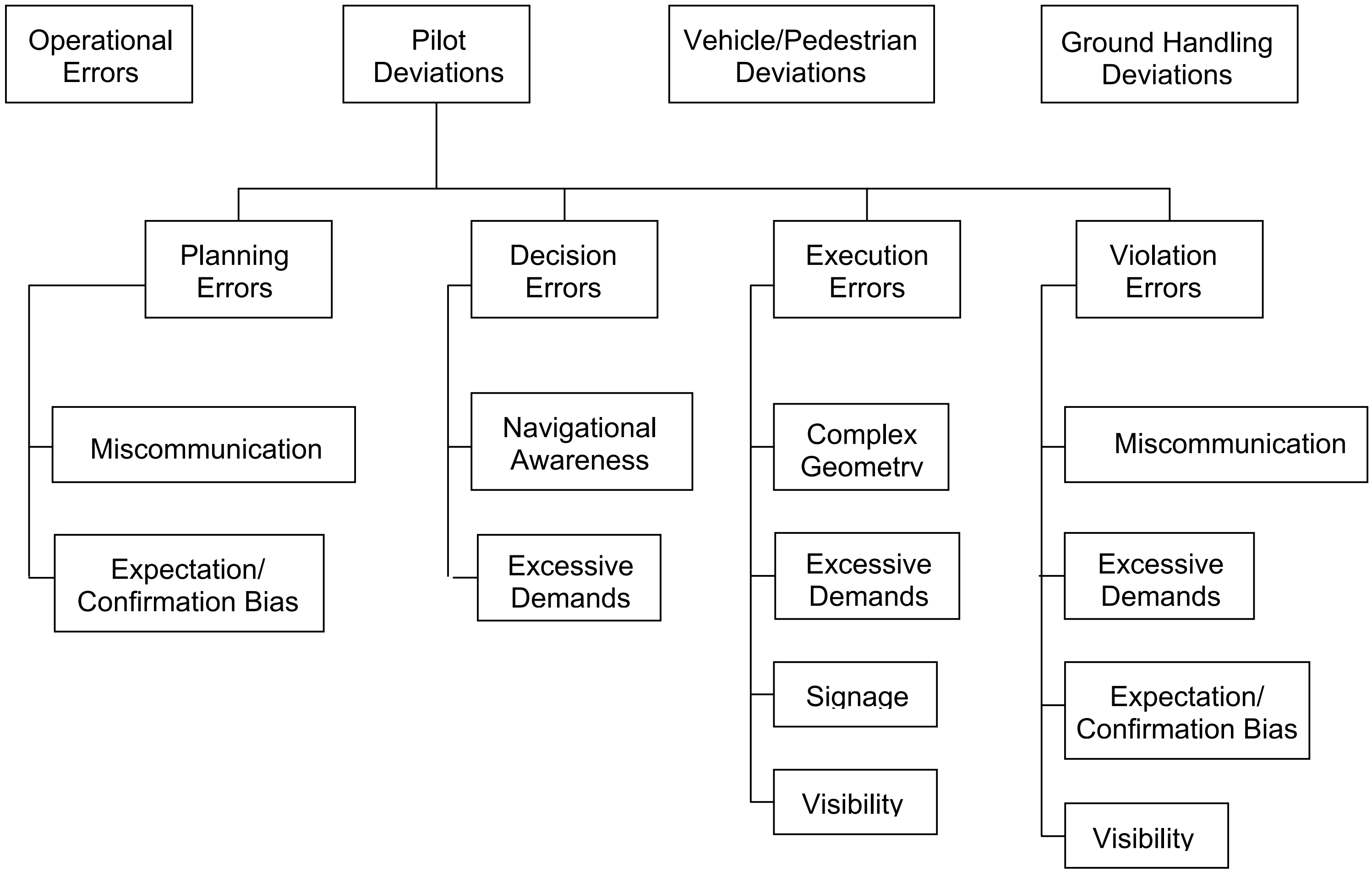

Figure 3.1-1 Error Taxonomy

3.2 Results from FAA Accident Incident Data System

The data from the 247 relevant AIDS reports were compiled and analyzed with respect to the error categories. While most of these reports do not contain enough detail to be able to provide insight as to why the events happened, they do permit a descriptive analysis of the types of events that were reported. Only 12 percent of the reports (29) had enough detail in the narrative to determine an error causal factor. Of these reports, there were four (14%) planning errors reported, all of which were the result of pilot-controller miscommunication. The largest portion of the reports (52% or 15 events) identified decision errors caused by either a lack of navigational awareness (14) or excessive procedural demands (1) as the primary causal factor. Execution errors accounted for 34 percent of the reports (10) and they identified complex airport geometry (3), signage (1), visibility (3), and excessive procedural demands (3) as the primary causal factors. These results can be seen in Figure 3.2-1.

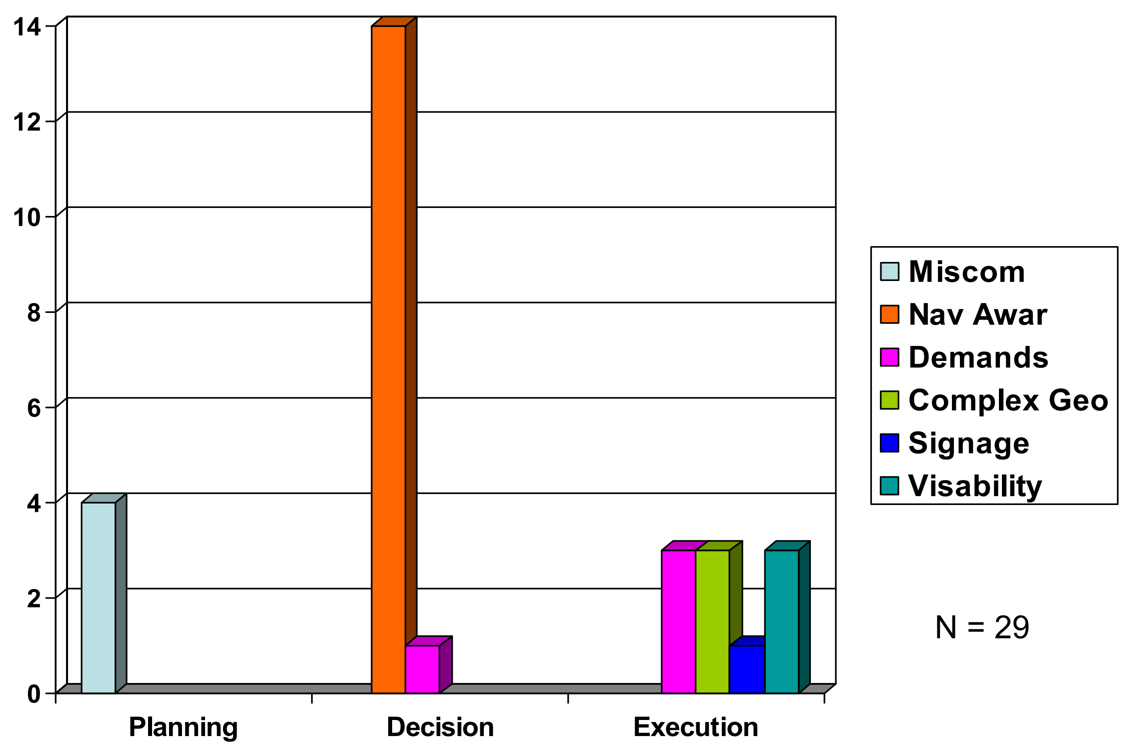

Figure 3.2-1 Pilot errors in the AIDS accident/incident reports

As stated earlier, the events contained in the AIDS reports tend to be heavily biased toward minor "accident" type of surface operations incidents. Therefore, a descriptive analysis of these reports will also be biased toward aircraft conflicts with other aircraft, ground vehicles, and airport obstacles. Using the FAA classification of errors, 2% of the reports described operational error, 6% described vehicle/pedestrian deviation, 22% involved ground handling deviations, and 70% were attributed to pilot causal factors. Figure 3.2-2 depicts these data.

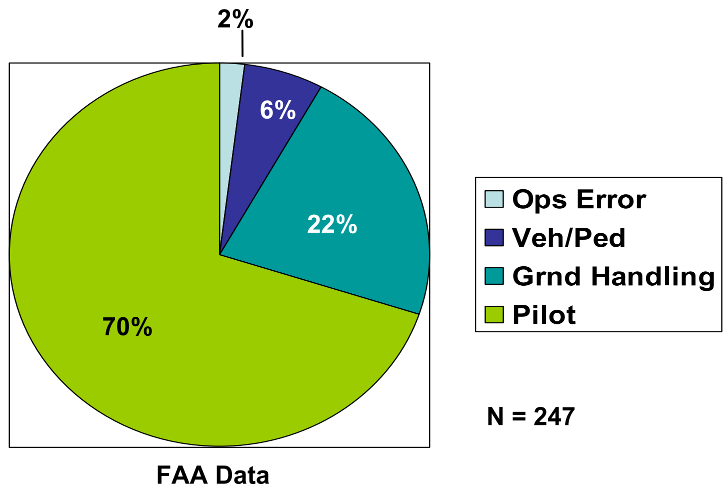

Figure 3.2-2 Error distribution from FAA AIDS database reports

Of the 174 reports that identified pilot error as the primary causal factor, 29 or 17 percent were covered above. The rest of the reports were not detailed enough to determine why the pilots made the error. Conflict with aircraft (22), with ground vehicles (35), and airport obstacles (26) constituted 48 percent of the pilot error reports. There were 22 incidents involving jet blast damage which was 13 percent of the pilot error reports. In 40 reports (23%) the pilot committed errors in controlling the aircraft. In these cases the pilot was either going too fast for conditions or misjudged the speed or turning ability and left the movement surface of the airport. In one case the pilot violated his clearance by not following the cleared taxi route. These data may be viewed graphically in Figure 3.2-3

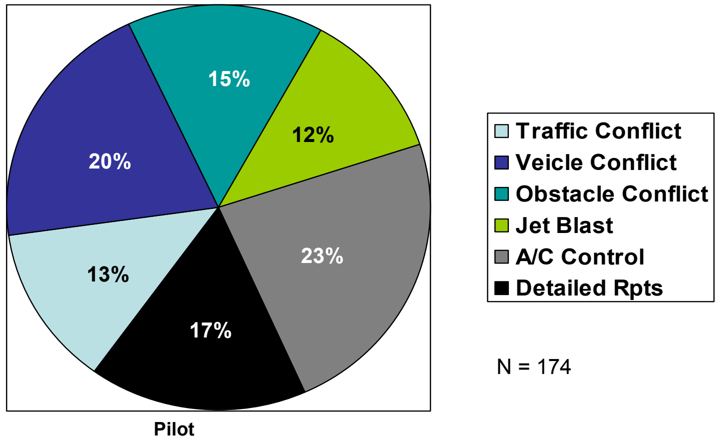

Figure 3.2-3 Pilot error categories from the FAA AIDS database

The FAA Runway Safety Report (2001)[18] states that runway incursion type of errors increased steadily from 1997 to 2000. There were 110 more reported runway incursions in 2000 than in 1999. However, the runway incursions that do occur are predominantly of minor severity. The overall distribution of runway incursion errors for the four-year time period was 25% operational errors, 20% vehicle/pedestrian deviations, and 55% pilot deviations. The increase in reported runway incursions in 2000 was primarily due to an increase in reported pilot deviations. Figure 3.2-4 graphically presents the pilot deviation data for the time period. Every airport is unique in terms of its configuration, traffic mix, etc. This diversity makes it difficult to establish a direct correlation between the rate of runway incursions and the number of operations. However, when severity is considered, the average rate of major runway incursions at the top 32 busiest U.S. towered airports was approximately twice the average rate for the rest of the airports. Airport complexity greatly influences the number and rate of runway incursions. Figure 3.2-5 illustrates this point.

18 Federal Aviation Administration, FAA Runway Safety Report: Runway Incursion Severity at Towered Airports in the United States 1997-2000, FAA, June, 2001.

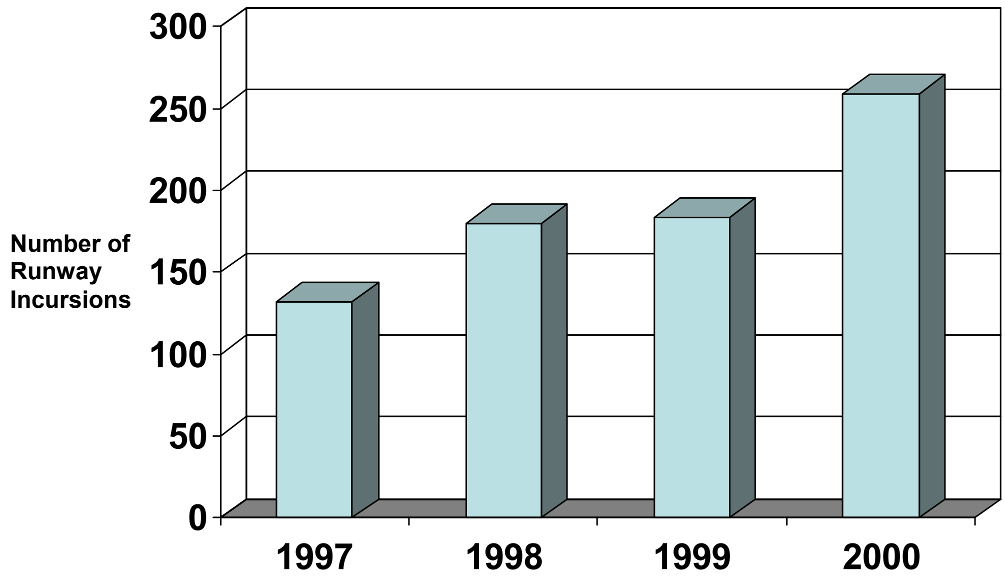

Figure 3.2-4 FAA reported runway incursions from 1997 to 2000

3.3 Results from Aviation Safety Reporting System

As stated earlier, the narrative of the ASRS reports provides richer and more detailed information regarding the incident than other reporting databases. Because of the anonymity provisions of the system, the reporters are willing to explain the situation in their own words and describe contributing factors frankly. However, Reynard (1994)[19] cautions that the ASRS reports cannot be considered to be measured random samples of the full population of like events since they are voluntarily submitted. There is no way of determining what fraction of the total occurrences the database represents. The only measure known is that it represents the minimum number of a specific event. For the purposes of the current study, however, it is the richness of the reports that provides insight into the reason that the error was committed.

As mentioned earlier, a total of 231 ASRS reports were examined in this study. The incident types and the data from the reports cover ground movements and have been classified based on the previously described two-level categorization scheme.

19 Reynard, W., ASRS: The Acquisition and Use of Incident Data, Aviation Safety Reporting System, California, 1994.

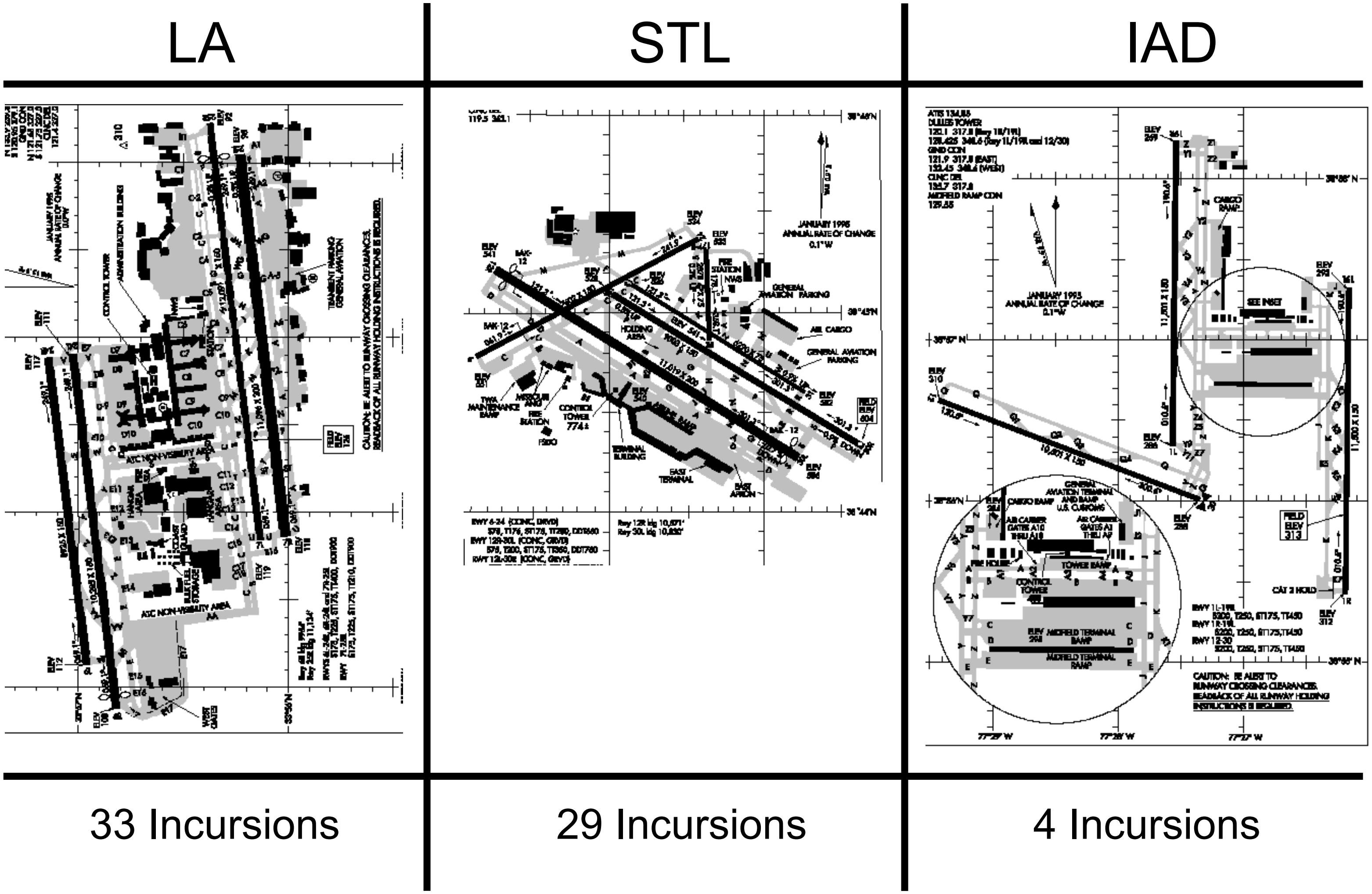

Figure 3.2-5 Relationship between airport complexity and runway incursions (FAA 2001)

Using the FAA classification scheme, 13% of the reports were operational errors, 4% were vehicle/pedestrian deviations or traffic conflicts, 5% were ground handling deviations, and 78% were pilot error. These data are depicted in Figure 3.3-1.

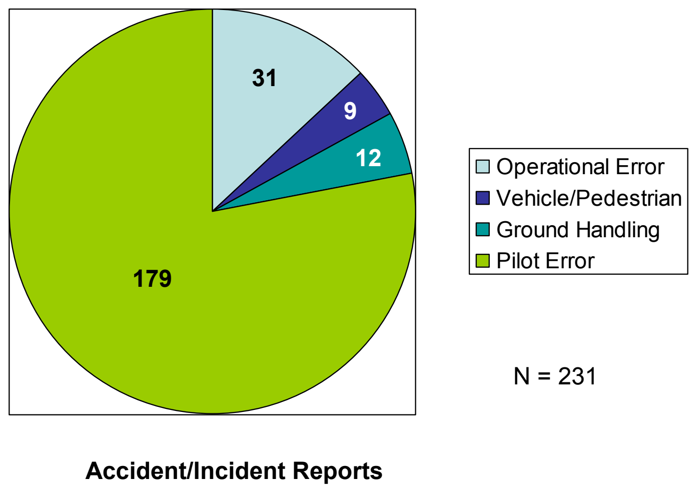

Figure 3.3-1 Accident/ Incident reports categorized in FAA-type scheme

The following is an overview of all of the ASRS reports that were reviewed, except for the ones attributed to the ATC system, or a total of 200 reports. The most common incident by far is a failure to hold short of a runway. This type of incident was cited in 67 reports or 34% of those examined. It is followed by turning the wrong way on a taxiway and entering or crossing a runway without clearance, each with 37 occurrences or 19% apiece. Therefore, these three types of incidents make up 72% of all the reports analyzed. Other incidents recorded, in order of their frequency, were: taxi without clearance (9); takeoff without clearance (9), traffic conflict (8), hit something at the gate (7), turn onto wrong runway (7), fail to hold short of taxiway (6), hit something during taxi (4), taxiway excursion (3), aborted takeoff (3), runway excursion (2), and jet blast damage (1). These data are depicted in Figure 3.3-2.

As a validation of the data, the results were compared to those of Hubener (1995) who looked at 209 ASRS surface operations reports from June 1993 to June 1994. In her study she found that 189 of these reports or 90% were runway and taxiway incidents.

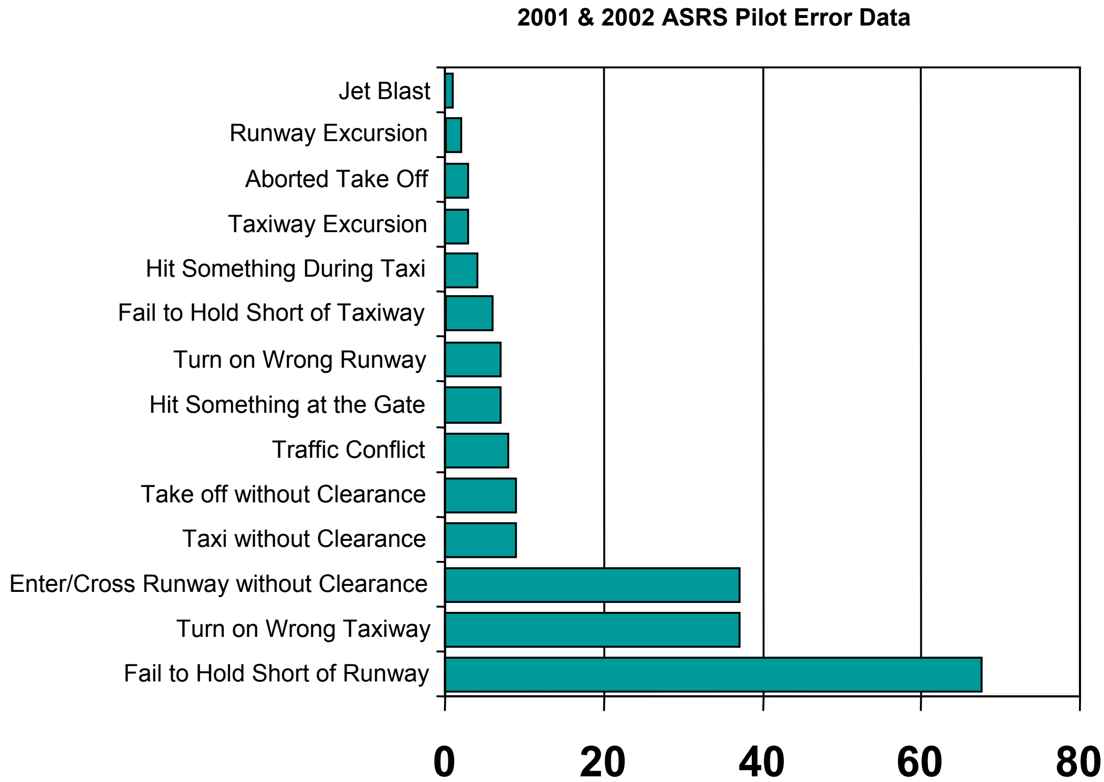

Figure 3.3-2 Overview of the 2001-2002 ASRS incident reports

The other 10% were gate incidents. The top three incident types reported by Hubener matched exactly those found in the current study. These three types of incidents, failure to hold short of a runway, turning onto the wrong taxiway, and entering/crossing a runway without clearance, made up 55% of her data. The other types of incidents and the frequencies that she reported can be seen in Figure 3.3-3. Even with the less frequently occurring incidents there is a high degree of correlation between the two data sets. This finding seems to indicate that the current data is a representative set of reported surface operations incidents.

One hundred and seventy-nine incidents were attributed to pilot error and of these, five involved control of the aircraft, either runway or taxiway excursions. These five were removed from the error analysis leaving 174 pilot errors that were categorized using the human error categories suggested by Abbott (1999) and Hooey et al. (2001). Examining the top-level error categories, 130 of the reports described situations where the pilot committed

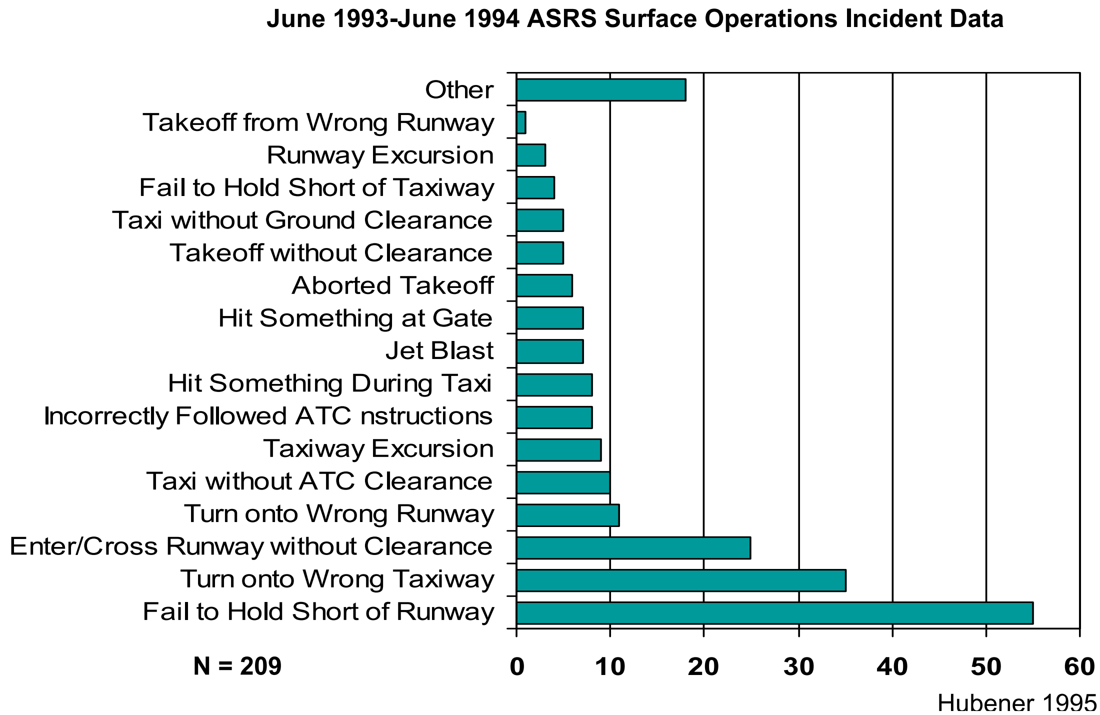

Figure 3.3-3 ASRS surface operations incident from Huebner 1995

errors in the formulation of intention or action. These manifested themselves as planning errors (45/26%), decision errors (53/30%), and violations (32/18%). The remaining 44 or 26% of the reported errors had presumed correct intention but the action taken was incorrect (execution errors). Figure 3.3-4 depicts this relatively even distribution.

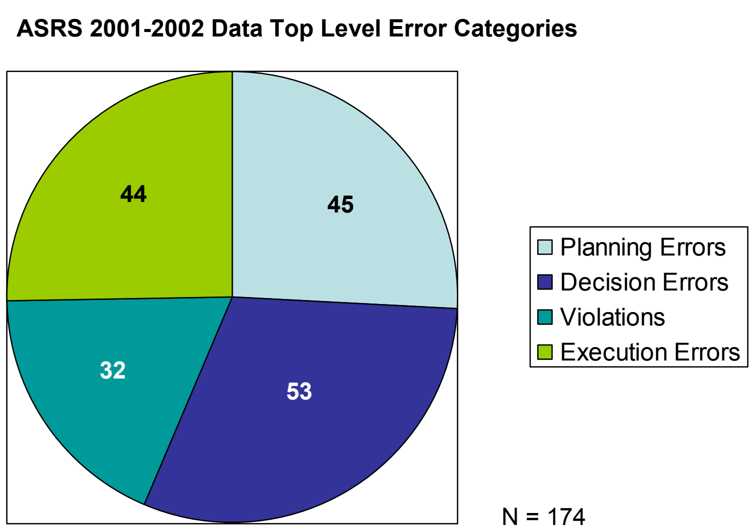

Figure 3.3-4 Top-level pilot error categories from the 2001-2002 ASRS data

Hooey et al. (2001) documented very similar results from their simulation study where they recorded navigation errors during a taxi task. Planning errors comprised 23% of the total number of errors, decision errors 42%, and execution errors 35%. They did not have any violation type of errors due to the simulation environment and the tasks that they asked the flight crew to accomplish.

A further breakdown of the errors into their primary contributing factor reveals that the planning errors, where the pilot formulated an erroneous plan or intention but carried out the plan correctly, were usually the result of miscommunication between the flight crew and ATC or between the flight crew members during the initial communication of the clearance. Miscommunication contributed to 71% of the planning errors errors. In 13 of the 45 planning errors, the flight crew committed a planning error because of some expectation that they had concerning the surface operation (e.g. took a taxi route that they usually got rather than the cleared route).

Decision errors, those that occurred when the route had been properly received and communicated and the pilot made a wrong choice at a decision point along the route, comprised 53 of the pilot errors in the study. A lack of spatial/navigational awareness was the primary contributor to 53% of the decision errors. This lack of awareness as to where the aircraft was on the airport surface and the overall configuration of the airport led to the flight crew making incorrect navigational choices. Decision errors are also caused by excessive procedural demands and distractions on the flight deck. At critical choice points, the "non-flying crew member" (usually the first officer on the ground) is occupied with procedural tasks (tuning radios, doing checklists, talking to ground/company, etc.) and cannot assist with the navigational tasks while the captain is taxiing solo.

Violations, which are errors associated with the failure to follow established procedures or performance of actions that are generally forbidden, constituted 18% (32) of the total number of pilot errors. Miscommunications between the flight crew and ATC, and between flight crew members are the major contributors to violation type of errors. This factor was cited in 41% of the violation errors. An excessive procedural demand on the first officer was cited in 31% of this type of error. Again the first officer becomes distracted and "head-down" with procedural duties and the captain mistakenly thinks that a clearance has been issued. Crew expectation contributed to 22% of the violation errors. In these cases the crew expected to be given a clearance and acted as though it had been issued even though it had not. Finally, in 6% of the reports the captain intentionally violated procedures/clearance and verbalized the intent “because they were running behind schedule.” There is not much that can be done to mitigate this “attitudinal” type of intentional error.

Finally, execution errors, those in which the clearance was correctly communicated, the pilot identified the correct place and maneuver, but made an error in carrying out the task, constituted 25% of the total number of pilot errors in this study. This type of error is generally caused by either the physical airport facility such as signage or markings accounting for 45% of the reports and complex geometry accounting for 7%, or by excessive procedural demands on the flight deck that accounted for 41%. The other 7% of the errors were attributed to visibility problems causing the captain to make an error in maneuvering. A pictorial depiction of these contributing factors is presented in Figure 3.3-5.

In summary, although there are a sizable number of contributing factors cited for pilot error during surface operations, the number one factor appears to be operational demands on the first officer. Looking at all the incidents reports covered in this study, this factor is identified as either a primary or secondary cause of the incident in 44% of the cases. Miscommunication between the flight crew and ATC or between the members of the flight crew, the second most common factor, appears in 26% of the reports, the third most common factor, navigational awareness, is cited in 17% of the reports, and finally the fourth most frequently cited factor is crew expectations appearing in 12% of the reports.

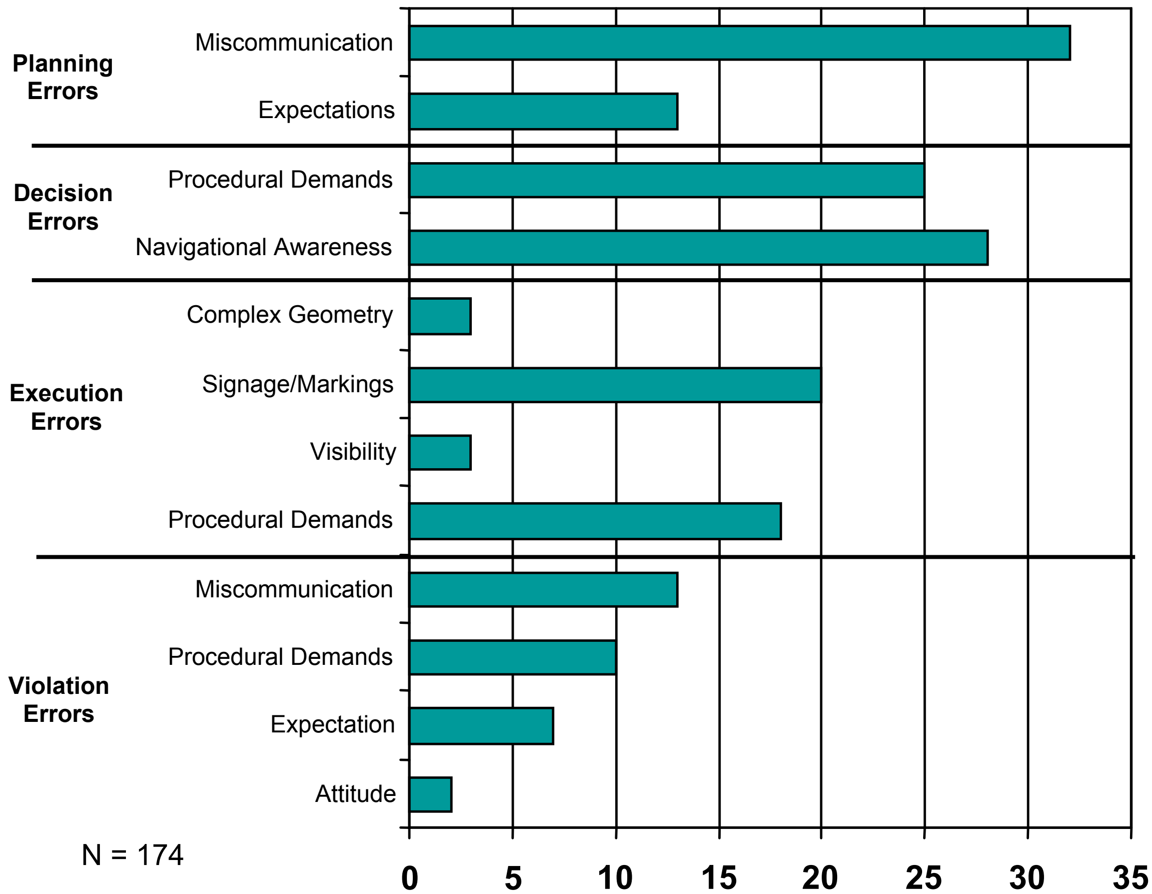

Figure 3.3-5 Contributing factors to the pilot errors

3.4 Results from Department of Transportation Study

The results of the Department of Transportation safety analysis for pilot reports of "runway transgression" incidents (Cardosi and Yost 2001) are presented in Table 3.4-1. The document points out that some of the pilot reports listed multiple contributing factors while others did not list any. Therefore, there is not a one-to-one correspondence between errors and contributing factors. There is a very high agreement between the trends exhibited in the data from this study and those of the MITRE study below (Adams et al. 1994). Forty-nine percent of the reports involved an aircraft crossing the "hold short" line. Two-thirds of these errors were attributed to the pilot not being able to see the line. Thirty-six percent of the reports involved pilots taxiing onto or crossing an active runway without clearance. The summary of this data indicated that fifty-one percent of the reports cited a need for better markings and 35 percent were attributable to controller/pilot communication errors.

Table 3.4-1 Pilot Reports of Runway Transgression Incidents (Cardosi and Yost 2001)

Failure to "hold short" as instructed – crossed "hold short" line Results • 2 runway incursions • 25 surface incidents Contributing factors • 25 couldn't see the hold short line or thought the marking was poor (includes 3 obscured by snow) • 7 miscommunication/misunderstood the clearance • 1 was confused as to where to hold • 1 cockpit distraction • 1 accepted "LAHSO" clearance then forgot to hold short • 1 instruction to hold short was issued too late for the pilot to comply • 2 poor crew coordination (one pilot knew the clearance the other didn't)	37
Taxied to (includes one aircraft that took off from) wrong runway Results • 8 surface incidents Contributing factors • 2 need better airport markings • 5 controller-pilot miscommunication/misunderstood clearance	8
Taxied onto, or crossed, runway without authorization Results • 22 surface incidents • 5 runway incursions Contributing factors • 11 controller-pilot miscommunication/mis understood the clearance (includes 4 incidents in which aircraft accepted a clearance intended for another aircraft with a similar call sign) • 12 cited need for better airport markings (one obscured by snow)	27
Took off without authorization Results • 2 surface incidents • 4 runway incursions Contributing factors • 4 controller-pilot miscommunication/misunderstood the clearance	4
Summary Data • 76 incidents (19 runway incursions and 57 surface incidents) • 39 were attributed to poor airport markings/signage • 27 involved miscommunications (including 5 instances in which an aircraft accepted a clearance intended for another aircraft with a similar call sign)	

Cardosi and Yost also reviewed the results of the results from an analysis performed by the Runway Incursion Joint Safety Analysis Team (JSAT) and documented in their Results and

Analysis Report (2000).[20] In describing their work, Cardosi and Yost state that the JSAT sampled NTSB operational error reports and pilot deviations. The team did not consider ASRS reports. However, the unique aspect of the JSAT analysis was the inclusion of information acquired from proprietary airline databases. The document analyzes 215 reports made between 1994 and 1999. The JSAT analysis results as reported by Cardosi and Yost include the following:

- At least one FAA study concluded that there is a "strong correlation between teamwork, or more precisely lack of teamwork, and the occurrences of operational errors"
- With respect to pilot procedures, complying with standard operating procedures (SOPs) was stressed as important as well as developing procedures for ground operations where none currently exist.
- Loss of situational awareness by controllers and/or pilots was the main causal factor in many of the incidents reviewed
- Inadequate and/or confusing ATC procedures have contributed to surface incidents and runway incursions

3.5 Results from the MITRE Survey

As stated previously, the MITRE study identifies factors relevant to the causes and prevention of human error in surface operations. The study presents results from a survey of almost 2000 airline pilots on their perceptions of situations and conditions encountered during operations on airport surfaces. It was felt that analysis of this type of data could provide a basis for identifying those factors that contribute to pilot error on the airport surface.

Adam et al. (1994) described the survey as consisting "of a mix of open-ended questions and questions with multiple-choice answers. This format was chosen because some factors were suspected, but not known as certain, whereas other factors were known, but not in detail. No attempt was made to structure the questions to collect data suitable for a formal statistical analysis to test specific hypotheses or draw statistically-significant comparisons among various factors." To enrich the results, the respondents were encouraged to add comments to their

20 Joint Safety Analysis Team, Runway Incursion Results and Analysis, August, 2000.

answers and to provide their own insights to the problem of pilot error. The two airlines surveyed in the study, between them, serve most of the domestic airports in the United States and both have international routes. Therefore, the responding pilots have a high likelihood of experiencing problems that are representative of those that the overall airline pilot population operating at airports throughout the United States would also experience.

The survey results corroborate the results of the previous incident data analyses. First, regarding navigational awareness, the results do not support the commonly held belief that pilots with major airlines are familiar with most of the domestic airports they fly into. Over half of the respondents who were specifically asked if they had made flights into unfamiliar airports, answered that they had (this included over half of the captains). The most frequent complaint from the respondents is that airport signs and markings do not provide enough information. Another complaint is that the controllers transmit complex taxi instructions speaking too rapidly as if the pilots were as familiar with the airport environment as the controllers. The fact that over half of the captains are unfamiliar with many of the airports is significant because the captains are the ones who taxi the aircraft and this is often done without the first officer's help because the first officer is busy with other flight deck tasks.

That leads to the second major issue addressed, which is flight deck procedures for surface operations. As was evident in the results from the ASRS database analysis and from the MITER survey, there were various good operating procedures used by pilots to help them correctly understand and follow the ATC taxi instructions. A large portion of the survey respondents did not use these procedures. The results indicate that there is a need for the development and implementation of structured standardized flight crew procedures for surface operations as well as development of formal training in their use. The survey indicated that there is confusion about the first officer's role in taxiing. The significance placed on these results is that "it is clear that ground operations (both arrivals and departures) have not been treated in the same way as operations in all other phases of flight. Current cockpit procedures for maneuvering the aircraft on the ground are too lax for the degree of hazard that exists in many airports."

The next major problem area cited by Adam et al. (1994) is communications, both pilot-ATC and crew member to crew member. The report concludes "pilots are not given sufficient training in communicating with ATC during surface operations. Use of standard phraseology, although more common by controllers, is not common by pilots. At the present time, most taxi instructions are issued by voice by means of radio transmissions. The quality of these transmissions and the noisy flight deck environment can make it difficult for a pilot to hear and correctly understand all the details of a complex taxi clearance, particularly if the pilot is not familiar with the airport. On the ground, the captain usually taxis the aircraft and the first officer communicates with ATC and performs other flight deck duties. Since the captain often has to taxi without support from the first officer, it is essential that the captain correctly understand all the ground movement instructions. This understanding requires accurate intercrew communication so that it is successfully maintained. However, the quality of the information exchange between the captain and first officer varies widely from crew to crew having been learned through informal training provided by the captains, or self-taught through experience."

The survey results indicate that captains and first officers differ in their perceptions of the communications that take place concerning taxi clearances and navigating the aircraft on the airport surface. Most pilots like to plan the surface operations ahead, especially at unfamiliar airports. Most captains report discussing these plans with the first officer, yet less than half of the first officers report discussing the plans with the captain. Even though it is the first officer that receives the taxi clearance from ATC while the captain monitors the exchange, the captains report that they repeat the ATC instructions to the first officer more often than the first officer reported repeating the clearance to the captain. The study also addresses specific pilot factors such as memory, attention, and fatigue as they relate to compliance with ATC instructions as well as the dissemination of safety-related information to the flight crews.

In summary, the major problem areas of navigational awareness, procedural demands placed on the first officer and communications, both crew-ATC and between crew members that were identified by the MITRE pilot survey data, were exactly the same pilot error factors revealed by the analysis of the ASRS incident reports.

4.0 MITIGATION STRATEGIES

It is obvious from the above data that uncovering the many factors underlying occurrences of pilot error during surface operations is a large and complex task. Multiple approaches were used because so many varied causes are involved. Incidents result from errors made by air traffic control, pilots, vehicles/pedestrians, and ground handlers. Within each of these groups of errors are many contributing factors. This large number of causal categories could generate an equally large number of intervention strategies. It is clear that the pilots are operating as a part of a system of interacting components. These components include the airport layout; surface navigation aids; communication links; flight deck procedures; FARs; ATC procedures; and the people involved in the operations, pilots, controllers vehicle drivers, pedestrians, and ground handlers. Pilots are reacting to or interacting with these various components of the airport surface system when they move their aircraft on the runways and taxiways. It is obvious that factors having the potential to either cause or prevent such errors/incidents must be sought within the whole airport surface system.

Abbott (1999) points out that until the issue of human error is taken on in a systematic or system-centered way, it may prove difficult to achieve the desired improvements in system safety. She goes on to state "while the issue of personal responsibility for the consequences of one's actions is important and relevant, it also is important to understand why the individual or crew made the error(s). In aviation, with very rare exceptions, flight crews do not intend to make errors, especially errors with safety consequences." Abbott goes on to say that understanding differences in the types of errors is valuable because management of the different types may require differing strategies. She summarizes some of the lessons learned about errors and their management (taken from Amalberthi 1998).[21]

- Experienced pilots make just as many errors as less experienced pilots, except for absolute beginners.
- Experienced/expert pilots make different types of errors than less experienced pilots. As expertise increases, more routine errors are made but fewer knowledge-based errors are made.

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21 Amalberti, R., Paradoxes of Almost Totally Safe Systems, special issue Safety Digest, 1998.

- The number of errors made tends to decrease in more demanding situations (because of cognitive control), but the recovery rate from errors also tends to decrease (because of lack of resources for detection and recovery).
- 75% to 85% of errors are detected, with a higher detection rate for routine errors.
- Expert pilots tend to disregard errors that have no consequences for the tasks underway. In fact, detection and recovery from error is considered to be a true manifestation of expertise.

Weiner (1995)[22] states that error management can be viewed as involving the tasks of error avoidance, error detection, and error recovery. Error avoidance is important because it is desirable to prevent as many errors as possible. Careful design of system components and operating procedures can help prevent occurrences of human error. Training and component selection can also have a positive effect on reducing errors. However, pilots, like most people, will inevitably make errors during the complex, action-intensive operation of their aircraft. It is in these instances where error detection and error recovery are important to mitigate the safety consequences of the error.

4.1 Intended Function

In order to develop operationally viable and cost effective surface operation system components that not only enhance error avoidance but also enhance error detection and recovery, it is necessary to define and understand the intended function of the system component or display element. The top level decision concerning the intended function of the candidate surface operations display concepts is whether it will be used to perform aircraft control or to provide crew awareness about the surface operations. Awareness displays should be located head-down and control displays should be head-up. The current industry definition of surface operations extends on approach from 1000 feet AGL to the gate and on departure from the gate to the departure end of the runway. The range of intended functions for a surface operations display may include: runway incursion detection in the air and prevention on the ground (being proposed today) using only the current infrastructure, which has surveyed runway position and approximate positions for other airport features (taxiways, buildings etc.); taxi path planning tool; spatial awareness of ownship relative to the airport surface; enhanced visual acquisition of

22 Weiner, E.L., Intervention Strategies for the Management of Human Error, Flight Safety Digest, February 1995.

other traffic; awareness of ownship relative to the cleared taxi path; enhanced IMC airport surface operations; route and hold-short depiction and deviation detection and alerting; Notice to Airmen (NOTAM) and aeronautical data overlays; and aircraft control information..

It is expected that any surface display will start with a basic function such as those that are based on spatial awareness (e.g., runway incursion prevention or airport geographical awareness) and move towards more complex uses (e.g., navigational and traffic awareness, surface route overlays, runway status alerting - hold bars and/or runway status indicator, and guidance concepts) as users and developers gain experience and the enabling technology and the required infrastructure is in place.

Any implementation of a surface moving map display system should consider the integration and use of individual map functions and features. For example, concepts that allow the pilot to use the display as a supplement to their out-the-window view in support of the visual search task need to consider head-down time. Additionally, surface map features that do not support the intended function of the concepts (i.e., situation awareness) should not be included. For example, the Airport Surface Situational Awareness concept is intended to provide the flight crew with a surface-moving map to aid in general orientation, navigation, and traffic awareness and is expected to improve situational awareness. The map display is not currently designed to support vehicle guidance and thus the inclusion of information that supports this task may be counterproductive. For example, surface map features, such as taxiway centerlines may suggest that the map could be used to support vehicle guidance and therefore should not be included on the display. However, recent studies (Andre et al. 1998)[23] suggest that route overlays, which are very similar, were found to be very informative in support of the navigational task.

4.2 Information Requirements

In order for each functional concept to address the defined human error types and factors, it will be necessary to determine the surface map features and functions that address the fundamental questions asked by flight crews during surface operations.

- Where am I?
  - Ownship position with airport map and stationary features

- Where am I relative to other moving objects?
    - Same information as above plus traffic
- What is the status of surfaces (runways, taxiways, other movement areas) in the movement area?
    - Same as above plus status information
- Where am I relative to my route / destination?
    - Same information as above plus cleared route
- What control inputs should I make to maintain my cleared route
    - Same information as above plus guidance cues

Relating these questions to the pilot error data, one can create a range of candidate display element concepts to mitigate the errors. Analysis of the 2001-2002 ASRS data reported above revealed that failure to hold short of a runway and crossing a runway without clearance made up 53% of the reported incidents. As a minimum, incursion detection/prevention display elements would address these error types. Currently, there is a candidate for implementation that uses existing database infrastructure to accurately display the ownship position with respect to the runway to prevent incursions. The existing airport databases have incorporated surveyed boundaries for the runways and digitized airport drawings for the remaining airport features. The advantage of this candidate concept is that it does not require extensive resurveying of the airport environment to achieve safety benefits. The disadvantage of this approach is that if other airport surface characteristics are presented to give the flight crew a "bigger picture" awareness of the runway environment, the lack of surveyed accuracy of these features may increase errors related to following the cleared taxi path. There have also been recommendations for in-flight alerting display elements to make the flight crew aware of the status of the runway while the crew is flying the approach

Advances in navigational accuracy (e.g. GPS) multifunction displays and vector-based, digitized, airport mapping databases will enable more comprehensive and accurate moving map display concepts to become a reality on the flight deck. These display concepts will permit not only heightened flight crew awareness (error prevention) but also crew alerting that will draw attention to errors (error detection) and enable them to be corrected (error recovery). Accurate

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23 Andre, A.D., Hooey, B.L., Foyle, D.C., and McCann, R.S., "Field Evaluation of T-NASA: Taxi Navigation and Situation Awareness System", IEEE/AIAA Digital Avionics Systems Conference, Seattle, Washington, 1998

depiction of the surface movement environment coupled with an accurate depiction of the ownship position can provide the flight crew with valuable spatial awareness to mitigate many of the planning and decision errors.

The FAA's Central Region (2000)[24] identified practices that were working to reduce surface operations incidents. Included among the recommendations were:

- Improved signage, airport markings placement, and lighting on taxiways/runways
- 24-hour runway guard lights
- Runway guard lights at problem intersections in conjunction with hold short lights
- Hold short markings double-sized and outlined in black
- Beaded paint
- Standardized taxi routes
- Warning signs on construction barricades
- Runway incursion devices

All of these recommendations could include information on a surface moving map display as well as information that could be incorporated into a display intended for airplane control. The inclusion of the cleared taxi route combined with traffic information will have operational as well as safety benefits. Young (1998) points out "simulations at NASA have shown that CDTI (along with the display of an airport map, route, and ownship position) can decrease taxi time by 10-15% (larger as the visibility decreases) while reducing the likelihood of navigation errors during taxi by 75% or more. These conclusions have been validated by field tests. An additional safety benefit that can be gained with this information package is the detection and mitigation of ATC operational errors. Since most of these errors result in traffic conflicts, the traffic awareness supplied by the moving map and surface CDTI should permit the crew to detect these errors and proactively respond to mitigate them. The major advantage of a flight deck-based surface moving-map display is that the benefits are not dependant on the airport facility but rather move with the aircraft from facility to facility.

Another possible feature of the surface operations display is the ability to present graphical Notices to Airmen (NOTAM) overlays (e.g. closed runways or taxiway segments, construction,

24 Federal Aviation Administration, FAA's Central Region Runway Safety Program Regional Administrator's Workshop Recommendations, FAA, May 2000.

transient obstacles like dirt or snow etc.). Research on low-visibility airport surface navigation has shown that graphical taxi clearances and instructions significantly reduce pilot workload and potential confusion on the airport surface (Battiste et al. 1996 and 1996).[25,26]

One way to accelerate implementation and take advantage of the benefits from the system is to initiate a phased implementation strategy in which the capabilities that are the "low-hanging fruit" are the focus of the initial efforts and the higher risk functionality phased in at a later date. In this strategy, a systems engineering approach is used to evaluate the desired capabilities of the display elements using requirements, cost/benefits analysis, technology readiness, and resource availability as the trade criteria. To evaluate the technology readiness of a candidate display concept, it is necessary to determine just what the operational concept is and then to define what equipment and infrastructure changes will be needed to implement the concept. The trades will consider how much existing display and support equipment (low risk) can be incorporated into the concept and how much new airborne equipment is needed. Also considered will be how much technology and infrastructure outside of the airplane will be required (i.e., ground or satellite equipment, database development, database maintenance, etc.). Further, what changes in the airport infrastructure and in procedures are needed to support implementation. Finally, it is necessary to determine the risks associated with the candidate concept (e.g., technical, time, infrastructure, certification, etc.).

Lastly for each of the candidate concepts and the resulting capability, it is necessary to ask if the resources exist to pursue the concept. It should be determined if the research resources are available to resolve the remaining issues associated with the concept. Given the costs associated with implementation, determine if the potential customers have the resources available (and the willingness to expend them) to implement the concept. For the risk profile of the technology, it must be determined whether suppliers have the resources available to produce the concept.

The results of the above analysis will determine in what order the display elements and system capabilities should be phased into implementation and how the system should evolve. Considerable activity is currently underway within the private sector to certify flight deck

25 Battiste, V., Downs, M., and McCann, R.S., Advanced Taxi Map Display Design for Low Visibility Operations, Proceedings of the 40th Annual Meeting of the Human Factors and Ergonomics Society, Santa Monica, CA, 1996.
26 Battiste, V, Downs, M., Sullivan, B.T. and Soukup, P.A., Utilization of a Ground Taxi Map to Support Low-Visibility Surface Operations, Proceedings of the AIAA Flight Simulation Technologies Conference, San Diego, CA, 1996.

technology that will enable the development of an integrated air/ground surface operations awareness/alerting system. Both portable (e.g., Electronic Flight Bag) and panel-mounted display systems are being pursued and there are wide ranging discussions, both technical and economic, advocating a phased approach to flight deck implementation. The FAA's Safe Flight 21 Program has described a four-phased effort aimed at reducing surface operations incidents/accidents, enhancing airport capacity, and reducing flight delays (Livack et al. 2001).[27] Figure 4.2-1 describes a four-phased effort based on the Safe Flight 21 work and the efforts described in this report.

The phasing of the display elements and supporting technology and infrastructure for a situation awareness display for surface operations would follow a road map that would include:

Phase 1 - The aircraft would be equipped with a track-up moving map display that would display the airport environment (including signage and markings) and the ownship. This phase would address pilot errors that are generated by a lack of spatial awareness during surface operations. This phase would require surveyed airport databases to ensure that the position information presented to the crew is accurate.

Phase 2 – Traffic information would be added in the second phase. This functionality would display other aircraft and vehicles on the airport surface. This phase not only addresses pilot errors causing traffic conflicts, but also addresses ATC operational errors that result in traffic conflicts. The depicted traffic will also provide a basic indication of runway occupancy. This phase would require the implementation of traffic detection/identification technology such as ASDE radar, ADS-B, or TIS-B.

Phase 3 – Active hold short and runway/taxiway status indications and alerting functionality would be added to the system. This phase provides the alerting function to permit the flight crew to more easily detect hold short and runway transgressions as well as traffic conflicts. The alerting functionality increases the "reactive" nature of the system in mitigating errors while the other information elements tend to make the flight crew more "proactive" in preventing the errors from occurring. This phase would require the implementation of data linked runway/taxiway status and active hold short indication. There should also be a common alerting

27 Livack, G.S., McDaniel, J.I., and Battiste, V., Airport Surface Moving Map Displays: OpEval-2 Evaluation Results and Future Plans, Safe Flight 21 Program, Department of Transportation, Federal Aviation Administration, Washington, DC, 2001.

scheme between the flight deck and ATC so that coordinated surface operations may be maintained.

Phase 4 – Taxi clearances and instructions would be added in graphical format and route deviation alerting would be added to the alerting scheme. This functionality would provide the flight crew with heightened awareness of the cleared taxi route, reducing planning, decision, and execution errors. It would also reduce or eliminate miscommunication between the flight crew and ATC and reduce the amount of radio traffic on the airport surface. This phase will require implementation of Controller-Pilot Data Link Communication (CPDLC) and the efficient and effective communication of surface operations clearances.

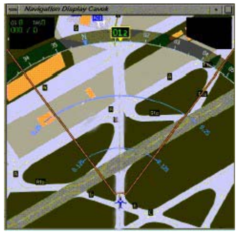
The introduction of graphical NOTAM overlays can be introduced during any one of these phases and will integrate additional airport surface information on the surface operations awareness display. This information will be transmitted to the aircraft using FIS-B. Livack et al. state that "some avionics manufacturers are proceeding with plans for certifying equipment that combines the capabilities identified in Phases 1 and 2." Some of the issues that still need to be investigated include the transition from air to ground, the perspective of the map display, the amount of information included on the map, methods for decluttering the map information, and the resolution or scale needed to achieve the awareness function.

Because of their flight criticality, aircraft control type displays are much more difficult to certify than awareness displays. Because control on the airport surface is performed under the closest separations of any flight phase (often less than 200 feet) a display that the controlling flight crew member uses for performing the task should be head-up to eliminate any head-down time. As said above, the information presented on the display should correspond to the intended function of the display. Since the display will overlay the outside visual scene, display elements should be kept to a minimum and should be scene linked to provide the conformal perspective for the display elements. Runway/taxiway edge markers that depict the cleared route, imbedded signage and markings and steering guidance are elements that should be considered for inclusion.

Phase 1

Capability:
- Basic track-up surface moving map with ownship position and airport signage and markings (requires surveyed airport

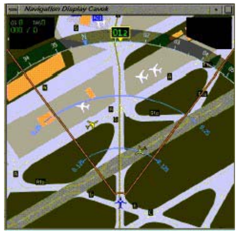
Solves:
- Flight crew unfamiliarity with airport
- Progressive taxi monitoring (basic)
- Positional/spatial awareness
- Memory aid for ATC instructions (basic)



Phase 2

Capability:
- Phase 1 plus
- Surface traffic (requires ADS-B/TIS-B)

Solves:
- Phase 1 plus
- Traffic taxi conflicts
- ATC operational errors
- Aid to visual scan prior to takeoff and landing
- Runway occupancy indication (basic)



Phase 3

Capability:
- Phase 1 & 2 plus
- Active hold short indications
- Active runway occupancy indication
- Crew alerting for hold short transgressions and traffic conflicts (requires common alerting scheme with ATC)

Solves:
- Phase 1 & 2 plus
- Runway incursions (advanced)
- Error detection for conflict situations

Phase 4

Capability:
- Phase 1 & 2 & 3 plus
- Data link of taxi clearances and instructions (requires CPDLC)
- Route deviation alerting

Solves:
- Phase 1 & 2 & 3 plus
- ATC/crew miscommunication
- Crew planning, decision and execution errors
- Memory aid for ATC instructions (advanced)

Note: Graphical NOTAM overlays can be added at any time in this phased

Figure 4.2-1 Surface operations awareness display development roadmap

The T-NASA system developed by NASA provides such a head-up presentation for aircraft control during surface operations.

One concept that should be investigated is switching from an inside-out conformal presentation to an outside-in plan view of the airplane when the task requires a visual perspective that the pilot cannot get by looking over the nose of the aircraft (for example approaching a hold short line with the aircraft nose). In some airport geometries it is important to get as close to the hold short line as possible to permit an aircraft behind the ownship to clear another hold short line with its tail.

4.3 Procedural Modifications

Airport surface operations today are more difficult and potentially more hazardous than they were in the past. The reason for this is that the expansion at many airports has created complex runway and taxiway layouts and the increases in traffic pressures has created problems for ATC in spacing and communicating with the many aircraft operating simultaneously on the airport surface. Flight deck procedures and inter-crew communications have not changed to accommodate these evolving complexities and fast-paced ATC operations. This is evidenced by the steady increase in runway incursions being reported by the FAA. To complicate this, the addition of surface operations displays such as electronic moving maps will have to be accommodated in any procedural changes.

4.3.1 Procedural Implications

In focus group discussions, Hooey et al. (1999) gathered comments regarding the procedural implications of implementing surface operations displays. If taxi clearances and other communication between the flight crew and ATC are performed using only data link, a major source of the crew's traffic awareness and one that is not degraded by low visibility, party-line information, will be eliminated. A means will have to be developed to replace the information that is gained by listening to the interaction between ATC and the other aircraft on the airport surface and in the air close to the airport.

The use of electronic moving maps to provide information about surface traffic as well as aircraft in the air near the airport may produce a greater reliance on the information presented head-down than on visual scan and/or party line information. This may shift the responsibility for traffic awareness and separation away from the flying/controlling pilot who is normally head-up to the non-flying pilot who will be head-down. The non-flying pilot will then have to communicate potential threats to the flying pilot. Given this procedural change, the question arises as to the effect of non-cooperative surface traffic. If the surveillance responsibility moves to a head-down operation, the infrastructure will have to accommodate detecting all surface traffic.

Another issue that arises is that of checking the ATC routing instructions for errors. With the proposed moving map implementation, the communication of route instructions moves from an auditory task to a visual task. The pilot must look down to get the route information either in data-linked text or graphically on the map. Any error checking of the taxi route that will be done will be visual and head-down. With automation and electronic route transmittals, there are more sources for undetected errors in the data stream. Therefore, procedures should be developed that define the role of each crew member in the error checking process and the communications that need to take place between them.

A head-up guidance display presents another set of procedural issues. Hooey et al. point out that "procedure manuals for airlines that have already adopted the HUD, Southwest Airlines and Alaska Airlines, suggest that the HUD has a profound effect on existing aircrew communications and procedures for approach, landing, and roll out." There is no reason to think that this would not be the case for taxi also. Due to the installation and certification costs, most airlines using HUDs have chosen to install a single HUD on the left side of the flight deck. Thus, the first officer does not see what the captain is seeing outside the aircraft and the captain may not be as aware of what is happening inside the aircraft. The Alaska Airlines manual states that because of the amount of attention focused on the HUD by the captain, it is imperative that first officers retain overall flight deck situational awareness with particular attention to any critical anomalies not apparent in the captain's head-up scan. The problem this creates is one of communication. The first officer may be less likely to call out control guidance (e.g. the next turn) knowing that the captain had the information in the head-up display. This could necessitate an emphasis on communication and the phraseology that is used to ensure that the efforts of the crew are coordinated and that the communications be used as a way for the crew to perform error checking.

4.3.2 Procedural Mitigation Strategies

The study data analysis provides a wide range of airport surface operations incidents and contributing factors. Currently, there are very few, if any, structured flight deck procedures and communications for crew coordination on ground movement instructions given by ATC and on navigation of the aircraft on the airport surface. The pilots develop individualized approaches to this verbal communication. This nonstandard and inconsistent verbal coordination often lacks the redundancies that reduce the likelihood of pilot errors and increase the probability of detection should an error occur.

The following procedural ideas are not new but rather an attempt to emphasize methods that will support the flight crews in preventing incidents. The most often cited factor contributing to surface operations incidents was the procedural demands placed on the first officer which required head down attention during taxi, preventing monitoring of the pilot flying. The flight deck crew performs a variety of tasks during the surface operations. Some of these tasks are directly related to steering the aircraft, navigating on the airport surface, and communicating with ATC getting taxi instructions. Most of the remaining tasks involve planning and preparation for the next phase of operations. Currently, a high level of emphasis is placed on preparing for the next phase of operations, especially departure, and on communicating with ATC and the airline as needed. The first officer is the primary crew member responsible for most of these preparation and planning tasks. The first officer's role needs to be reexamined and better defined to ensure active participation in the actual surface operations. Taxi navigation, for example, should not be left solely to the pilot flying but rather should be a crew-coordinated effort. The FARs state that "no certificate holder shall require, nor may any flight crew member perform any duties during a critical phase of flight except those duties required for the safe operation of the aircraft…. Critical phase of flight includes all ground operations involving taxi…."[28]

The three most often reported incidents all involve taxi awareness: failure to hold short of a runway, turning the wrong way on a taxiway, and crossing/entering a runway without clearance. Sumwalt (1992)[29] addresses the taxi navigation issue saying, "a high attention level is crucial in situations where inactive runways are designated as taxiways, especially when crossing an active runway…. Generally while taxiing, the flight crew should keep a close watch for taxi/runway hold lines – which should never be crossed unless all flight crew members agree the

28 Federal Aviation Administration, Federal Air Regulation, Part 121.542
29 Sumwalt, R, Taxi!, ASRS Directline, Issue Number 3, California, 1992.

corresponding clearance has been received. If there is any doubt, the right to cross should be confirmed…."

Finally, most if not all of the ATC operational errors and 40% of the incidents involving entering a runway without clearance were "taxi into position and hold" (TIPH) incidents. The Airline Pilots Association (ALPA) has suggested a set of procedures to help prevent the "Position and Hold" type of incidents, which include:[30]

- Carefully scan the approach corridor prior to accepting a TIPH clearance
- Observe the Traffic Alert and Collision Avoidance System display for possible landing traffic
- Turn on all appropriate lights when cleared into position and hold
- Query the controller if held in position for a lengthy time
- Query the controller if hearing a landing clearance for one's runway without an advisory for traffic holding in position.

The review and revision of procedures and crew communication requires a "systems" approach looking objectively at which tasks must be done, and then finding the best way to use the available people and equipment to accomplish these tasks. Because of the safety issues involved, certain redundancies must be built into the procedures and communication to catch the normal kinds of errors that people can make. The captain and first officer must have clearly defined roles and responsibilities, and they must work together as a team even if they have not flown together before. They must know exactly what to expect from each other, and they must coordinate on safety-critical issues.

30 Haase, D.J., Taxi into Position and Hold, ALPA Operations Bulletin 95-1, 1995.