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Runway Status Lights Evaluation Report

FEDERAL AVIATION
ADMINISTRATION

RWSL
RUNWAY STATUS LIGHTS

U.S. Department of Transportation
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142-1093

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13. ABSTRACT (Maximum 200 words)
The Federal Aviation Administration (FAA) conducted a proof-of-concept demonstration of the Runway Status Lights (RWSL) at Boston's Logan International Airport. The RWSL, employing a network of lights on the airport movement surface, conveys information to enhance the pilot's situational awareness of airport operations and to reduce the incidence of runway incursions and airport surface accidents. The FAA extended the effort conducted previously by MIT Lincoln Laboratory by installing an operational system in a live environment, integrating the system with primary radar, designing and installing a prototype lighting system and demonstrating the performance requirements needed to uncover the lights. Maximum use of commercial off-the-shelf equipment (COTS) hardware and software was utilized to minimize cost and expedite the challenging schedule. The RWSL proof-of-concept demonstration accomplished all of its engineering objectives. One hundred hours of data were collected, representing 8298 operations involving arriving and departing aircraft with the network of lights covered, i.e. not observable to the pilots. The analysis of the data was used as a baseline to define system performance. The performance of the lighting network registered over 98% agreement with the Air Traffic Control (ATC) instructions. Because of restrictive limitations placed on uncovering the network of lights to pilots, statistically significant quantitative information was not collected. Specific recommendations and suggestions for improvement are included in this document.

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Runway Status Lights (RWSL), Airport Movement Area Safety System (AMASS), Airport Surface Detection Equipment (ASDE-3), Runway Entrance Light (REL), Take-off Hold Light (THL), Light Computer (LC), Light Control Computer (LCC), Smart Transformer

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (ha) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

°C=5/9(°F - 32)

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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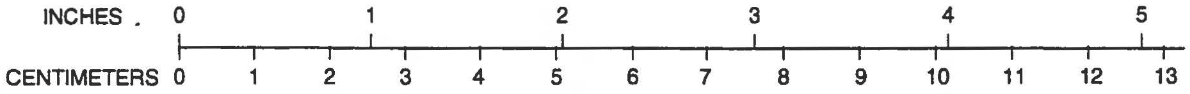
QUICK INCH-CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10286.

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LIST OF ACRONYMS

ACID	Aircraft Identification
AIU	ARTS Interface Unit
ALPA	Airline Pilots Association
AMASS	Airport Movement Area Safety System
AMASS-LM	AMASS Light Manager
ARR	Arrival State
ARTS	Automated Radar Terminal System
ASDE-3	Airport Surface Detection Equipment-Version 3
ASTA	Airport Safety Traffic Automation
ATC	Air Traffic Controller
ATIDS	Aircraft Target Identification System
CCR	Constant Current Regulator
COTS	Commercial-Off-The-Shelf
DBT	Departure Abort State
DEDS	Digital Electronic Display System
DEP	Departure State
DH	Dufresne-Henry, Inc.
DPIC	Display Processor Interface Control
EK	Edwards and Kelcey
ELWW	Elevated Wig-Wag Light
FA	False Alarm
FAA	Federal Aviation Administration
FSK	Frequency Shift Key
GA	General Aviation
KTS	Knots
LC	Light Computer
LCC	Light Control Computer
LDG	Landing State
LM	Light Manager
LRO	Landing Roll-Out
MDBM	Multiple Display Buffer Memory
MD	Missed Detection
MIT	Massachusetts Institute of Technology
MITLL	MIT Lincoln Laboratory
MTBD	Mean Time Between Discrepancies
PAPI	Precision Approach Path Indicator
PBQ&D	Parsons, Brinckerhoff, Quade & Douglas
PLC	Programmable Logic Controller
REL	Runway Entrance Light
RIRP	Runway Incursion Reduction Program
RSLS	Runway Status Light System
RTCA	Requirements and Technical Concepts for Aviation
RTG	RWSL Time Generator
RWSL	Runway Status Lights Program

LIST OF ACRONYMS (cont.)

SATC	Shadow Air Traffic Controller
SCIP	Surveillance and Communication Interface Processor
SMGCS	Surface Movement Guidance and Control System
SNR	Signal-To-Noise Ratio
SP-184	Special Committee 184
STP	Stop State
SX	Smart Transformer
SXS	Smart Transformer Subsystem
TAX	Taxi State
THL	Takeoff Hold Light
TSRV	Transport Systems Research Vehicle
UPS	Uninterruptible Power Supply
USAF	United States Air Force

EXECUTIVE SUMMARY

BACKGROUND

The Runway Status Lights (RWSL) installation at Logan Airport is a proof-of-concept demonstration that was carried out under the Airport Surface Traffic Automation (ASTA) program (now the Runway Incursion Reduction Program). Its **goal** is to expose the system to users to evaluate if it is possible to reduce runway incursions, and thereby improve airport safety, by utilizing a network of lights (that are operated by a primary radar) to convey additional information to improve pilots' situational awareness of airport operations. Stating this another way, the test was conducted to see if an automated system, based on radar-driven logic, could be developed that emulated air traffic controllers (ATCs) closely enough to be used as a backup to eliminate human error. This effort began in 1992 and was completed in July 1997.

The Federal Aviation Administration (FAA) decided to sponsor a proof-of-concept demonstration, based on the promising results of MIT Lincoln Laboratories' initial model board experiment that was conducted in 1992 and 1993 at Logan Airport. The MITLL demonstration showed that algorithms could be developed to control lights that used the inputs of a marine band radar and ARTS. However, it wasn't clear at that time how the system would be perceived by both pilots and ATCs, or if it was possible to actually control a large number of lights and where they would be placed. The next step in the development of a status light system required installing equipment in an operational environment to determine if the ultimate user of the system, the pilot, found the lights to be effective, and to ensure that the lights did not slow down or disrupt airport operations. It was crucial to obtain this user/operational input before proceeding any further in system development.

The Runway Status Lights installation consists of lights installed on the airfield that are driven by the Airport Surface Detection Equipment (ASDE-3) primary radar, the Automated Terminal System (ARTS), and the Airport Movement Area Safety System (AMASS). Runway Entrance Lights (RELs) were installed on both sides of taxiway/runway and runway/runway intersections. Takeoff Hold Lights (THLs) were installed at the runway takeoff hold positions. These runway status lights illuminate to inform pilots and ground vehicle operators when a runway is unsafe to enter or not clear for takeoff.

APPROACH

The demonstration that was structured by the FAA was an ambitious and aggressive program. First, it extended the MITLL model board concept by putting it into a live environment in which it would actively affect how users operate on an airfield. Second, it integrated it with the ASDE-3/AMASS primary radar system. This required recoding the safety and light control algorithms and integrating it with AMASS, because this allowed an evaluation of the concept in its most likely configuration. It is more likely to be an additional feature to an ASDE-3/AMASS at a large airport than another standalone system. At the same time, a number of the safety algorithms were enhanced and modified to make them robust enough for use in a real airport environment under varying weather, visibility and traffic conditions. Third, it was necessary to design and install a prototype lighting subsystem. Because there was no technology currently in use at airports to do this it was a significant undertaking.

We had to ensure that a technology to control the lights was available and would be affordable. This involved a significant effort to identify a technology to turn individual lights on and off in rapid succession. It also involved selecting an associated light fixture and modifying its operation to support the RWSL concept. This resulted in the capability to conduct end to end system testing to demonstrate not only that we could extend and implement MIT's light control algorithms, but in addition that those lights could be operated quickly enough to mimic ATC commands and not slow down airport operations. A fourth factor that made this demonstration very challenging was the system performance requirements that had to be met to allow uncovering the lights. The requirements for RWSL performance are much more stringent than ASDE-3/AMASS because the light indications, which could adversely impact safety, affect a much larger user group, and, more importantly, play an active role in traffic flow.

Boston's Logan International Airport was selected because it has an exemplary safety record that could be used as a baseline for quantitative analysis of system performance. In addition, because of the complexity of the airport layout at Logan, it was clear that if the concept worked at Logan, it would probably work anywhere. Overall, over 170 lights were installed on runways 9/27 and 4L/22R at Logan.

It should be noted that the RWSL installation was not intended to be a preproduction system. Maximum use was made of Commercial-Off-The-Shelf (COTS) hardware and software wherever possible to reduce expense and eliminate time consuming approvals to utilize new or specialized equipment on the airfield. However, in some cases, concessions were made to ensure a fair assessment of the new technology. For instance, new circuitry was installed for the Runway Status Lights. This occurred to make sure that the noise and signal losses that could occur with existing circuitry did not degrade the system capabilities. In addition, if the smart transformers didn't work with a clean circuit, it is unlikely they would work in a normal airport environment.

An underlying tenet of the test program/installation was that nothing we did could adversely affect the safety of operations at the airport at any time. Impact on all normal operations was to be kept to a minimum. This meant that extensive system testing was conducted to ensure it would operate reliably and predictably before it was installed. In addition, in some cases new equipment was installed to provide separate services such as power and communications. Finally, whenever RWSL interfaced with operational equipment, we ensured that our tap off the data did not feedback any signals that could negatively impact normal operation in any way.

The demonstration followed a rigorous systems engineering approach throughout the design, implementation and testing. The process included both engineering issues and human factors. Specifications were developed that guided the development of the software. Early testing was conducted whenever possible to reduce risk. For instance, as soon as the software was in a stage that it could be tested, data was collected at Logan to evaluate the performance of the algorithms which were then tested in a laboratory environment. Once the Wig-Wag fixture was selected and the Light Control Computer (LCC) was operational, a subsystem comprising the LCC, lights, and power supplies was integrated in a warehouse to evaluate their compatibility and verify interfaces between the major components of the system.. In parallel, different light fixtures were obtained and installed at the airport, so that we could observe their performance. We also utilized NASA's simulation and conducted fly-over tests to obtain human factors information on pilots' reaction to the operation of the lights. As soon as the system was installed at the airport, hooded testing was conducted to evaluate end-to-end system operation that included everything except the user's interaction with the system.

FINDINGS

The RWSL proof-of-concept demonstration accomplished all of its engineering objectives. It developed, installed, and tested a system from end to end, in order to provide quantitative measures of the performance that can be expected. The testing that was accomplished also highlights where deficiencies exist, and identifies where additional testing is needed. Overall, we only had limited success in achieving our primary objective and further testing is needed with real pilots and ATCs in the loop.

RWSLs were operated in an operational environment. The system/equipment encountered the full gamut of environmental conditions such as day and night, rain, fog, snow and freezing conditions, jet blast and wake vortices. It also was evaluated during both high and low operational activity. A wide cross section of the user community became familiar with the concept through involvement in testing, briefings that were given to Massport users, as well as by way of demonstrations and brochures that were provided throughout the test program. Finally, the entire system concept was evaluated through a series of laboratory, warehouse, simulator, hooded and unhooded test phases. The evaluation includes an assessment of the impact on airport operations, measurement of light response times, compilation of users' reaction to the lights, evaluation of the adequacy of a radar as a primary sensor, and calculations of installation costs and issues. It also measured system integrity and, to some degree, reliability.

Specifically, almost 100 hours of data were collected, representing 8298 operations involving arriving and departing aircraft, between February and August 1996 with the lights covered. The data includes periods of time when there was very heavy activity with peak loads up to 100 operations/hour and an average of 85 operations per hour. In the analysis of the test data, ATCs' communications with pilots and observations by experienced controllers in the RWSL test facility were used as the baseline for defining system performance, both qualitatively and quantitatively. RELs and THLs registered 98.8% and 98.6% agreement, respectively, between the on/off state of the lights and ATC clearance instructions.

Three nights of data collection occurred with the lights uncovered, using the test program's own pilots and vehicle operators. We were not able to collect statistically significant quantitative information because of the highly restrictive limitations that were imposed on (a) the duration of testing, (b) the number of independent, representative observers, and (c) lighting conditions. However, our projected performance in these areas was that we would have in excess of 99% agreement between ATC clearances and light state and a mean time between discrepancies in excess of seven hours based on some software changes we made to improve the radar inputs and procedural changes.

The proof-of-concept installation that was tested is not ready for operation, today, because it did have some deficiencies. Two deficiencies are attributable to the radar input source, and two are attributable to the RWSL safety and control logic. The majority of the THL discrepancies are caused by false radar targets. The majority of the REL discrepancies are caused by bad ARTS to ASDE-3 handoffs. The RWSL logic deficiencies can be attributed to an inability to determine when an aircraft has taken off, and logic that is needed to allow proceeding with a takeoff when a previous arrival is still on the runway ahead of a departing aircraft. We feel that, for the most part, these deficiencies can be eliminated which will significantly improve RWSL performance. However, correcting these problems was beyond the scope of the program. (Nonetheless, it had a major impact on uncovering the lights in the last phase.) Additionally, there are some light subsystem deficiencies associated with the capabilities of the Smart Transformers, selection or design of the light fixtures and their placement (better fixtures, trickle current for lights, more bandwidth for the smart transformer communications). It appears that these can also be corrected with additional work and that they do not represent an insurmountable obstacle for the program.

CONCLUSIONS AND RECOMMENDATIONS

The RWSL proof-of-concept demonstration shows that a light-based system, that derives its information from a primary radar sensor, is feasible. There are no technical show stoppers at this time. Response from users was good. The lights should improve pilots' situational awareness and improve airport safety. The safety algorithms, which act as an automatic backup to ATCs, can be tuned to operate the lights at the correct timing without impeding traffic flow. Similarly, the technology exists to individually control lights in a rapid sequence. In addition, there are other applications for the technology such as control of Surface Movement Guidance and Control System (SMGCS) lighting and better displays for AMASS which should be investigated.

The most significant remaining issue is to expose the lights to a representative group of pilots in an operational environment. We were not able to expose the lights to a large enough group of the user's (pilots and vehicle operators) to get their inputs and we must do this because the dynamics and visibility of an airport environment can not be simulated effectively. Consequently, before proceeding to preproduction, we need to find a way to uncover the lights in a realistic operational environment and to develop a training curriculum that is acceptable to all parties. This uncovered testing will allow us, once and for all, to ascertain if a pilot will instinctively proceed when a light is turned off without having obtained ATC clearance. At this time there is too much subjective speculation on this issue. We also need to verify the initial performance metrics that we derived from discussions with ATCs. Although false alarms and missed detections are common terminology when describing radar performance, it is not clear that they are appropriate when describing the RWSL performance. A panel comprised of representatives from the pilot and ATC communities should be formed to establish the important metrics and performance that is required to implement RWSL and guarantee safety. Finally, installation cost is another area that needs to be addressed further in the future. As the remaining technological hurdles are overcome, we need to investigate ways to reduce the overall cost of the installation.

INTRODUCTION

1.1 BACKGROUND

Air traffic, both national and international, is expected to increase significantly in future years. This increase in traffic will raise issues concerning airport capacity, surface safety, and surface traffic flow efficiency. Compounding these problems, most major U.S. airports have geographic, environmental, zoning, and monetary restrictions that limit or prohibit additional construction of runways and taxiways. Given these constraints, additional future capacity must be achieved by using existing airport facilities more efficiently. Automation provides one of the most promising means to achieve this goal.

The Federal Aviation Administration's (FAA) Airport Surface Traffic Automation (ASTA) program was initiated to provide air traffic controllers (ATCs), the airlines, airfield managers, and pilots with automated data to enhance surface safety and help optimize the flow of traffic on the airport surface.

The Runway Status Lights (RWSL) were developed under the FAA's ASTA program to help reduce the incidence of runway incursions and airport surface accidents. It does so by providing a preventive, back-up system of automatically controlled lights on the airport surface that inform pilots when runways are unsafe for entry or takeoff, and by providing controllers with enhanced surface radar displays.

The primary objective of the RWSL is to improve airport safety by preventing runway incursions by both aircraft and ground vehicles. Runway incursions are caused by human error usually brought about by lack of situational awareness, failure to transfer information, and navigation errors. RWSL is intended to improve human performance (tower controllers, pilots, and ground vehicle operators) by providing an automatic, advisory backup system to protect against human error. The purpose of the RWSL is to convey the status of a runway, indicating whether or not a runway is being used for a specific operation, under all weather conditions and at all times of day or night. It is not, however, intended to convey clearance to proceed onto a runway. The system comprises a set of automatically controlled runway status lights designed to inform pilots and ground vehicle operators when a runway is unsafe to enter. Lights are also used to warn pilots in position for takeoff when the runway is presently not clear or when another aircraft or ground vehicle is projected to enter the runway in front of the takeoff.

These functions are accomplished by means of a combination of runway entrance lights (RELs) and takeoff hold lights (THLs). RELs are positioned on either side of the taxiway (or runway) at the intersection of the taxiway with the runway and are visible from the taxiway hold line, whereas two sets of staggered THLs are positioned short distances ahead of the takeoff hold position and are visible from the takeoff hold position. At some acute angled intersections, more than two REL fixtures may be installed. In all situations, the final decision to proceed is made jointly by the controller and the pilot. The lights are intended as a backup and advisory to the pilot or vehicle operator and not as the sole basis for making a decision.

Initially, MIT Lincoln Laboratory (MITLL) developed a proof-of-concept demonstration of the RWSL at Boston's Logan International airport. They developed the necessary surface surveillance and safety logic to allow a computer to operate the runway status lights and associated controller displays without human assistance. The system was installed and tested off-line at Boston's Logan airport using an inexpensive commercial marine radar as a primary surveillance source. The system operated live and in real time, but the runway status lights were not physically installed. They were displayed on a scale model of Logan Airport located in a demonstration room which had a good view of the airport. This development and test environment allowed visual comparison between the actual aircraft and the resulting lights and displays. In addition to providing a convincing demonstration of the system, real-time viewing of the aircraft movement was an important aid in the development of the surveillance processing and safety logic software. Surveillance performance and runway status light operational performance were evaluated quantitatively, in this context.

1.2 RWSL ASSESSMENT PROGRAM OVERVIEW AND OBJECTIVES

The objective of the RWSL assessment program was to evaluate, in an operational environment, the performance of a RWSL installation from the users' perspective in meeting its intended purposes of (a) reducing the incidence of runway incursions, and (b) increasing pilots' situational awareness while on the airport surface. The users that are most impacted by the installation of RWSL on the airport surface are pilots, who can directly observe the operation of the system, and tower controllers, who indirectly observe its effects by the way that it affects communications with pilots, traffic flow and normal airport operations. An operational assessment of RWSL at Logan provided the first opportunity, in a fully operational environment, to evaluate the integrated system in terms of its effectiveness in improving safety and the degree to which it may cause interference with normal airport operations. It should be noted, however, that the RWSL was an assessment system, not a fully operational or production quality installation.

The specific goals for conducting an operational assessment of the RWSL were to:

1. Demonstrate that design risk is minimized.

2. Establish product utility:

    (a) Assess the performance of RWSL from users' and stakeholders' perspectives in an operational environment:

        (i) Effect on airport safety.
        (ii) Impact on normal airport operations.

    (b) Increase users' confidence in the RWSL concept.

3. Evaluate the compatibility of the RWSL concept with connecting systems. In particular, assess the suitability of RWSL for inclusion in the FAA's overarching vision of airport safety improvement systems and, more specifically, incursion prevention systems such as AMASS.

4. Identify and resolve critical operational issues.

5. Identify needed modifications and improvements.

6. Stimulate stakeholders' (and potential stakeholders') interest in the RWSL concept.

An RWSL experimental system, based on MITLL's Model Board, was designed and implemented so that a complete end-to-end evaluation could take place that involved the pilots. As part of the effort, RWSL was integrated with the Airport Surface Detection Equipment (ASDE-3), Automated Radar Terminal System (ARTS) and the Airport Movement Area Safety System (AMASS) to support ASTA's surface safety automation function. Over 180 status lights were installed at taxiway/runway intersections and take-off hold positions on two of Logan's primary runways: 4L/22R and9/27.

The assessment was conducted at Boston's Logan airport because Boston's complex layout provided a challenging environment to test the RWSL concept while it's error-free operation provided an ideal standard (truth) for assessing RWSL performance. The Logan assessment was conducted in two phases. First, system performance was verified with the status lights shielded from view during a period of "hooded assessment." This enabled us to evaluate control logic performance as well as system congestion. The second phase required uncovering the lights to expose them to pilots during a period of "unhooded assessment." This was the most critical part of the concept evaluation because it is impossible to prove how the pilots will react beforehand and consequently we cannot fully evaluate the concept without uncovering the lights. During this phase, RWSL was operated with the lights uncovered to evaluate whether light timing was acceptable and whether the light fixtures were easily discernable and effectively positioned in the airport environment.

1.3 REPORT OVERVIEW

This report is comprised of an Executive Summary, Introduction, eight chapters of technical material, and Appendices A through J.

Chapter 2 provides an overview of the RWSL assessment program. It describes the RWSL concept of operations, objectives of the Logan testing, and phases of testing. The chapter describes the system configuration and then discusses the performance requirements and our operating experience at Logan. The chapter ends with suggestions for future improvements.

Chapter 3 discusses the systems engineering approach that was followed in the design, development, installation and testing of the Logan installation. It describes the many risk reduction activities that took place that included extensive laboratory and field testing of components and integrated subsystems and systems. The chapter also summarizes efforts with the manufacturers of commercial-off-the-shelf (COTS) components to tailor their products so that they could be used in the RWSL application.

Chapter 4 contains a complete description of the light logic that was employed at Logan and how the software was integrated with AMASS. It describes the physical and functional architecture and the interfaces with AMASS, ASDE-3 and the ARTS Interface Unit (AIU). The chapter also discusses the interfaces with the Light Control Computer (LCC) and Light Computer (LC) computers. It describes the extensive laboratory testing that was conducted to test the logic, and recommendations for future improvements.

Chapter 5 provides information on the light subsystem and the warehouse and light station testing that were performed to design, develop, and implement the airfield lighting for the assessment. It describes both the hardware that is used to control the lighting, as well as the functionality and fail-safes that are built into the software. There is also a discussion on testing that was performed on the airfield to select a light fixture and warehouse testing that assessed smart transformers, lamp response, and constant current regulator (CCR) power and response characteristics. The chapter concludes with a description of our operating experience and recommendations for future improvements.

In Chapter 6, we describe the airfield installation. The chapter begins with a summary of the contracting process then discusses the equipment that was installed in the tower, power vault and out on the airfield. This is followed by a description of the system testing that occurred and an extensive discussion of our operating experience. The chapter concludes with future installation recommendations.

Chapter 7 focuses on the system testing that took place on the RWSL installation. It is broken down into descriptions of the overall test program, and then into discussions of hooded testing and our dry run of unhooded testing. It also describes reliability and human factors testing that was conducted.

Chapter 8 provides an overall evaluation of the system effectiveness and cost estimates for a production version.

Chapter 9 presents conclusions and recommendations.

The appendices contain additional information on the assessment program, its equipment, installation, hardware and software. Appendix A describes the LCC. Appendix B provides further information on the Light Manager (LM) logic. Appendix C discusses the hooded data processing, analysis, and validation procedures. In Appendix D, we describe the procedures that the Shadow ATC's followed in collecting test data. Appendix E provides additional data on the light fixture visibility testing that was collected at the airfield. Appendix F describes the LCC-LC communications protocol. Appendix G provides a detailed description of the smart transformer subsystem operation. Appendix H summarizes system variables and default settings. Appendix I lists the hooded tests analyzed. Appendix J contains a bibliography of RWSL-related reports.

2. RWSL SYSTEM OVERVIEW

2.1 INTRODUCTION

On December 3, 1990, a Northwest DC-9 Aircraft, lost in the fog at Detroit's Metropolitan Airport, entered an active runway as a departing aircraft began its takeoff roll. The oncoming aircraft struck the DC-9's fuselage, setting the plane on fire and killing eight passengers. In February 1991, a landing USAir Boeing 737 struck a commuter plane left on the runway. The toll was 34 lives. In 1994, two people died when a TWA MD-80 on takeoff struck a commuter plane, which had mistakenly entered the active runway. During the past 20 years in the United States, at least seven fatal and two major non-fatal aircraft accidents were caused by runway incursions[1]. With air traffic expected to increase at least 3% annually into the millennium, prevention of runway incursions has become a major priority for the Federal Aviation Administration (FAA).

In a sweeping mandate to improve airport surface safety, the FAA sponsored the Runway Status Lights program, as part of the Airport Safety Traffic Automation program. ASTA's goals were to provide air traffic controllers, airlines, air field managers, pilots, and airport ground vehicle operators with automated data to enhance surface safety and to optimize traffic flow without impacting airport capacity. RWSL is an advisory system used by pilots, ground vehicle operators and air traffic controllers to reduce runway incursions. The RWSL system is integrated with the Airport Surface Detection Equipment, Automated Terminal System, and the Airport Movement Area Safety System to support ASTA's Surface Safety Automation function.

RWSL comprises sets of lights that are automatically controlled and designed to improve the situational awareness by presenting runway status information to the aircraft pilot and ground vehicle operator. Information is conveyed to the pilots and ground vehicle operators by two types of light: the runway entrance light and the takeoff hold light. RELs, located on both sides of rwy/twy and rwy/rwy intersections, are visible from taxiway hold lines. An extra set of RELs, placed at certain acute rwy/twy intersections, improve pilots' viewing them in adverse weather

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[1] Runway incursion is the term used by the FAA to define an aircraft, ground vehicle, person, or object that creates a collision hazard or results in loss of separation with an aircraft taking off, landing, or intending to land without the local ATC's knowledge or permission.

conditions. Two pairs of THLs are located and visible beyond the takeoff hold lines. The lighting fixtures used to convey the runway status information are the elevated modified Wig-Wag lights and, in some locations, semi-flush in-pavement lights.[2]

The runway status lights operate automatically in response to data received by the AMASS system's Light Manager, the light control and monitoring system and the light control computer. RELs are illuminated when the surveillance data from ground and terminal radars indicate the trajectory of an object aligned with a runway is landing, departing or approaching an intersection with a taxiway. THLs are illuminated when the surveillance data indicates the runway ahead of an aircraft in the takeoff position is occupied.

Originally known as ASTA-1, the Runway Status Light System (RSLS, later RWSL) was developed, under an interagency agreement between the FAA, the United States Air Force (USAF) and MIT Lincoln Laboratory. MITLL conducted a proof-of-concept evaluation at Boston's Logan Airport which used a commercial off-the-shelf radar and customized portable software. MITLL's ground surveillance—with a modified Raytheon Pathfinder marine X-band radar and sensor-fusion of those radar tracks with approach radar tracks— provided a picture of the airport surface and approach space. Software safety algorithms identified the operational state of the aircraft, projected possible future trajectories and conflicts, and generated runway status light commands. MITLL developed a model board which visually orchestrated Logan Airport's runways and taxiways with the RWSL's; they used the board to demonstrate the RWSL to the FAA, government agencies, and industry in the fall of 1992.

After MITLL's proof-of-concept evaluation, the FAA conducted a real time field demonstration at Logan Airport in May 1997. The RWSL test program included the installation of lights, constant current regulators, a light control and monitoring system, improving the RWSL safety logic software to ensure system safety and airport capacity and validating the following RWSL system concept. These activities were completed in May 1997.

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[2] Brightness in five settings was adjustable from the tower during testing to suit ambient natural lighting conditions.

2.2 SYSTEM CONCEPT OF OPERATIONS

RWSL is a system of automatically controlled runway status lights designed to inform pilots and ground vehicle operators when it is unsafe to enter or depart active runways. RWSL conveys runway status information to the pilots and ground vehicle operators by two types of lights: RELs and THLs. REL operation (see Figure 2-1) is based on the concept of a "hot zone," a projected area ahead a high-speed target to be left free of other targets. The length of the hot zone is determined by the target's speed and a time interval dependent on the target's state, i.e., landing approach, takeoff, taxiing, etc.

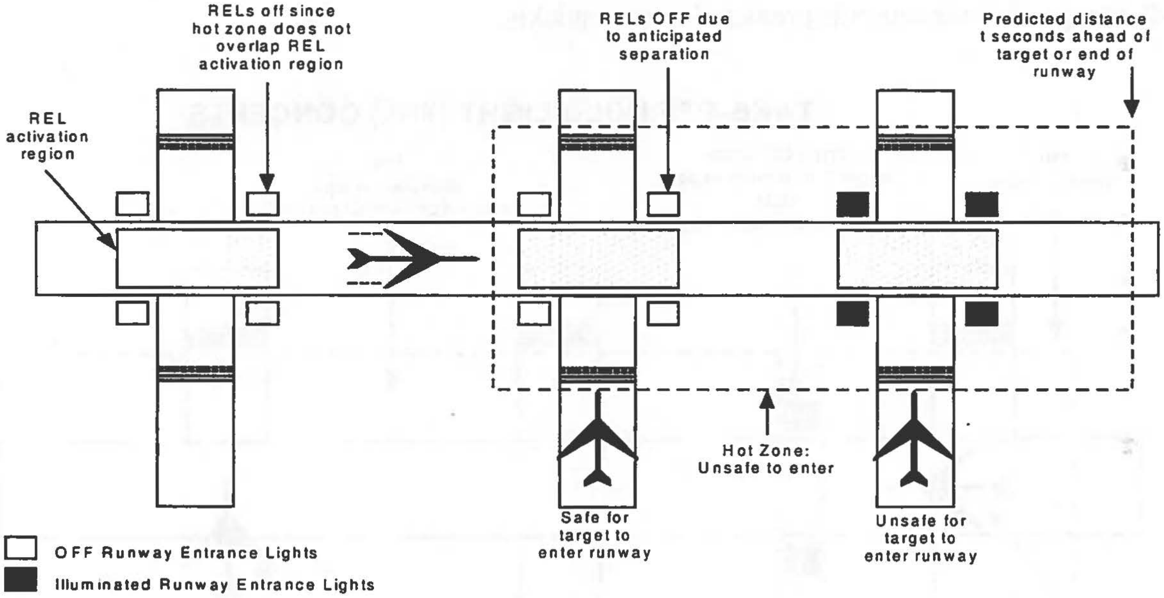

FIGURE 2-1 RUNWAY ENTRANCE LIGHT (REL) CONCEPTS

RELs are illuminated *only* if a moving target's hot zone intersects the REL activation region. RELs are illuminated as the leading edge of the hot zone intersects the REL activation region, and extinguished as the trailing edge (of departing aircraft) leaves the region. RELs behind a moving target are off unless a second moving target triggers their activation. For specific states of a moving target, i.e., a departing or arriving aircraft, the lights at *all* intersections are illuminated to provide maximum safety[3]. The REL illumination logic includes the procedure known as "anticipated separation." ATCs use anticipated separation to issue clearances and instructions to aircraft prior to a legal separation, expecting that separation will follow once the clearance or instruction is executed. RWSL logic mimics ATCs' actions in these situations.

A runway is determined unsafe for departing aircraft if another target is on the same or an intersecting runway. THLs (Figure 2-2) are activated if a target is in position for takeoff and the departure runway ahead is not clear of a stationary or moving target. Unlike the RELs, a target must be in position for the THLs to operate and illuminate. The THL activation region is the entire runway ahead of a departing aircraft as well as the small area extending on both sides of the runway. THLs extinguish when the stationary or moving target exits the departing runway. The anticipated separation concept also exists for THLs. THLs ahead of a departing aircraft (target) will extinguish if the target is predicted to exit quickly.

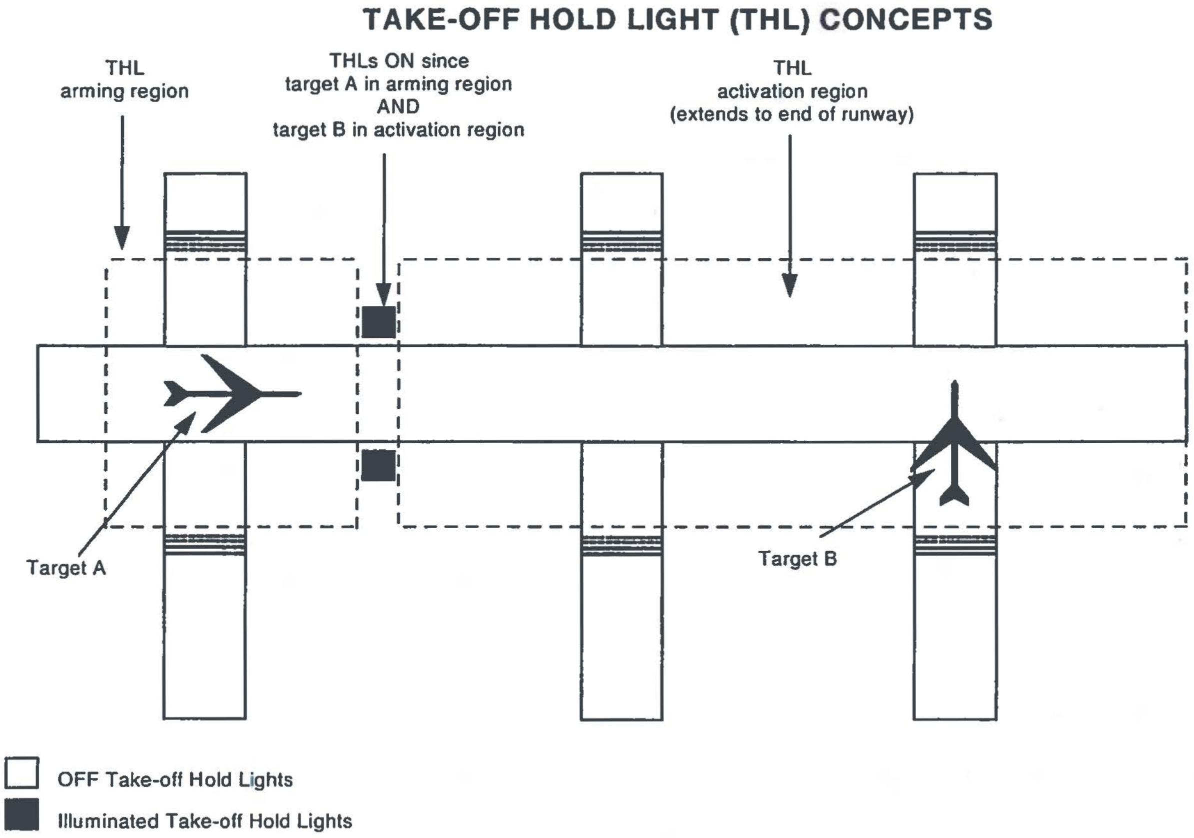

FIGURE 2-2. TAKE-OFF HOLD LIGHT (THL) CONCEPTS

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[3] They also thus comply with FAA standards and procedures that their presence and testing does not interrupt normal traffic flow or AT operations.

2.3 OBJECTIVES OF LOGAN ASSESSMENT

The operational assessment of the RWSL at Logan Airport provided the FAA its first opportunity to evaluate the concept in an integrated system and operational environment and to determine its effectiveness in attaining program objectives. The primary objective of the RWSL system was to assess the system in an operational environment from the users' perspective in attaining its goal of improving the situational awareness of pilots and ground vehicle operators on the airport surface and reducing the chance of runway incursions. Airplane pilots, ground vehicle operators and ATCs are directly impacted by the operation of the RWSL system in the operational environment. The airline pilots and ground vehicle operators directly observe runway status and the ATCs indirectly receive the impact of the runway status lights via their communications with pilots and operators and the lights' effect on traffic flow.

The objectives of the assessment can be defined into the categories of hooded and unhooded testing. The objectives of the hooded testing were:

- Establish RWSL utility from the user's perspective.
- Evaluate RWSL concept and compatibility with existing systems.
- Evaluate RWSL system for inclusion in FAA runway incursion program with prevention systems like AMASS.
- Identify and resolve critical operational issues, modifications and improvements.
- Raise awareness and interest from users and stakeholders in the RWSL concept.
- Ensure safe RWSL operation in Logan environment.
- Ensure no impact on normal airport operations.
- Minimize design risk.

After the hooded testing and data analysis, the original scope of unhooded testing was scaled back at the request of the FAA's New England Regional Office. The FAA's New England Regional Office determined that the human factor response was still unknown in the operational environment to evaluate the impact of the RWSL system on users. A critical factor in assessing the human response to the RWSL was the interpretation by the user of the runway status lights. Misinterpretation of the runway status lights or confusion about the status of the lights has a direct impact on airport safety and traffic flow. Key engineering assumptions made during system implementation—e.g., three-second tolerance between light transition and the ATC's directive, and length of hot zone and state transition points—required validation in an operational environment.

Scheduled to be run during night time operations at Logan, unhooded testing had as its objectives to:

- Determine whether "implied" clearance associated with the light transition state existed with airport users.
- Validate lamp response time, illumination levels, and visibility to both pilot and ground vehicle operator.
- Determine whether the lamps caused confusion with existing runway lighting systems.

The information obtained during the unhooded testing will be valuable in future deployments and modifications to the RWSL installations.

2.4 PHASES OF R&D TESTING

During 1994, the FAA and NASA Langley embarked on a program to integrate the RWSL light logic into NASA's Boeing 737 flight simulator using a three-dimensional visual scene of the Denver, Colorado airport. A simulation of Logan Airport was later added. Pilots were invited to "taxi" around the simulated airport as they were presented with a number of scenarios which exercised the RWSL. Respondents included 21 pilots, airlines representatives, the General Aviation (GA) community, and the Airline Pilots Association (ALPA). Test results were used as design drivers for both the LM logic and the physical placement of the lights relative to runway and taxiway edges.

The FAA conducted visibility tests to determine the type of light fixture to be used during the unhooded testing, the light locations, and the characteristics (e.g., beamwidth, intensity) of the lamps. FAA tests intended to maximize the lamps' viewing potential for airport operators, but to minimize their effect on other airport lighting systems and personnel, especially on pilots preparing for takeoff.

A light test station was set up at Logan Airport to determine the optimum light fixture to be used during the unhooded testing. Three light fixtures were selected: the PAR-56, a Precision Approach Path Indicator (PAPI), and an elevated modified Wig-Wag light (ELWW). The tests used a light meter and a bucket truck to measure the luminance and beamwidth of the lamps. A major finding was the need to implement shields on certain fixtures to prevent light from "spilling" onto areas best left dark.

A light visibility test was run to gain knowledge on light intensity and beam characteristics. An experienced pilot observed THLs at the takeoff hold point at the approach end of Rwy 27 (and other critical rwy/twy intersections) while seated in the bucket truck, its height adjusted to simulate that of a cockpit.

In July 1996, further light tests were conducted using an aircraft. The aircraft flew into and around Logan Airport to determine light visibility, light characteristics, and users' ability to distinguish the runway status lights from other airport lighting systems.

A simulated RWSL installation was built in a warehouse at the Volpe Center before the system was installed at Logan Airport. The simulated RWSL installation was comprised of the Light Control Computer, the Light Computer, and a set of fifty smart transformers (SXs), isolation transformers and light fixtures. The simulated installation replicated the runway status light operations on Rwy 9/27. The performance characteristics and the response of the Light Subsystem were measured at all CCR levels. The warehouse test also provided the opportunity for integration testing by integrating the AMASS and the LM logic with the LCC using pre-recorded target track files.

The RWSL LM logic, originally tested by MITLL in 1993, used a demonstration model board located on the 16th floor of Logan's ATCT. The model board demonstrated the major features of the airport as well as the runway status lights. Data was collected and the LM logic was further tested in 1994 and 1995 at Logan during testing of an AMASS system. Target tracks derived from the ASDE-3 radar data and the ARTS tracks were used to debug the LM logic and determine the main deficiencies of the system. A set of operational scenarios were developed to identify all possible runway incursions against which the RWSL was intended to provide protection. Artificial target tracks were created to mimic these scenarios and the operation of the LM logic was verified in each scenario.

During hooded testing at Logan Airport in 1996 and 1997, the lights were shielded from the airport user. Ten thousand operations were collected and analyzed to verify LM logic performance, system integrity, and system reliability, and to determine whether the RWSL might safely be tested during normal airport operations. In May 1997, limited unhooded testing was conducted to assess the system from the perspective of the airport user, to assess the LM logic, and to verify system operation within Logan's normal airport environment.

2.5 SYSTEM CONFIGURATION

The system tested at Logan Airport (see configuration in Figure 2-3) used modified AMASS equipment to process surveillance data from an ASDE-3 radar and an ARTS interface. Raw radar returns generated by ASDE-3 and ARTS were received by the modified[4] AMASS, which used this data to reject clutter, detect multipath, and form target tracks. AMASS target symbols and flight information were generated and displayed on the AMASS display.

Target tracks (including tracks labeled as multipath) were passed on to the Light Manager, which determined which lights were required to be switched on and off. Commands to switch lights were sent to the Light Control Computer, which formatted them, packed them into groups, and transmitted corresponding light control information via fiber optic cable, to the Light Computer located in the field lighting vault. The LC superimposed light control signals and light address information onto the primary power signals, and fed them, via underground cables, to a set of Smart Transformers, located on five distinct circuits on Rwys 4L/22R and 9/27, and powered by a

CCR located in the Logan Airport lighting vault. Each SX controlled a light fixture containing two 120-Watt lamps in series and switched its corresponding light fixture according to the command. At either the runway entrance hold line or the takeoff hold position, at least four lamps were visible, two in each fixture on each side of the taxiway or runway.

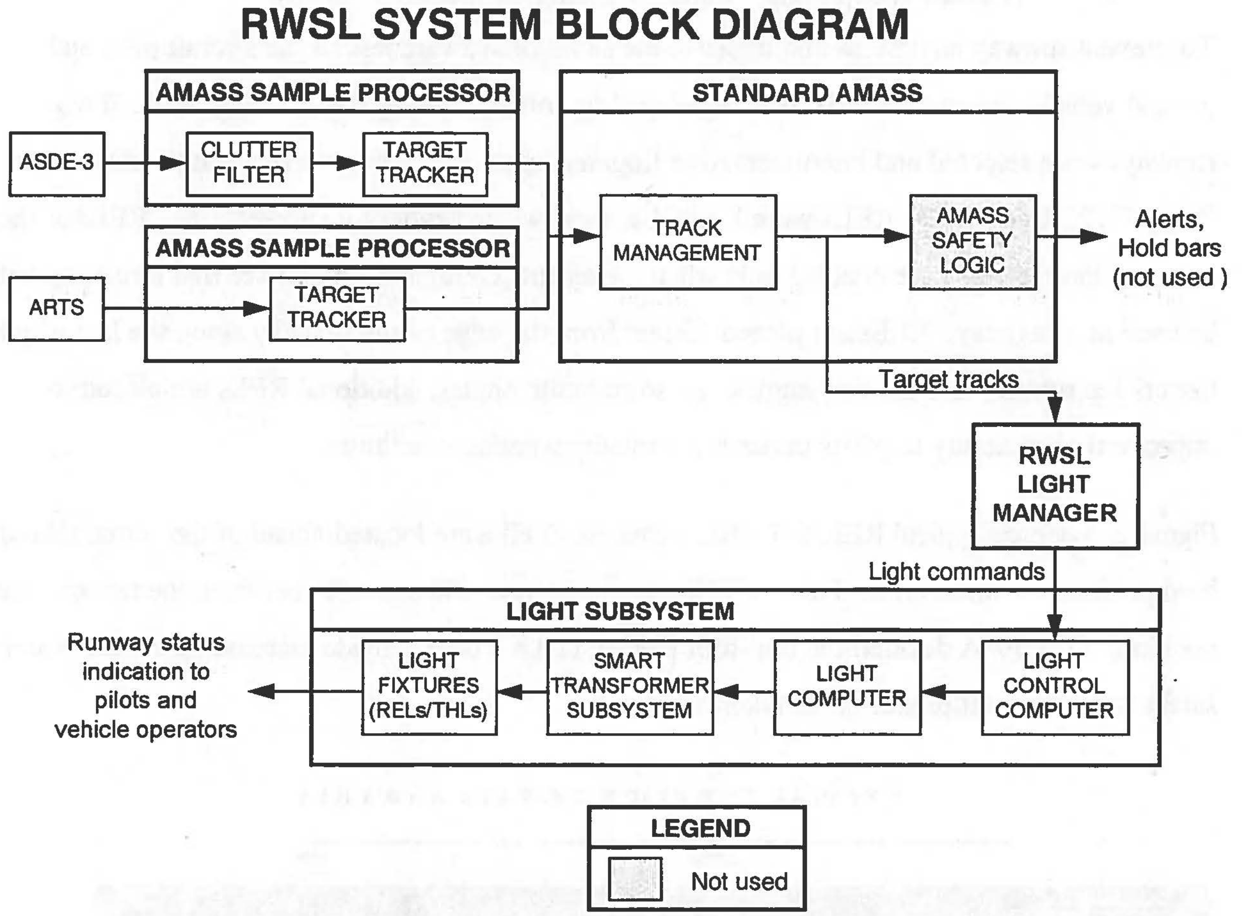

FIGURE 2-3. RWSL SYSTEM BLOCK DIAGRAM

In attempting to improve runway safety, six incident geometry scenarios were identified in which the RWSL would provide a visual alert to the aircraft pilot and ground vehicle operator. They are:

1. Aircraft A departing, aircraft/vehicle B taxiing across runway.
2. Aircraft A arriving, aircraft/vehicle B taxiing across runway.

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[4] The AMASS alert function and hold bar logic were disabled for the RWSL assessment.

3. Aircraft A departing, aircraft B departing on crossing runway.
4. Aircraft A departing, aircraft B arriving on crossing runway.
5. Aircraft A departing, aircraft B departing on the same runway, except when required departure separations of 3000 feet apply.
6. Aircraft A departing, aircraft B taxiing on the same runway.

To prevent runway incursions and improve the situational awareness of the aircraft pilot and ground vehicle operator, RWSL was developed to convey runway status information. Two runways were selected and instrumented at Logan Airport to convey runway status information: Rwys 4L/22R and 9/27. RELs were located at rwy/twy and rwy/rwy intersections. RELs at the rwy/rwy intersections are enabled only when the airport configuration dictates that a runway will be used as a taxiway. RELs are placed 13 feet from the edge of the taxiway along the line which bisects the runway and taxiway angles. At some acute angles, additional RELs are placed to improve their visibility to pilots under low visibility weather conditions.

Figure 2-4 depicts typical REL and THL locations. THLs are located ahead of the actual takeoff hold position for an aircraft. Pairs of THLs are located at 200 and 600 feet from the takeoff hold position. (The FAA decided the 600-foot pair of THLs would provide increased awareness and safety for an aircraft preparing its takeoff roll.)

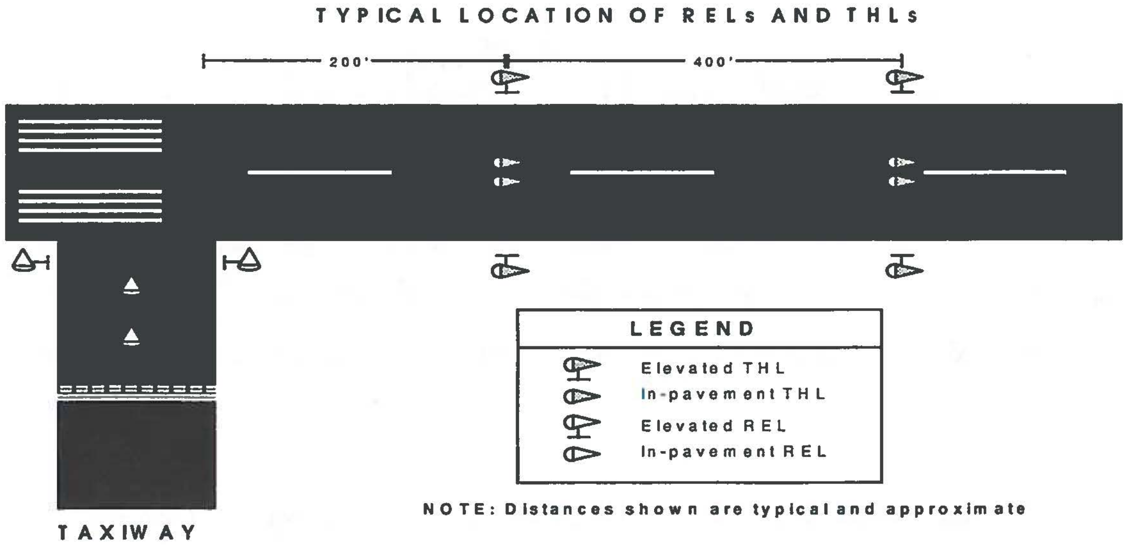


FIGURE 2-4. TYPICAL LOCATION OF RELS AND THLS

The light fixtures used to convey runway status information are the elevated modified wigwag light and the semi-flush in-pavement light. At most rwy/twy and rwy/rwy intersections, the elevated modified Wig-Wag lights are used. At the intersections of Rwy 4L and Twys Sierra, Echo and Whiskey, the semi-flush in-pavement lights are used to improve the visibility of the RELs. Similarly, the elevated modified Wig-Wag lights were used at the various takeoff hold points along Rwys 4L/22R and 9/27. Only at the takeoff hold point located at the approach end of Rwy 22R were semi-flush in-pavement lights were installed to make the lights more noticeable to pilots, whose attention is focused on the runway centerline prior to takeoff.

RELs and THLs are driven automatically by the computer processing of surface and approach radar information. The RWSL system detects the presence of an object on or near the runways, predicts their projected path, assesses potential conflicts on the airport surface, and determines the state of the RELs and THLs. If the RWSL system determines that a conflict may exist at a rwy/twy or rwy/rwy intersection, the RELs are illuminated red; if a conflict exists ahead of an aircraft preparing for departure, the THLs are illuminated red.

2.6 PERFORMANCE REQUIREMENTS

The performance requirements measured RWSL ability to expose the runway status lights to the airport user. During the hooded testing, it was imperative to demonstrate and quantify a level of performance that would be acceptable to pilots, ground vehicle operators, and ATCs. To ensure safety and traffic flow, it was also important to consider the infinite amount of operating conditions under which the system would operate. Conversely, it was also important to identify those conditions, if any, in which the system might adversely impact airport safety, operations, and traffic flow.

Two levels of performance measurements were defined to describe the level of utility the system must achieve prior to and after exposing the runway status lights to the users. The first set of measurements relate to the system's potential adverse impact on airport safety and traffic flow. The second set of desirable performance measurements were described to provide a basis to gauge system acceptance by the user during unhooded testing.

The terms that quantify the performance measures needed to achieve its goals and objectives are:

Missed Detection: failure of a runway status light to illuminate as it should, as judged from the intent of the system and the state of the traffic on the airport and in the immediate airspace.

False Alarm: status light illumination that should not have occurred, as judged from the intent of the system and the state of traffic on the airport and in the immediate airspace.

Discrepancy: occurs when a status light is on, in accordance with the design of the system, while an apparently safe operation is under way that contradicts an instruction issued by the tower ATC and lasts for more than three seconds after the completion of the tower ATC's instruction.

Data analysis performed after the hooded testing concentrated specifically on the number of discrepancies the user could potentially be exposed to during an airport operation since a discrepancy may directly and adversely impact airport safety and traffic flow. Discussions with pilots, ATCs, and FAA officials determined the following essential system performance measurements needed to be established prior to exposing the runway status lights to users:

1. Zero discrepancies resulting in an adverse effect on airport safety.
2. In any four-hour period, no more than one discrepancy.

2.7 OPERATING EXPERIENCE

RWSL is an assessment system that automates airport surface traffic in a dynamic environment using runway status lights and surveillance radar. The operating experience was used to determine the specific requirements needed of the individual system components if the RWSL is to be deployed as an operating system within the FAA's Runway Incursion Reduction Program (RIRP).

Performance goals were set and tests conducted to identify the technical and software problems, which were then corrected. During system integration and hooded testing, performance was expected to achieve the best performance possible within the constraints of the commercial-off-the-shelf equipment available.

The RWSL is comprised of several subsystems that operate as an integrated system. Traffic surveillance data from the ASDE-3 and ARTS radar is processed by the RWSL to determine the appropriate state of the runway status lights. The major components of the RWSL are:

- Radar processing
- Light Manager (light logic)
- Light Control Computer
- Communications (Light Computer)
- Smart Transformer Subsystem (SXS)
- RELs and THLs

RWSL system performance and availability are dependent on receiving valid inputs from the ASDE-3 and ARTS radar systems. Both hooded and unhooded testing were conducted when both the ASDE-3 and ARTS radar were available. The ASDE-3 radar was subject to various maintenance shutdown periods throughout testing. During these expected outrages, efforts were coordinated between the RWSL test director and the FAA's maintenance personnel. Unexpected maintenance delays occurred infrequently and were quickly resolved thus allowing testing to occur.

The ARTS radar underwent similar maintenance shutdowns. An unexpected prolonged delay occurred prior to the continuance of a phase of the hooded test program when a software patch was added to the ARTS program. The software patch caused the ARTS Interface Unit on receiving an unknown data message from the ARTS computer to fail and terminate the program. The problem was rectified by modifying the AIU software to accept the additional data message received by the ARTS computer.

The LM light logic residing in the AMASS computer functions as the "brains" of the RWSL system. Extensive verification testing of the light logic and the associated computer software was performed in the laboratory environment using both operational and simulated data at Logan Airport. All runway configurations and potential airport situations were evaluated and performance deficiencies were identified and corrected within AMASS constraints. Changes made to the LM code during the operational assessment phase accommodated specific operational situations and eliminated performance deficiencies. Modifications to the human interface of the AMASS system keyboard boards were performed to reduce the probability of a system crash during the hooded or unhooded test programs.

Tests were conducted to verify the accuracy of the ASDE-3 light logic map registration and response relative to the radar and the critical locations of lights on the airport pavement.

The LCC is the maintenance and control console. Light commands from the LM in the AMASS computer are sent to the Light Subsystem where they are converted to light groups, displayed, recorded, and sent to the lighting vault on the field. Lights are commanded in groups, both manually and from the LM, to reduce the required communications bandwidth.

As part of the system requirements, status from the SX subsystem on the airfield is required to report status within 10 seconds to enable detection of a failed lamp or failures within the SXS. The initial system design intention to poll SX data within two seconds of a light command issuance was reduced to one second during system integration testing. The one-second poll rate, done by broadcast mode, ensured the command response reliability and system integrity.

The LCC light groups were designed with the goal of four or less group commands per second per circuit. These group command rates ensured the ability to issue light commands and allowed time for polling prior to the issuance of the next light commands. Laboratory tests using log files recorded at Logan Airport indicated that the per-circuit command rate may exceed the goal by 50% twice an hour. Stress tests indicated that a command rate of 100% over the goal causes no problems in system operation and has a negligible impact on performance. The LCC operated throughout the hooded and unhooded test programs with no hardware failures.

Communications between the test station, located on the 16th floor of the Mass Port tower, and the airfield lighting vault was accomplished via fiber optic [cable] from the LCC to the LC. A data rate of 19.2 kbps provided high reliability. LCC transmitted commands once per second and the LC immediately returned a status table.

Errors detected during integration testing were traced to timing problems in the software and were corrected. During the hooded and unhooded testing, no occurrence of any undetected communication was detected. If an undetected error had occurred, it was likely to have self-corrected within one second via broadcast mode.

The SX is an electronic module installed in the light fixture base can on the field and is electrically connected between the light and the isolation transformer that allows for individual control of the airfield lights as well as constant monitoring of the status of the light. Five separate circuits were used to implement the RWSL system, each powered by a CCR. The LC in the power vault interfaced with the fiber optic link from the tower and the series circuit communications modems connected to each power circuit near the CCR. The series circuit modem superimposes a control signal on the power cable that contains the unique SX addresses and state of the selected SX.

The control and monitoring of the airfield SX were accomplished using communications over the power cable; the SXS was susceptible to errors due to noise and interference from the airport environment. Extensive SXS testing took place at the warehouse, the manufacturer's laboratory, and at Logan Airport. The Logan environment caused various failures of the individual SX and reduced their electrical and hardware reliability. Problems identified included with water leakage, electronic component failure (five units contained an outdated diode specification) and mechanical failure due to rough handling and assembly problems. Additional control problems encountered with the CCRs were corrected. There were no failures with the LC.

The light fixtures used to convey the runway status information during the operational assessment of RWSL were the elevated modified Wig-Wag light and the semi-flush in-pavement light. During warehouse integration testing, the illumination time for the elevated modified Wig-Wag light to reach 50% was measured at all five steps of a 6.6 Amp CCR. The warehouse tests concluded that the mean response times of the lamps to illuminate would not allow the RWSL system to become exposed to the airport user in an normal operational environment. Discussions with the SX manufacturer allowed a modification known as "trickle current," the lamp is heated with 1.5 amps, which allows the lamp to attain a 50% duty cycle more efficiently. Tests conducted with the trickle current implemented indicated a mean illuminated response time of 1.5 seconds and a light extinguish mean response time of 0.5 seconds.

The elevated modified Wig-Wag lights were installed at Logan at locations beyond the intended hold-line positions, and closer to the actual runways. Upon initial installation, the lamp's frangible couplings did not withstand the jet blasts and vortices. The light fixtures were fortified with strengthening kits steel tethers. Additionally, light fixtures were equipped with anti-rotation plates and at certain location, baffles, to prevent light spilling into other areas of the airport.

2.8 FUTURE IMPROVEMENTS

The successful implementation of the RWSL system from the MITLL concept/model board to an operational implementation in a complex operational environment, Logan Airport, enabled an understanding of the operational requirements and impacts in an airport environment. The ASDE-3 and the ARTS radar as primary surveillance sensors were incorporated with the MITLL light control safety logic to sufficiently control the real time traffic at Logan Airport. The RWSL incorporated and evaluated new technologies for implementation at Logan Airport, including SX technology, the elevated modified Wig-Wag light and the semi-flush in-pavement light. The experience with these airfield lighting systems was shared with the lighting manufacturers who then incorporated the recommended changes to their product.

The many aspects of RWSL testing proved the system and the concept are viable and warrant future testing and evaluation. Prior to the RWSL system being ready for production, future improvements and testing are needed to correct the deficiencies, collect significantly statistical data and further expose RWSL to the users. RWSL needs to be exposed in an operational environment for an extended period of time under normal operating conditions to receive the observations from the airline pilots, ground vehicle operators, and ATCs.

Unhooded testing at Logan Airport provided neither sufficient nor statistically significant data. Further testing of the RWSL system at an operational airport would allow essential unhooded testing to be conducted in an operational environment that would have fewer operational and physical constraints. RWSL testing should allow the inclusion of a less expensive sensor and a smaller, more affordable lighting system. Such testing would enable the system to evaluate the operation within an existing electrical environment and compare the SXS with other airfield lighting systems. Tests conducted on a smaller airfield would also allow a set of minimum semi-flush in-pavement lights to be installed and defined. Different elevated lighting fixtures would be examined that are more wind resistant and less expensive and differentiate themselves from existing airfield lighting systems. An evaluation using an ASDE-X or ATIDS system for a primary surveillance source could be evaluated. Additional system engineering would ensure all electrical components have the functionality, reliability, integrity and availability that would be required for a RWSL production system.

To enhance aviation community awareness prior to any testing, a joint airline, airport and FAA working group should be formed. This working group would develop acceptable performance measures and exit criteria for conducting uncovered RWSL testing, stimulate interest among the airport users and distribute educational material, videotapes, brochures etc., to the aviation community.

The hooded and unhooded testing exposed deficiencies in the overall system capabilities related to the ASDE-3 and ARTS radar, the AIU and AMASS systems. The AMASS system at Logan Airport on certain runway configurations would inaccurately predict runway arrival for slow moving aircraft. The inaccurate predicted runway arrival would cause REL lights to be illuminated on the wrong runway. Modifying the AMASS processing for heading accuracy would greatly improve the RWSL runway predictions. Better use of ARTS data—by incorporating the ASR-9 data directly to predict runway arrivals—would allow a more accurate transition from the terminal-to-ground surveillance radar. Further improvements for the terminal radar for the RWSL system include the circumventing of range and elevation masks, use of the ARTS sensor fusion and ARTS data for determining approach runway.

Further improvements to the RWSL system would be obtained by creating a database of characteristics for aircraft to predict their performance in an operational environment. The limitations of the ground surveillance radar limited performance for determining the departure characteristics for aircraft. Enhanced data would enable a more departure algorithm within the RWSL control logic. Further enhancements to the RWSL logic would include the development of logic for crossing runways, automating the RWSL runway configuration, incorporating braking and wind conditions to calculate the hot zone lengths and early departure algorithms.

Pilot evaluation of the RWSL system should continue at the NASA Langley simulator to evaluate the pilot responses to the lights under various operational conditions to ensure the lights will not cause safety problems. The lessons learned from the additional analysis and human factors would be included in the RWSL system design.

Future improvements within the hardware of the RWSL system include improvements to the smart transformer subsystem. Many lessons were gleaned from both the warehouse and the system integration tests. Improvements to the smart transformer subsystem would include the development of a reliable command retry scheme for the Light Computer; incorporate the functionality of the LCC into the LC; develop a means to automatically control the light illumination level; investigate frequency multiplexing to eliminate crosstalk; and investigate using a power cable embedded with a fiber optic cable to improve communications.

3. SYSTEM ENGINEERING APPROACH

3.1 INTRODUCTION

The RWSL System deployed at Logan is best characterized as a proof-of-concept assessment system. To put the documented results into the appropriate context, it is necessary to view the effort reported herein relative to the overall system engineering process. Prior breadboard/brassboard work by MIT Lincoln Labs demonstrated significant promise for the RWSL concept by processing target (aircraft) observations derived from surveillance radar with computer software which emulates air traffic controller actions. The next step in the system development process, following the breadboard/brassboard phase, is to prototype the end-to-end RWSL System for testing in the operational environment. This means exposing the system to pilots to assess their reaction to the lights and the resulting impact of pilot action on airport operations.

A prototype system does not necessarily embody all of the automation details and features of an operational system but, like an operational system, the prototype must not compromise safety and its impact on airport operations must be carefully controlled.

Prototype system assessment is a critical step in the overall system development process and is directed at learning the "real" system requirements before operational deployment. In addition to verifying the mechanical and electrical parameters of the system, the complexities of human reaction and action can only be fully evaluated in the actual operating environment. System simulation and special tests provide important insights but system validation can only be accomplished by actively involving the end user in the actual operating environment.

By virtue of the schedule and available program resources, development of the assessment system for Logan is best characterized as a rapid prototyping approach. Key elements of the development process employed for RWSL are:

- Establish requirements and goals
- Build upon previous development efforts and employ commercial-off-the-shelf equipment
- Ensure operational integrity with no compromise of safety

- Focus on quantifying pilot response to system in operational environment
- Document all development and testing

The overall realization of the RWSL rapid prototyping process is best characterized as evolutionary: build a little, test a little and repeat the cycle by incorporating identified improvements. The classic waterfall-approach to system development, which proceeds unidirectional from requirements to a deployed system, was not workable. Primarily, detailed system requirements were not available for RWSL at the onset of the RWSL Program; RWSL was more "concept" than "system" and the FAA does not have specific operational requirements for the RWSL concept. One of the goals of the effort is to exploit the assessment system development effort and testing experience to enable the subsequent development of specific requirements for an operational RWSL system. Detailed documentation (including this report) of the prototyping effort and assessment system test results is an important program output in support of this goal.

This chapter summarizes the overall process used to develop RWSL and prepare the system for unhooded testing. Important requirements and steps in the process are presented along with supporting references.

3.2 SYSTEM DEVELOPMENT PROCESS

Key ground rules established in support of the rapid prototyping development process were to exploit the results of previous work and to employ commercial-off-the-shelf equipment. This is consistent with overall program objectives: minimize risk, cost and development time. Specifically, previous work on the RWSL concept by MIT Lincoln Labs provided a valuable launch point for evolving the Light Logic used in the assessment system at Logan. In essence, the previous formulation of aircraft detection scenarios and corresponding resulting light states provided the initial requirements for the Light Logic. Based on a series of in-depth design reviews of all operational scenarios (and the required light states) by operations experts (Logan tower controllers, pilots, human factors experts, system engineers) and simulation-based evaluation of these initial scenarios, the Light Logic for Logan was evolved to encompass the full range of operational conditions and situations which may be encountered at Logan. Appendix B documents the final Light Logic and provides the basis for future formal requirements. The concurrent evolution of the requirements and the operational logic proved to be highly efficient and effective, consistent with the rapid prototyping methodology.

The MIT Model Board is a working scale model of the originally envisioned RWSL installation at Logan. Driven by computer-based light logic, the Model Board is a valuable tool for medium-scale viewing of the lights within the geometric context of the Logan runways and taxiways. This provided an effective means for observing and refining the light location requirements at Logan prior to the rather expensive and time-consuming installation of the fixtures. This requirements/design process was also supported by human factors testing with the NASA Simulator where initial feedback on RWSL effectiveness was obtained from pilots in a simulated operational environment.

AMASS is designed and installed at Logan for use by tower controllers. Surveillance data from the ASDE-3 and ARTS radars is processed by the AMASS software and targets are displayed on a graphical view of the airport. An early decision in the RWSL engineering process was made to use the existing front-end processing in AMASS, and its associated interfaces with the surveillance sensors, to drive the RWSL Light Logic. This approach reduced the development risk associated with the real-time data interfaces and software processing algorithms required for RWSL. In retrospect, however, although AMASS embodies the desired functionality, performance limitations associated with the AMASS front-end processing have a significant negative impact on RWSL performance. This is a potential pitfall of using existing equipment for an extended application when the as-built performance with the extended application is unknown and not under the direct control of the development team.

The SX Subsystem development and deployment represents the highest risk in the system engineering process. The SX technology is relatively new and had been previously deployed at a number of airports, but not in highly dynamic applications such as RWSL. However, the RWSL development team felt that the technology offered sufficient capability to outweigh the associated risk. A detailed specification for competitive procurement of the SX Subsystem was developed which spells out the system-level requirements. Again, because of the short procurement cycle of only a few months, the basic equipment had to be available off the shelf. There was a rather severe learning curve to be overcome by both the vendors and the development team: the team did not know the proprietary design and performance details of the available equipment and the vendors did not know how their equipment would work in the RWSL application.

Key to reducing the technical and programmatic risk associated with the SX Subsystem prior to deployment at Logan was the extensive experimental testing in the Volpe Warehouse facility. This facility permitted the development team to learn the SX technology and the vendors participated in the testing to acquire a detailed understanding of the RWSL application. This understanding was necessary since the vendor was required to customize their software used in the Light Computer to meet specific requirements. The warehouse provided an ideal environment for end-to-end testing of the overall system operation prior to full deployment at Logan 2E. Again, this is an important element of the rapid prototyping process when it is often necessary to accommodate specific as-built limitations or restrictions of COTS equipment. For example, available Constant Current Regulators are not specified nor specifically designed to operate with the highly dynamic load presented by the SXs. Warehouse testing of three different CCR designs showed unacceptable performance with the Westinghouse LC design and the best performance with the ADB ferro-resonant unit. Crouse-Hinds CCRs were acquired for Logan through the competitive procurement process and demonstrated to be acceptable in the warehouse. Important improvements in the specific equipment procured for Logan were also made by the vendors based on the warehouse testing: the addition of trickle current to reduce the excessively long illumination time of the lamp and the added capability to accommodate up to 20 light groups in each SX. The SX Subsystem specification was updated as required to reflect lessons learned in the warehouse.

Light Logic implementation on the AMASS platform and development of the Light Control Computer were achieved in parallel with the SX Subsystem testing in the warehouse, thereby enabling significant schedule compression. Operations data recorded by the AMASS installed at Logan enabled realistic testing of the Light Logic in the laboratory and warehouse environments. Simulated targets (sprites) are used to test unsafe and unlikely, but potentially disastrous, operational situations. The LCC interfaces with the AMASS and the LC and was developed by members of the development team not directly involved in the SX Subsystem development in response to the LCC Specification. Initial testing and verification of the LCC utilized the warehouse test facility. This process provided important cross-checks on the system development.

Light fixtures must provide the desired illumination characteristics and must conform to FAA requirements for airport safety. In the event that the fixture on the airfield is struck by an aircraft or vehicle, all elevated fixtures must employ frangible couplings and tethers for safety. Testing of standard fixtures in the Light Test Station led to the conclusion that the standard Wig-Wag elevated fixture exhibits the most desirable illumination and physical characteristics for RWSL, and was selected for warehouse testing and eventual installation at Logan. Subsequent to initial installation at Logan, it was quickly learned that the mechanical strength of standard Wig-Wag fixtures is inadequate to withstand the jet blast encountered at the installed runway locations of RWSL. Working closely with the fixture manufacturer, strengthening kits were designed and installed on the existing fixtures at Logan. Here is a case where existing requirements for standard equipment proved inadequate for the RWSL application and need to be refined for future RWSL installations.

Installation of the cables and light fixtures at Logan on runways 9/27 and 22L/4R represents the major construction associated with RWSL. This work was performed under a Massport contract and was coordinated with other light system installation work at Logan during the summer of 1996. New cables were installed in existing and raceways and new conduit. The raceways are shared with the cables for other runway marker lights. Because the SX Subsystem is intended to operate with standard lighting equipment, standard procedures were employed to install cables for the five series circuits employed by RWSL. Subsequent testing of the system revealed that new requirements (or guidelines) for cable routing are probably needed to optimize SX performance in future installations.

3.3 PERFORMANCE VERIFICATION

Verification is the process of determining if the system performs as required, as compared to validation which is the process of determining if the system performs as desired. Because the ultimate goal of the RWSL program is to expose the lights to pilots and vehicle operators in the operational environment of Logan Airport, system integrity must be ensured: RWSL must not present false information to the end user. The verification process includes:

- Laboratory and warehouse testing
- End-to-end system tests
- Hooded testing.

Laboratory and warehouse testing, as indicated in Section 3.2, is an integral part of the rapid prototyping process employed to develop RWSL. Software verification is critical to ensure the correct operation of the system. Operational data recorded by AMASS at Logan enabled realistic testing of the Light Logic in the laboratory. This testing was supplemented with synthesized test drivers to ensure full coverage of all conditions which may be encountered at Logan but may not be embodied in the recorded operational data. Special performance evaluation software is used to quantify the associated performance statistics. Custom test software is also used to verify the correct transformation of the light data into group commands by the LCC. Testing was repeated as necessary in support of the evolutionary development process to ensure the integrity of the most recent build.

End-to-end testing is a critical element of the Light Subsystem verification process. The warehouse provided a convenient environment for initial end-to-end testing. Test instrumentation enabled 16 light fixtures at a time to be instrumented for automated direct measurement of the response to commands. This enabled the quantification of time response statistics and performance reliability statistics for the SX Subsystem. At Logan, end-to-end testing is considerably more difficult with lights distributed over a distance of about two miles along each of the two runways, the LC and CCRs located in the Lighting Vault at the south end of the field and the LCC located on the 16th floor in the tower. Section 7.4 presents the process used at Logan, enabling verification of the correct response of every RWSL fixture on the field. In addition to verifying the correct response to commands from the LCC, the reliability of the response and the elapsed time between when the command is issued and achieved is measured as part of the end-to-end testing process. This testing is all part of the process of verifying the integrity of the system prior to unhooding. It is critical to verify that all lights respond as expected to the commands.

Hooded testing provides the means for verifying the Light Logic in the operational environment. Combining the hooded testing with the end-to-end testing provides complete verification of

RWSL. During hooded testing of RWSL, the output of the Light Logic in the operational environment of Logan is recorded. Independent instrumentation is used to capture key operations as observed by experienced tower controllers employed by the RWSL Program. Post-time processing of the recorded data and direct comparison with the "truth" provided by the shadow controllers enables the calculation of quantitative performance statistics. In addition to determining if the light state (on or off) identified by the Light Logic is correct, the time at which the transition takes place relative to time clearance is issued by the tower controller is measured. Achieving the correct light state within three seconds of the desired event is one of the hooded system performance measures. A second performance measure established for hooded test evaluation is that in any four-hour period there should be no more than two occurrences of the potential for a pilot to view a red light (if it were unhooded) when the light should be off. Over 100 hours of hooded testing provided system performance statistics for the full range of airport operations. During hooded testing, obvious system errors were corrected and desirable improvements were incorporated as part of the evolutionary process. Because the surveillance data is recorded during each test, it is relatively easy to reprocess prior data when a change is made to the software, thereby ensuring that the associated system change did not invalidate previous test results by introducing new errors. Prior to hooded testing, all RWSL equipment and software was placed under formal configuration control to ensure the continuing validity of prior testing. Configuration control is an important element of all operational systems and must not be compromised in the evolutionary process used for the development of RWSL.

3.4 UNHOODED TEST PREPARATION

Throughout the system development process, the goal of eventually exposing the lights to pilots in the operational environment provided a continuing focus for the development team. Paramount in this focus is the need to ensure safety in the operational environment. Although the expressed purpose of RWSL is to improve safety by essentially providing a backup to the air traffic controller, erroneous system operation or misinterpretation/misuse of the lights by a pilot could have the undesired opposite effect. Unhooded operation of RWSL embodies the system engineering process of validation, which is the process of determining if the system performs as desired. In other words, it is the process of determining if the system is truly effective in the operational environment. This is quite different from the previously discussed verification process where system performance is measured against the system requirements. The validation process has the potential to expose inadequate or even incorrect requirements (established at the onset of the program) which are generally based on limited testing and various assumptions. For example, light characteristics (color, brightness, positioning, response time, etc.) are the result of numerous requirements and tests but the net effectiveness of the lights can only be measured by exposing them to the end user.

System validation is much more difficult than verification to achieve, primarily because the human end user (pilot or vehicle operator) becomes part of the operational evaluation. The lights convey certain "information" which may modify the behavior/response of the human in a positive or negative manner. Human response to the lights in the operational environment is a complex process and difficult to predict with absolute certainty. Simulator-based human factors testing at NASA Langley with several cockpit teams showed significant promise for the RWSL concept. Although simulator testing is valuable, system validation can only occur in the actual operational environment and needs to encompass the full range of operational conditions. Validation of RWSL is not necessarily unique. Introducing pilots to any new system that has the potential to modify operational behavior has similar performance validation requirements.

Pilot (and vehicle operator) training is a critical element of preparing for unhooding the lights. This involves disseminating information on the system operation and use, along with training courses for pilots, vehicle operators and air traffic controllers. Information kiosks were developed for the pilot lounges and numerous briefings given to the chief pilots of major airlines. Articles were written for the airline trade publications and RWSL information/procedures developed for NOTAMs and the Jeppesen bulletins. All informational materials are developed under direct guidance from the experienced air traffic controllers, pilots and human factors experts on the development team.

The system validation process requires quantitative performance measures and data that can be used to assess the actual effectiveness of the system. Questionnaires and interview forms for pilots, operators and controllers were developed to support this requirement. Further, the experienced air traffic controllers on the development team provide an independent source of performance data during unhooded testing through monitoring of the controller-pilot voice traffic and visual observations of the aircraft motion relative to the RWSL light states. Because RWSL operation is continuously monitored by the development team during unhooded operation, any anomalous operation or system malfunction can be rapidly corrected or the system can be disabled. Recall that the end user is trained to interpret an off light as being nonexistent. Detailed test plans identify the specific procedures to be followed in support of unhooded testing and validation data recording.

Prior to full unhooded testing, limited testing with some of the lights exposed is part of the process to provide an initial indication of the human factors response to the lights. Static tests with bucket truck and dynamic tests with a light aircraft (see Section 7.5) provided initial indications of light visibility and operation. Subsequent dry run tests provided additional operational information with a subset of the lights exposed. Unfortunately, approval was not obtained from the FAA for full unhooded testing of RWSL. Therefore, validation of the system is incomplete.

3.5 CONCLUSIONS

The rapid prototyping approach employed to develop the assessment RWSL System for evaluation at Logan proved to be both efficient and effective. Key to the success of using available and COTS hardware/software is the supporting need for specialized testing within the context of the intended application. Given that the COTS equipment is not necessarily designed for the RWSL application, its capability to support the application must be learned through test and experimentation. Close cooperation of the vendor and the development team greatly facilitates this process. Also, flexibility in the detailed requirements is necessary to accommodate limitations and restrictions associated with the as-built equipment, providing that this flexibility does not compromise the safety and integrity of the final system. Finally, detailed documentation of plans, procedures and results as the system is developed is key to capturing the lessons learned and maintaining a focus on the desired end result.

Warehouse testing of the Light Subsystem was a key step in the process of reducing the technical risk prior to installation at Logan. Failure to identify and correct the slow lamp response characteristics prior to the Logan testing could have been a show-stopper. Also, measurement of the actual SX Subsystem operating characteristics in the warehouse was critical to the subsequent system evolution for Logan. It also became clear after installing the system at Logan that all of the environment-specific characteristics impacting system performance cannot be captured in the warehouse. Field testing is a crucial step in the system development process, thereby necessitating the Logan installation. In particular, discovery of the required mechanical characteristics of the light fixtures was an important output of the Logan installation and testing. Laboratory testing of the Light Logic using surveillance data recorded at Logan, in combination with simulated operational scenarios, is also viewed as a critical step in the overall system development process.

The process of verification testing through engineering measurements and hooded system evaluation also demonstrated its value at Logan. End-to-end system operation was verified, errors were identified and corrected, and performance limitations of the as-built system were identified. Selected human factors testing provided valuable insights into light placement and characteristics. Because the overall process was continuously focused on the ultimate goal of unhooded testing, detailed unhooded operating procedures and training courses were a result of the process. Unfortunately, closure was not achieved with the validation process because approval for unhooding was not obtained from the FAA.

4. LIGHT LOGIC AND AMASS

The following sections provide a description of the existing Airport Movement Area Safety System capabilities and the functional enhancement to AMASS required for the operation of the Runway Status Light system.

4.1 ARCHITECTURE

4.1.1 Constraints

Development of the technology for an RWSL has been constrained by resource limitations. This led to a design philosophy that emphasized the reuse of existing systems and the use of commercial off-the-shelf hardware and software.

The FAA is in the process of equipping major domestic airports with a modern primary surveillance radar called Airport Surface Detection Equipment-Version 3. In addition, the FAA is conducting a test program of pre-production prototypes of the AMASS which, when integrated with ASDE-3, will alert controllers when aircraft are projected to be in conflict with other aircraft or ground vehicles.

A key system design decision was to use the existing ASDE-3 and AMASS systems at Logan Airport, augmented with light control logic modeled after the MITLL proof-of-concept model-board prototype. Custom software was developed to implement the Lincoln Laboratory algorithms and integrate them with the existing AMASS software.

4.1.2 Functional and Physical Architecture

The functional block diagram for the operational assessment system is shown in Figure 4-1. The operational assessment system consists of the Automated Radar Terminal System and ASDE-3 sensors, the AMASS, and the RWSL components. ASDE-3 provides surface surveillance information, and ARTS provides data on targets in the approach airspace to the AMASS processor for development of target tracks and determination of runway occupancy. AMASS uses this information to provide the controllers with an indication of runway status and potential conflict situations. The same information is used by the Light Manager logic to determine which lights are to be turned on or off and when, providing pilots with a similar indication of runway status.

Light commands are routed through the Light Control Computer to the Light Computer, which converts the light commands to radio frequency signals for transmission over the power lines to the Smart Transformers which control and monitor the lights. The test center, where control for the Logan demonstration resides, is located on the 16th floor of the Logan Tower.

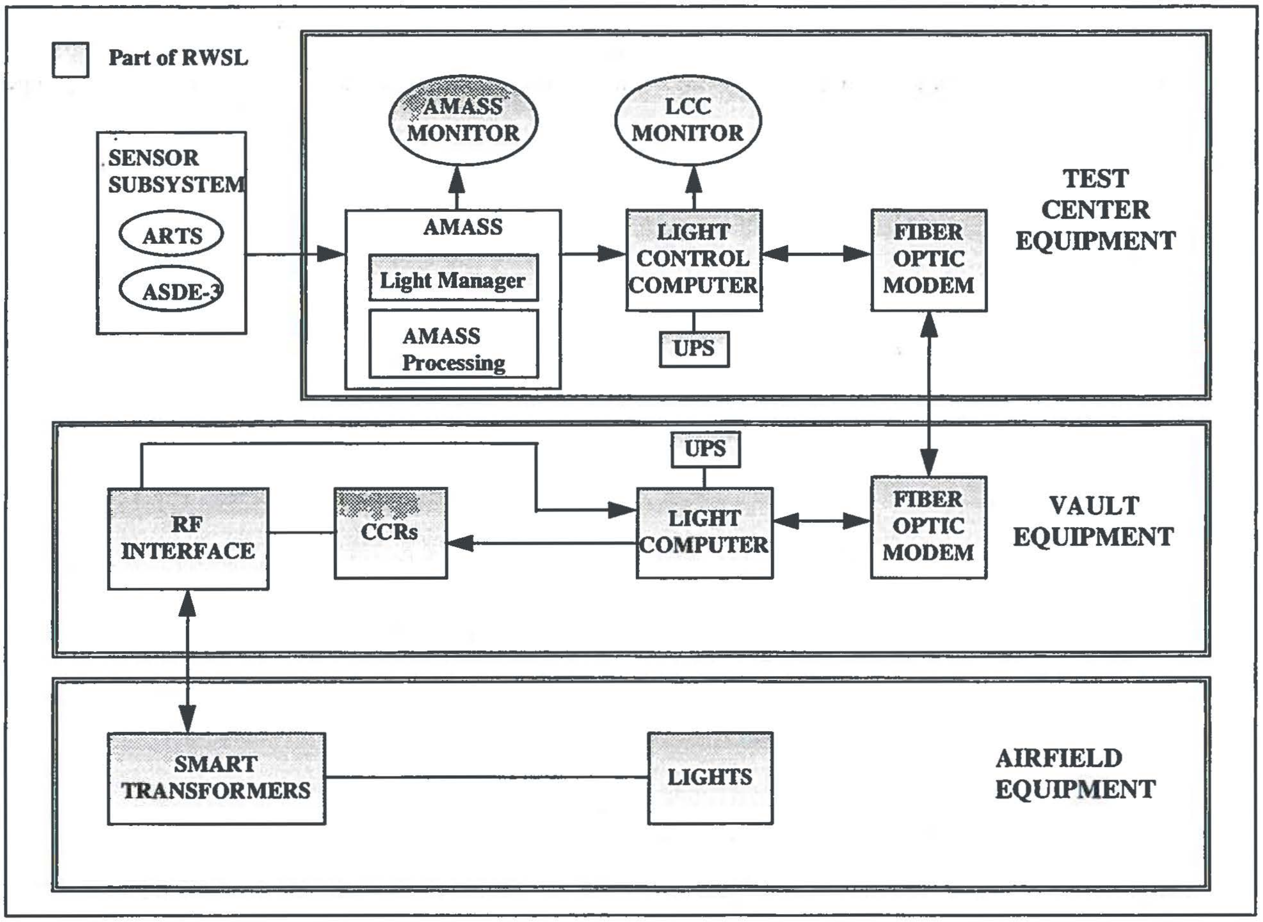


FIGURE 4-1. BLOCK DIAGRAM OF THE OPERATIONAL ASSESSMENT SYSTEM

4.1.3 AMASS

AMASS provides controllers with status, caution, and warning information that emphasizes key operational events to prevent runway incursions from developing and incursions from becoming collisions. A pre-production version of the AMASS software was enhanced to include Light Manager functions necessary to support the control of runway status lights and communicate with the Light Control Computer.

4.1.3.1 Hardware -The AMASS software executes in an MS-DOS environment on an IBM PC-compatible industrial PC supplied by Norden and previously installed at Boston Logan International Airport. AMASS supports a keyboard and mouse, which are used when configuring AMASS before starting a test run, and for certain management functions while AMASS is on-line. A VGA video monitor serves as the only display.

AMASS receives airport situation data from the Automated Radar Terminal System and Airport Surface Detection Equipment. ASDE-3 data is received from the ASDE-3 Display Processor Interface Control (DPIC) via a proprietary interface. ARTS data is received from the ARTS Interface Unit via an RS-232 standard serial port. A second RS-232 serial port is used to communicate with an uninterruptible power supply (UPS). The Light Manager enhancement to AMASS sends light control commands via a third RS-232 standard serial port connected via short-haul modems to the Light Control Computer. The additional serial port required by the Light Manager is the only modification to the AMASS hardware performed specifically for this project.

4.1.3.2 Location - The AMASS PC is located on the 21st floor of the Logan Airport control tower. A keyboard, mouse, and video monitor were located both on the 21st floor and in the 16th floor test center, from which the RWSL tests were managed. A manual switch is provided to select between the two sets of keyboard, mouse, and video monitor.

4.1.3.3 AMASS Functionality - The AMASS tracks targets detected by the ASDE-3 and ARTS, integrates ASDE-3 tracks with ARTS tracks, applies safety logic, and provides caution and warning messages to the controller in the tower cab. The AMASS augments ASDE-3 with a state-of-the-art automated alerting system. In less than one second, AMASS tracks all ground operations, compares each movement, and automatically provides visual and audio alert of potential conflicts, or even the slightest deviation in airport procedures.

4.1.4 ASDE-3

The Airport Surface Detection Equipment-Version 3 provides to AMASS information about aircraft on or near the airport runways and taxiways. The ASDE-3 radar is located on top of the Boston Logan control tower, at a height of 275 feet. AMASS employs custom hardware, consisting of wedge memory to buffer the radar data and a sample processor to extract aircraft targets, to analyze the ASDE-3 radar data. The custom hardware develops and maintains target tracks and communicates information on each target to the AMASS PC via a proprietary interface.

To aid the extraction of targets from the radar data, the AMASS sample processor maintains a clutter map and a target history. The clutter map is used by a clutter filter algorithm to filter out radar data that typically represents topological features, such as permanent airfield equipment. The sample processor then applies algorithms to determine which remaining radar data are valid targets, to develop target tracks by relating valid targets to targets in the target history, and to calculate centroid position and velocity of targets, which are converted into the coordinate system expected by the AMASS PC. ASDE-3 does not report target altitude.

4.1.5 ARTS Interface Unit

The Automated Radar Terminal System provides to AMASS information about departing or arriving aircraft in the approach airspace. Radar data from ARTS is processed by the ARTS Interface Unit, which maintains target tracks and communicates information about each target to AMASS.

4.1.5.1 Hardware -The AIU consists of an ARTS interface, an Intel 80486-based computer, and a modem with which it communicates with the AMASS target processor. The ARTS interface provides an electrically isolated tap of communication between the ARTS Multiple Display Buffer Memory (MDBM) and the Digital Electronic Display System (DEDS). The computer processes the MDBM communication and transmits target information via a microwave-link modem to the AMASS PC.

4.1.5.2 Location -The AIU is located on the 5th floor of the Boston Logan control tower in its own cabinet. Target track data is communicated over an RS-232 serial link to the ARTS processor, located in the AMASS cabinet on the 21st floor, which is responsible for buffering and transferring ARTS target data to the AMASS safety logic.

4.1.5.3 Functionality - The AIU provides a non-intrusive interface to the ARTS system and converts the target data received into a form acceptable by the AMASS PC. The ARTS interface of the AIU monitors communication between the ARTS MDBM and DEDS systems. The MDBM provides pre-processed position, altitude, velocity and aircraft identification (ACID) information for each target. A target's information is transmitted only when changes occur. The AIU maintains tracks of ARTS targets based on the changes transmitted by the MDBM. The AIU performs filtering to remove ARTS targets not within predefined acquisition areas. It then parses the ARTS data strings and converts the data to an internal representation shared with AMASS.

The AIU maintains its own track database, employing an Alpha-Beta tracking algorithm to smooth target position and velocity, adding, deleting, and updating tracks based on information received from the MDBM. The tracking algorithm correlates untagged targets with tracks, coasts targets for which new information has not been received, and filters parallel tracks. The tracker provides special arrival track functions, including assigning arrivals to runways based on target position and velocity vectors and on the position of the runway threshold.

The resulting tracks are communicated to the AMASS PC.

4.1.6 AMASS-LCC Interface

Light Manager REL and THL states are transmitted to the Light Control Computer, where the state information is transformed into commands suitable for transmission to the Light Computer in the airport electrical equipment vault. The AMASS-LCC interface consists of a serial communications point-to-point circuit adhering to the EIA RS-232 standard.

The LM function sends a Light State message to the LCC at the completion of each ASDE radar sweep after processing completes for the REL Logic function and the THL Logic function. The Light State message contains the current commanded state for each REL group and each THL group as determined by the LM function logic (see Section 4.2 and Appendix B). Details of the protocol employed are given in Appendix A.

4.2 LIGHT MANAGER LOGIC

The Light Manager function provide capabilities for automatically controlling the runway status lights. Two types of runway status lights are implemented — runway entrance lights and takeoff-hold lights—with separate logic used for each type. Runway status lights may be in one of two states: ON, in which the lights are red, indicating that it is unsafe to enter the runway or unsafe to begin takeoff, or OFF.

The Light Manager logic functions in response to real-time surveillance and is designed to avoid interfering with controller clearances or impeding the normal flow of traffic. The capability to separately disable or enable REL and THL processing and the display of the state of RELs and THLs is provided on a Light Manager configuration screen available from the AMASS main menu.

The purpose of the Light Manager is to determine which runway status lights should be illuminated, based on whether a runway is being used for a specific operation, such as arriving aircraft or taxiing aircraft. The Light Manager alerts pilots in the following incidents geometries:

1) Departing aircraft and taxiing aircraft or ground vehicle crossing runway
2) Arriving aircraft and taxiing aircraft or ground vehicle crossing runway
3) Two departing aircraft on crossing runways
4) Departing aircraft and arriving aircraft on crossing runways, except during land and hold short operations
5) Two departing aircraft on the same runway (tail chase), except when required departure separation of 3000 feet apply
6) Departing aircraft and taxiing aircraft on runway
7) Arriving aircraft and taxiing aircraft on runway

REL and THL logic overviews are provided below. A more detailed description of the Light Manager logic is provided in Appendix B.

4.2.1 Runway Entrance Light Capabilities

REL logic provides a means to illuminate runway entrance lights at a runway/taxiway or runway/runway intersection to indicate that the runway is unsafe to enter at that intersection. RELs are operated based on a **hot-zone** — an area ahead of a high speed target that should be free of other targets. The hot zone is projected ahead of any target moving along the runway or on approach to land. The specific length of the zone is determined by a combination of the target's speed and a time interval that depends on the target's state (see Section 4.2.3). Hot zones are used in conjunction with **REL activation regions** — areas on the runway associated with a set of RELs at an intersection. RELs in a set are illuminated if a hot zone overlaps with their associated activation region, and are off otherwise. The RELs behind a target are always off (unless there is a second target approaching behind the first target). Thus, as the leading edge of the hot-zone passes each intersection, the corresponding RELs are turned on by the LM logic. The lights at each intersection remain on until the trailing edge of the hot zone passes the intersection. For the specific case of arriving aircraft, the lights at all intersections along the entire arrival runway are activated.

To improve traffic flow, the REL illumination logic employs the concept of **anticipated separation**. Anticipated separation is based on the notion that controllers can issue clearances and instructions to aircraft in anticipation that legal separation between aircraft will exist when required, even though legal separation does not currently exist. LM logic mimics the action of controllers in these special situations, effectively moving the trailing edge of the hot zone a small distance in front of the aircraft, based on the speed of the aircraft.

Figure 4-2 illustrates the basic concepts used to control the RELs.

There are two types of hot zones, each with a different type of length:

1. t-second zones, whose length is the distance corresponding to *t* seconds ahead of the target, where *t* is a function of the target state
2. whole runway zones, whose length is the whole runway ahead of a target.

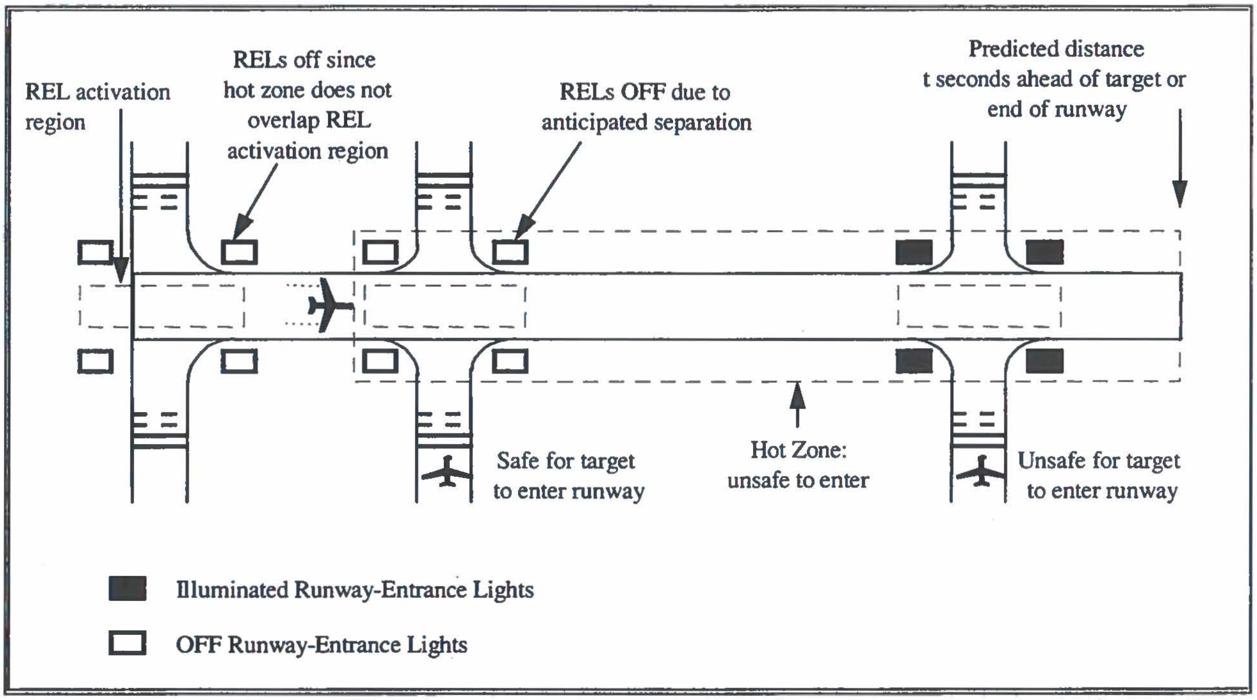


FIGURE 4-2. REL CAPABILITIES

The type of hot zone will be dependent on the target's movement state, as computed by the existing AMASS logic:

a. Targets in the arrival state (ARR) will have a t-second hot zone

b. Targets in the departure state (DEP) or in the departure abort state (DBT) will have whole runway hot zones

c. Targets in the landing state (LDG) will have a whole runway hot zone while their speed is greater than or equal to an adaptable parameter (55 kts), and will have a t-second hot zone otherwise. A sub-state of LDG, called landing roll-out (LRO), is associated with targets travelling slower than the adaptable parameter.

d. Targets in the taxi state (TAX) or the stop state (STP) will have a hot zone length of zero since their target speeds are so low that it is safe for other targets to cross the runway ahead of them.

The length of t-second hot-zones is 25 seconds for Runway 4L at Logan airport, or 36 seconds for the other runways instrumented during the RWSL test phase, which are Runways 22R, 9 and 27.

The intersection of two runways poses a special problem. It is possible that a pilot observing illuminated RELs at a runway/runway intersection might be traveling at high speed and consequently might take unsafe action upon seeing lights which are on. To prevent this from happening, the RWSL logic deactivates all RELs at runway/runway intersections except for those cases when a runway is consistently being used only as a taxiway in the current airport configuration. Note that this implies that RELs will never be illuminated at runway/runway intersections in land and hold short operations, even if the possibility of an incursion exists. As a further measure of safety, RELs at a runway/runway intersection are extinguished if a high speed target is approaching.

4.2.2 Takeoff Hold Light Capabilities

THL logic illuminates takeoff-hold lights if a target is in position for a takeoff or starting its takeoff and the runway is not safe for takeoff. This implies that a target must be in a position to see the THLs before they can be illuminated. Note that THLs are illuminated based on the actions of two targets, in contrast to RELs, which are illuminated based on the action of a single target. The THL function has logic to determine when a target is in position for a takeoff or has started its takeoff. If a target is in position for takeoff or has started its takeoff, the THL logic determines whether the runway is safe for takeoff.

A runway may be unsafe for takeoff if: (1) there is another target on the same runway as the target about to take off, or (2) there is another target on an intersecting runway. For the first case the THL function determines that the runway is unsafe for takeoff if there is a target inside the **THL activation region**, an area that includes the entire runway ahead of the lights as well as an extension on either side of the runway. Figure 4-3 illustrates the basic concepts used to control the THLs when there is another target on the same runway as the target about to take off.

For the second case, the THL function determines that the runway is unsafe for takeoff if there is a potential conflict with a high-speed target on an intersecting runway. The logic is based on the concept of an **intersection window**, an area at the intersection of two runways. The runway is unsafe for takeoff if target A, which is in position for takeoff or starting its takeoff, and target B, which is in any target state except stopped and taxiing, could be in the intersection window

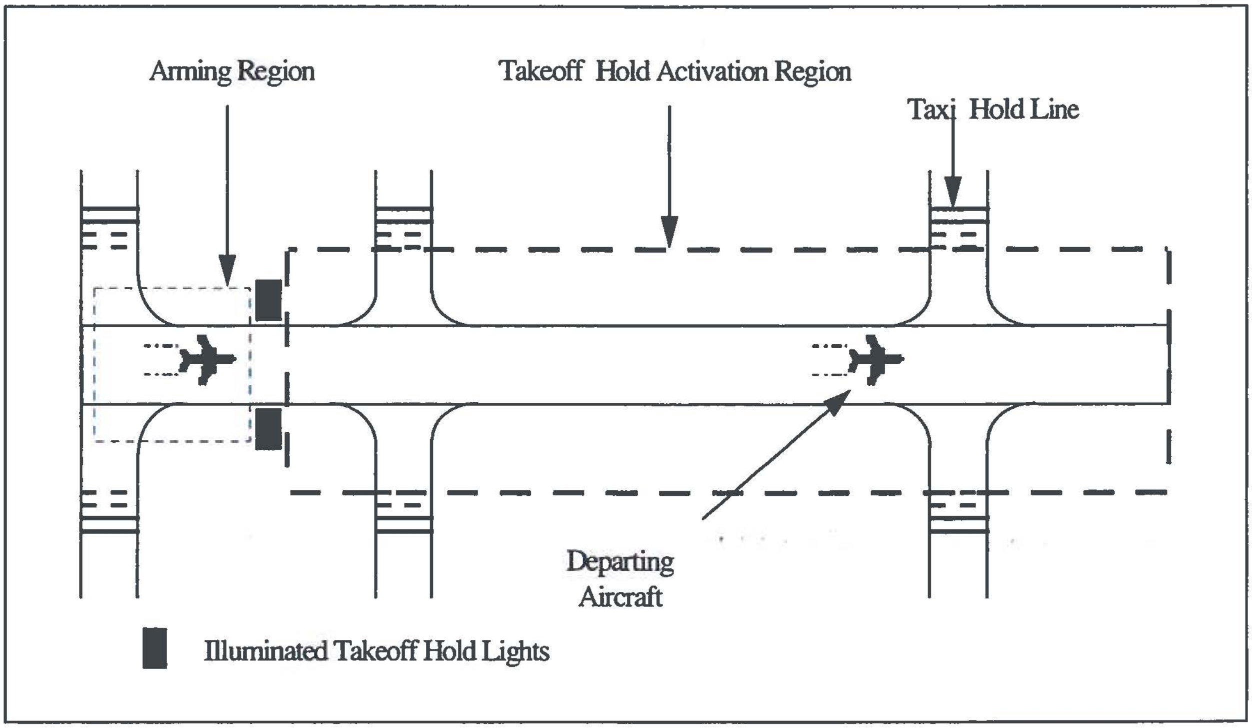


FIGURE 4-3. TARGET AHEAD OF TAKEOFF POSITION

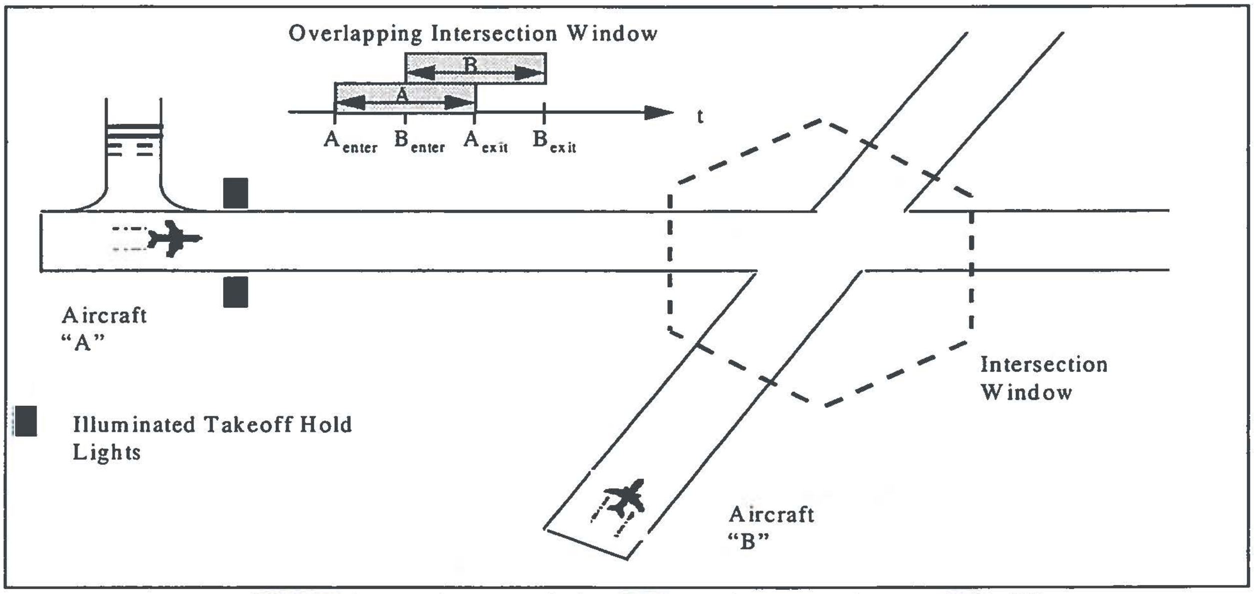


FIGURE 4-4. TARGETS ON INTERSECTING RUNWAYS

simultaneously if target A started to take off. Figure 4-4 illustrates the basic concepts used to control the THLs when there is traffic on an intersecting runway.

Like REL logic, the concept of **anticipated separation** also exists for THLs. THLs will extinguish if an aircraft crossing the departure runway ahead of the aircraft waiting to take off is predicted to leave the departure runway soon.

Special logic handles split THL groups. Split THL groups occur at certain locations on Logan's airport surface in which the taxiway/runway geometry dictates that THLs be installed in such a way that the two pairs of THLs straddle an intersection (see Figure 4-5). This situation occurs on runway 27 (THLs are straddled by D-1 taxiway), runway 9 (W taxiway), and runway 22R (N-1 taxiway).

The original problem with this situation is illustrated by Figure 4-5 for runway 22R. If aircraft A is holding at hold position 1 and aircraft B enters the runway from taxiway N-1, ahead of aircraft A, both pairs of THLs would turn on because aircraft B is in aircraft A's activation region. The second pair of THLs might then be observable to aircraft B's pilot, causing a THL interference for aircraft B. The logic was modified to associate THL arming regions with each pair of lights, as opposed to a specific hold position. Aircraft B would then activate the first set of THLs but not the second. If there is no target in the arming region associated with the second pair of THLs, both pairs of THLs will be armed by an aircraft holding at hold position 1, to provide improved visibility of the THLs from the pilot's position.

4.2.3 State Machine

Table 4-1 defines the Light Manager states and Table 4-2 defines the state machine used by the Light Manager to classify targets for processing by the light logic. Target states, by and large, are taken directly from the AMASS target states. The LM logic defines a substate of the Landing state, called Landing Roll-out, based on the speed of the target. When the speed of a target in the Landing falls below a specified value, the target state changes to Landing Roll-out, and the hot-zone length is changed from whole-runway to a t-second length, as described in Section 4.2.1.

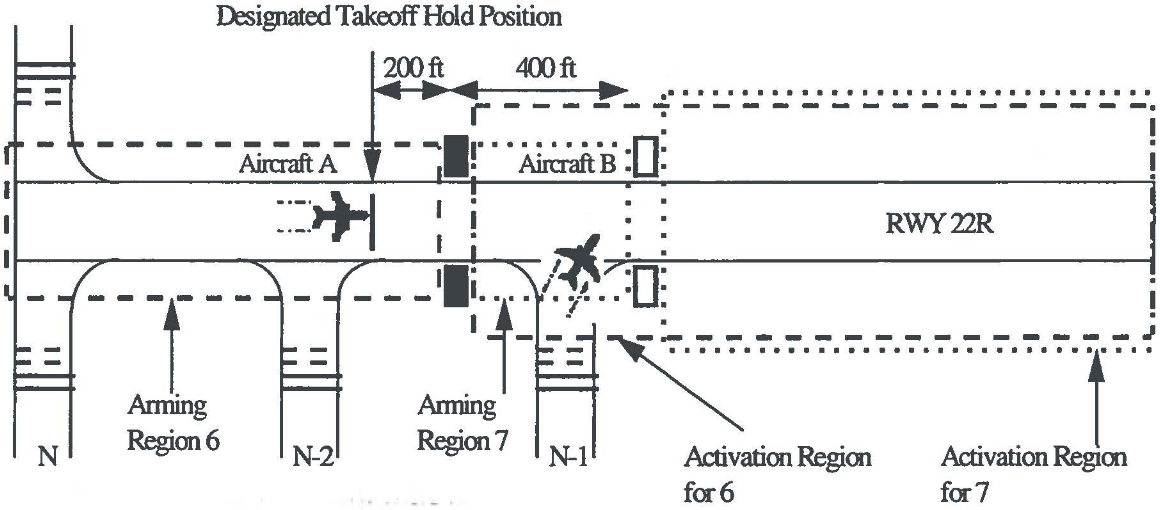


FIGURE 4-5. CONTROL OF A SPLIT THL GROUP

TABLE 4-1. LIGHT MANAGER STATES

State	Abbreviation	State	Abbreviation
Stop	STP	Arrival	ARR
Taxi	TAX	Landing	LDG
Departure	DEP	Landing Roll-out	LRO
Departure Abort	DEP ABT	Unknown	UNK

The speeds used to determine state are adjustable parameters (see Appendix H).

The movement state ARR (arrival) is the state of a target if and only if it is an ARTS target. Because ARTS targets are created and handled separately from surface targets, the only possible transition for an ARTS target is from "Not a target" to ARR and back to "Not a target" when it is dropped, either because it is handed off to a surface target or it has passed out of the airport space.

TABLE 4-2. LIGHT MANAGER STATE MACHINE

Present State	Next State	Condition
UNK	STP	velocity < taxi_to_stop (4 ft/sec)
	TAX	velocity ≤ taxi_to_dep (64 ft/sec) and velocity ≥ taxi_to_stop (4 ft/sec)
	DEP	velocity > taxi_to_dep (64 ft/sec)
STP	TAX	velocity > stop_to_taxi (12 ft/sec)
	Not a target	dropped target.
TAX	STP	velocity < taxi_to_stop (4 ft/sec)
	DEP	velocity > taxi_to_dep (64 ft/sec)
DEP	DEP ABT	velocity < dep_to_dep_abort (36 ft/sec) or velocity < peak_velocity * (dep_to_dep_abort percent / 100)
	Not a target	dropped target
DEP ABT	TAX	velocity < dep_abort_to_taxi (36 ft/sec)
ARR (ARTS target)	Not a target	handed off or dropped target
LDG	LRO	velocity < landing_to_landing_rollout (55 ft/sec)
LRO	TAX	velocity < landing_to_taxi (36 ft/sec)
Not a target	STP	velocity < taxi_to_stop (4 ft/sec)
	TAX	velocity ≤ none_to_landing (64 ft/sec) and velocity ≥ taxi_to_stop (4 ft/sec)
	LDG	velocity > none_to_landing (64 ft/sec)
	ARR	ARTS target

4.3 AMASS MODIFICATION

Support for runway status lights was integrated into the AMASS source code. The Light Manager logic operates separately from the AMASS safety logic, but depends on target information in the AMASS target database.

4.3.1 Existing Software

The major functions within AMASS are Target Management, Safety Management, Alarm Management, Adaptation, Display, Simulation, and Data Retention. To support the runway status light capability, the existing Logan pre-production AMASS has been enhanced to provide capabilities to automatically control runway status lights. These new capabilities are provided by the Light Manager function as shown in Figure 4-6 and described in Section 4.3.2. Existing AMASS functionality includes provisions for much of the signal processing and logic that is required to support the LM function, including the processing and maintenance of target reports from ASDE-3 and ARTS, and incursion processing, which establishes target location, direction, and movement.

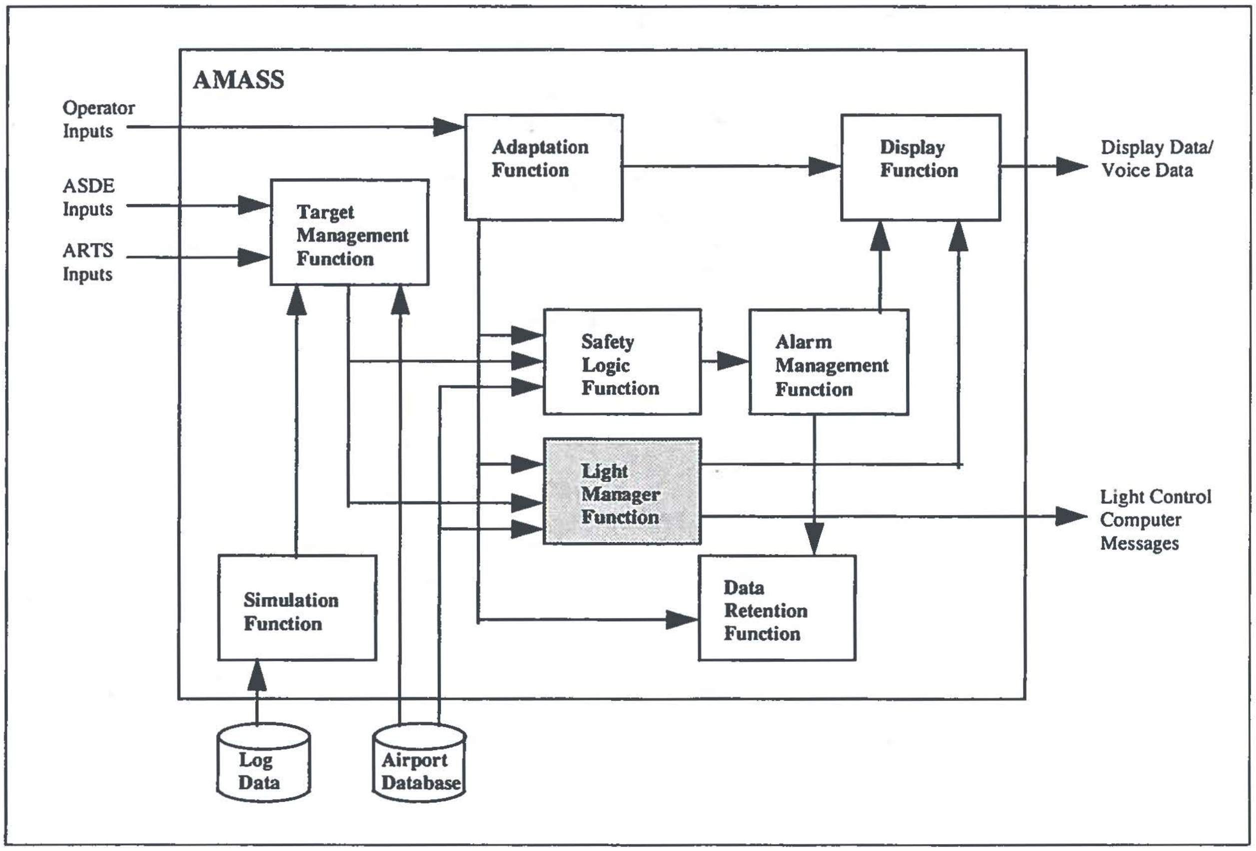


FIGURE 4-6. FUNCTIONAL BLOCK DIAGRAM

The Target Management function provides for the processing and maintenance of target reports from the Airport Surface Detection Equipment and from the Automated Radar Terminal System. Target Management establishes the following values:

1) Location State - determines if a target is on a valid segment of the airport.

2) Direction State - determines the general direction (N, S, E, W) and alignment (Normal, Opposite) relative to a runway of a target.

3) Movement State - classifies a target based on velocity as Arrival, Departure, Departure Abort, Taxi, Stop, or Lander.

The Safety Management function performs single target situation and paired target situation checking on all targets detected by the Target Management function over each radar sweep. Alarm lists are generated based on table look-ups and are passed to the Alarm Management function as input data.

The Alarm Management function provides textual, visual (iconic), and aural alarms of an alert event detected by the AMASS system. Alerts received from the Safety Management function are filtered and processed according to priority. All alerts sent to the Alarm Management function are logged by the Data Retention function.

The Adaptation function is used to create the databases containing the airport area definition.

The Display function provides for the output of target and alert video data overlaid on the ASDE display in the control tower. The Display function also supports a user interface provided via the ASDE keyboard.

The Simulation function provides the means to introduce synthetic targets into the system or playback pre-recorded track data (or scenarios) for the purpose of system test and training.

The Data Retention function provides continuous long-term recording without operator intervention. This function records the following items: ASDE tracks, ARTS tracks, synthetic tracks, ASDE radar sweep synchronization records, alarm events, airport parameter changes, system configuration, system error events, and safety logic filters. Off-Line disk maintenance functions provide for formatting and clearing of the recorded data, copying the data to and from files, and converting the data to ASCII format for inspection.

4.3.2 New Software

The Light Manager function, an enhancement to the AMASS system, provides the capabilities and services to illuminate runway-entrance lights at runway/taxiway and runway/runway intersections, and to illuminate takeoff-hold lights at takeoff-hold positions on a runway. The logic employed by the Light Manager function is described in detail in Section 4.2 and Appendix B of this document.

Three major functions form the Light Manager functionality:

1) REL logic provides a means to illuminate runway entrance lights at a runway/taxiway or runway/runway intersection to indicate that the runway is unsafe to enter at that intersection.

2) THL logic provides a means to illuminate takeoff-hold lights if a target is in position for a takeoff or starting its takeoff and the runway is not safe for takeoff.

3) LCC Message Processing provides a means to communicate light states from the AMASS PC to the Light Control Computer.

The LM leverages existing AMASS functionality as a means to efficient target processing and seamless integration from the user perspective. The AMASS functions to which the LM interfaces are described below, along with a description of the purpose of each interface from the perspective of the LM function.

1) Target Management Functions - The interface to this function is through the AMASS track database. The track database is used as an input to the LM function providing target location, direction, and movement state.

2) Display Functions - The LM function interfaces to this function to display REL and THL objects and their current state (i.e., illuminated or off). This interface is also used to provide screens for viewing and modifying LM site variable parameters.

3) Adaptation Functions - The interface to this function is through the AMASS adaptation database. The adaptation database is used as an input to the LM function providing configuration data (e.g., runway configuration).

The AMASS airport database is used as an input to the LM function providing airport segment data, surface boundary coordinates, surface intersection coordinates, and runway threshold coordinates.

The LM has its own logging functions, which produce an LM log file used to evaluate light logic and timing. In addition, the AMASS display was enhanced to improve visibility and take advantage of the larger multisync display used in the RWSL test direction room on the 16th floor of the Boston Logan control tower.

4.4 UNIT TESTING

Complex software systems such as RWSL have innumerable sources of malfunctions which can cause unwanted performance anomalies. The chances for their occurrence, just as are the chances for obtaining correct performance, are a matter of statistical probability. Confidence in failure-free system performance increases as the number of successful demonstrations of system performance capabilities increases.

Unit-level testing of the LM function was performed to demonstrate that the light control logic software performs in accordance with specified operational requirements. A limited set of operational scenarios was used to demonstrate and validate the light control logic capabilities. These scenarios demonstrated how the various light control logic capabilities interact to produce the desired runway status lights behavior. The scenarios were used to blend a carefully researched description of some set of real ongoing activities with a look at how runway status lights could support those activities.

The tests that were executed are functional tests whose requirements were derived from the software requirements. The software was tested for functional correctness, and all tests were performed in a scenario fashion. The tests included nominal and off-nominal scenarios.

4.4.1 Test Tools

To implement the scenarios, several test tools that are provided in AMASS were used. One testing approach was to place the AMASS in playback mode (i.e., Workstation Disk mode) and then execute the playback with the LM function enabled. During playback mode, the AMASS has the capability to replay previously recorded track data. This data is processed by the AMASS and LM functions as if it were being received from the ASDE and ARTS, thereby simulating actual conditions at Logan Airport. A drawback with this mode of testing was that it was difficult and time consuming to find an exact match for the scenario in the recorded track data.

Another testing approach was to place the AMASS in Workstation Sensor mode. In this mode, AMASS allows a user to define multiple synthetic targets operating to a user-defined profile. These targets are injected into the AMASS processing stream in the same way that tracks are injected during playback mode. The performance characteristics of the synthetic targets can be defined to simulate various types of aircraft.

The final approach used was a hybrid of the first two approaches. The AMASS was placed in playback mode and previously recorded track data was processed by AMASS. At particular times during the playback, a synthetic target was injected to create the conflict situation specified in the scenario.

Ideally, all of the scenarios would have been implemented using the second approach (i.e., placing the AMASS in Workstation Sensor mode and injecting synthetic targets). This provides a mode of testing that is repeatable and simple to execute. Unfortunately, AMASS does not provide a capability to create synthetic tracks in the arrival state (i.e., ARTS tracks) so all scenarios that involved an arrival had to be executed using either test approach #1 or test approach #3.

To evaluate system functional correctness, various data describing the operation of the lights were recorded and post-run analysis tools were used to analyze performance. As well, the AMASS display was observed to verify that the lights were being controlled correctly.

4.4.2 Test Scenarios

A total of 50 scenarios (see Figure 4-7) were constructed for the RWSL by operations personnel familiar with airport surface movement at Logan Airport, covering all possible aircraft and ground vehicle geometries that would impact the runway status lights. The scenarios were defined in terms of a particular geometry (e.g., two planes are in a tail chase on the same runway) and state of the two targets involved in the scenario. Target states are combined into one of three categories based on the intent of an aircraft, rather than its AMASS state. Possible states are Departure, Arrival, and Taxi. As well, provision was made for targets involved in special or exceptional situations, such as a vehicle performing a runway inspection.

SCENARIO

D - Departure
A - Arrival
T - Taxi

HO - Head On
TC - Tail Chase
CR - Crossing
2P - Plane/Plane
VP - Vehicle Plane

	HO2P	HOVP	TC2P	TCVP	CR2P	CRVP
DD	2	▨	5	▨	2	▨
DA	2	▨	2	▨	4	▨
DT	1	1	1	2	3	2
AA	1	▨	1	▨	2	▨
AT	1	2	1	1	2	2
TT	2	2	1	1	2	2

 # OF SCENARIOS

FIGURE 4-7. TEST SCENARIOS

Due to limited resources and limitations of the test tools, it was necessary to establish which scenarios should be tested. After studying all of the scenarios, it was determined that some were not relevant to RWSL. These scenarios defined conflict situations that would not result in operation of the runway status lights. For example, the scenario in Figure 4-7 represented by the intersection of row AA and column TC2P described a conflict situation where two arrivals are in a tail chase situation. In this scenario, the aircraft are airborne and runway status lights cannot be used to alert the pilot to the conflict situation. A small number of scenarios like this were eliminated from test consideration. In other cases, it was found that several scenarios were nearly identical. When this occurred, a subset of the scenarios was selected for testing. After applying these filters to the scenarios, 25 scenarios remained to be simulated and analyzed. These are described more completely in Table 4-3 along with the test results.

4.4.3 Scenario Test Results

In order to document the results of the scenario tests, data was logged and an analysis report was generated using an off-line data analysis tool. The reports generated by the data analysis tool indicate the state of the targets and the state of the lights. All of the scenarios were executed multiple times to make sure the results were consistent and easy to duplicate. This involved keeping a journal of the playback file used, and the time and state of the injected synthetic targets and other targets involved in the scenario.

TABLE 4-3. SCENARIO TEST RESULTS

Scenario Description	Target States	Pass / Fail
# 1: Aircraft in position on 4L or commencing full length departure while an aircraft is in position on 22R. THLs should be ON. (HO2P)	D / D	Fail
# 3: Commuter cleared for takeoff on 4L at Charlie taxiway while aircraft B is in position on 4L at Sierra taxiway. THLs at Sierra taxiway should be ON and remain ON until first aircraft is airborne and turned away. (TC2P)	D / D	Pass
# 4: Aircraft A is cleared for takeoff on 22R and commences its roll from November. Aircraft B is cleared into position on 22R at November. Aircraft A aborts takeoff. THLs should remain ON for aircraft B. (TC2P)	D / D	Pass
# 8: Aircraft A on full departure roll on 4R while aircraft B is in position on 9 at Sierra taxiway. Runway 9 THL illuminated until the potential for conflict within the runway 9/4R intersection window no longer exists. (CR2P)	D / A	Pass
# 9: Aircraft A rolling 33L activates the East REL at the intersection of 33L/27. Aircraft B cleared for takeoff on 27. The illuminated East REL will be a problem for the crew on aircraft B. (CR2P)	D / D	Pass
#10: Departing aircraft inadvertently taxis into position on 22R at November taxiway while an arriving aircraft is on short final for 4L. THL should be ON for aircraft in position on 22R due to opposite direction traffic. Rare occasion. (HO2P)	D / A	Pass
#12: Aircraft A on final for 4L while aircraft B is in position for takeoff on 4L. THL is OFF. (TC2P)	D / A	Pass
#13: Departing aircraft in position for takeoff, arriving aircraft B lands over A. THL should go ON for A. (TC2P)	D / A	Fail
#16: Departing aircraft aborts on 27 and approaches 33L. Arriving aircraft B lands on 33L. REL on 33 should be OFF. (CR2P)	D / A	Pass
#17: Aircraft A landing on 33L, Aircraft B departs 4L on Charlie. REL on 33L/4L should not turn ON. (CR2P)	D / A	Pass
#18: Aircraft A cleared for takeoff on 4L while lost aircraft B taxis on SW on 22R. THLs on 4L and 22R are ON. (HO2P)	D / T	Pass
#19: Aircraft in position for a full length departure on 4L while a vehicle commences an inspection SW on 22R from November. THLs on 4L should be ON. (HOVP)	D / T	Pass

TABLE 4-3. SCENARIO TEST RESULTS (cont.)

Scenario Description	Target States	Pass / Fail
#20: Aircraft A lands on 4L and rolls to the end. Aircraft B is cleared into position and hold for a full length departure on 4L. 4L THL ON until aircraft A (now at taxi speed) clears the runway. (TC2P)		
#22: Departing aircraft begins takeoff roll ... THL OFF. A vehicle is cleared onto the runway behind the departing aircraft. The THL will illuminate. This will delay the vehicle from proceeding. (TCVP)	D / T	Pass
#23: Aircraft A in position for takeoff on 22R at November. Aircraft B crossing 22R at Charlie taxiway. The THL on 22R at November goes out when the crossing traffic clears. (CR2P)	D / T	Pass
#24: Aircraft A on 1 1/2 mile final for 27. Aircraft B in position on 33L and cleared for takeoff. SE REL on 33L should not come ON from the time the takeoff clearance is issued to aircraft B until it is beyond the SE REL on 33L. (CR2P)	D / T	Pass
#25: Aircraft A on takeoff roll on 22R from November. Aircraft B holding short of 22R on Tango. SW REL remains ON until Aircraft A passes the Tango intersection. (CR2P)	D / T	Pass
#30: Aircraft lands on 22L and holds short of 27. Aircraft B lands on 27 full length. The EAST REL at the intersection of 22L/27 should be OFF. The NE REL at the intersection on 22R/27 should be ON to identify the hold short point. The problem is how do the lights operate if the next arrival on 22L is full length. (CR2P)	D / T	Pass
#32: Aircraft on final for 22R (too far out to activate REL). Aircraft B taxiing west on Charlie turns right onto 4L instead of Kilo. No RWSL protection. (HO2P)	A / A	Pass
#33: Aircraft on approach to 22R while a vehicle commences an inspection NE on 4L from the approach end. THL not ON. (HOVP)	A / T	Pass
#41: Aircraft A taxiing SW on 22R from November while Aircraft B taxiing NE on 4L from the approach end. THLs should come ON. Aircraft must talk to tower. (HO2P)	A / T	Pass
#45: Two aircraft taxiing NE on 4L from the approach end to November. If THLs were to illuminate for second aircraft ... this would appear problematic. The THLs should illuminate. (TC2P)	T / T	Pass
#46: Aircraft cleared to taxi SW on 22R from November while an inspection vehicle is SW bound on 22R at Charlie. THL illuminated on 22R for taxiing aircraft problematic. (TCVP)	T / T	Pass
#50: Aircraft has landed on 22R and is now in taxi state. Vehicle at Sierra wants to cross 22R in front of landing aircraft. RELs should not interfere with a crossing clearance. (CRVP)	T / T	Pass

As noted in Table 4-3, two failure conditions were discovered during this testing. The first failure was detected during scenario #1 (see Figure 4-8). In this scenario, aircraft A is in position for a takeoff on runway 4L while aircraft B moves into position on runway 22R and then takes off. Prior to aircraft B's takeoff, the THLs facing aircraft A are illuminated and the THLs facing aircraft B are illuminated. In this scenario, aircraft B has begun its takeoff, even though the runway status lights would have indicated that the runway ahead was occupied. Although aircraft B has begun its departure by mistake, it is expected that the THLs facing aircraft A would continue to be illuminated during aircraft B's takeoff. Analysis of the data logged during this test showed that the THLs facing aircraft A are instead off for a large portion of the takeoff roll. Further analysis showed that this unexpected behavior was caused by one of the THL-anticipated separation algorithms. In this algorithm, aircraft B's speed and distance from aircraft A was used to estimate when aircraft B would be airborne. The algorithm assumed that aircraft A and aircraft B were facing the same direction (i.e., that aircraft A had moved into position to takeoff behind aircraft B). In this scenario, that assumption was invalid and because aircraft B was far away from aircraft A, the THLs facing A were turned off. After discovering this problem, the algorithm was updated to take aircraft direction into account when applying the anticipated separation test.

Scenario: Aircraft B takes off while aircraft A is in position for takeoff at opposite end of runway
Problem: THLs are turned off because aircraft B satisfies speed and distance criteria used to anticipate when airplane becomes airborne. Algorithm enhanced to also look at direction.

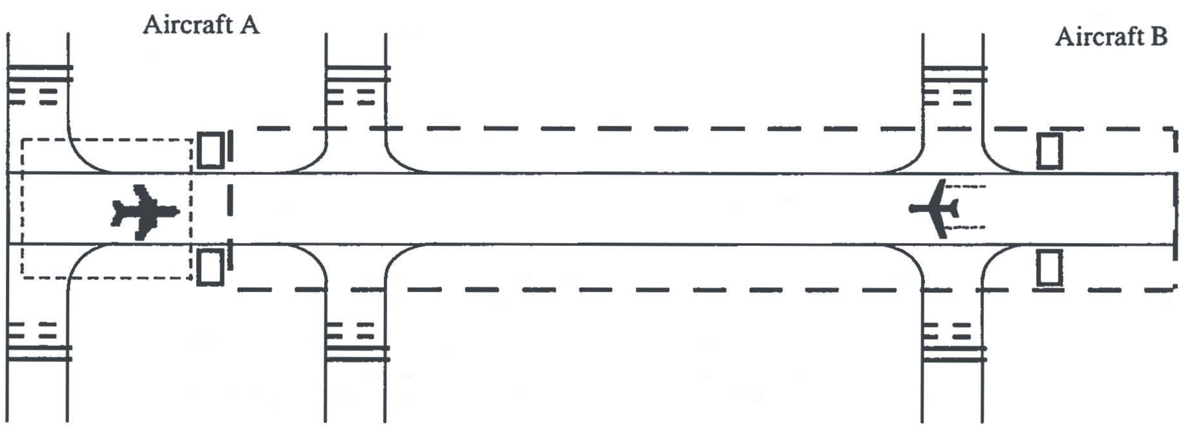
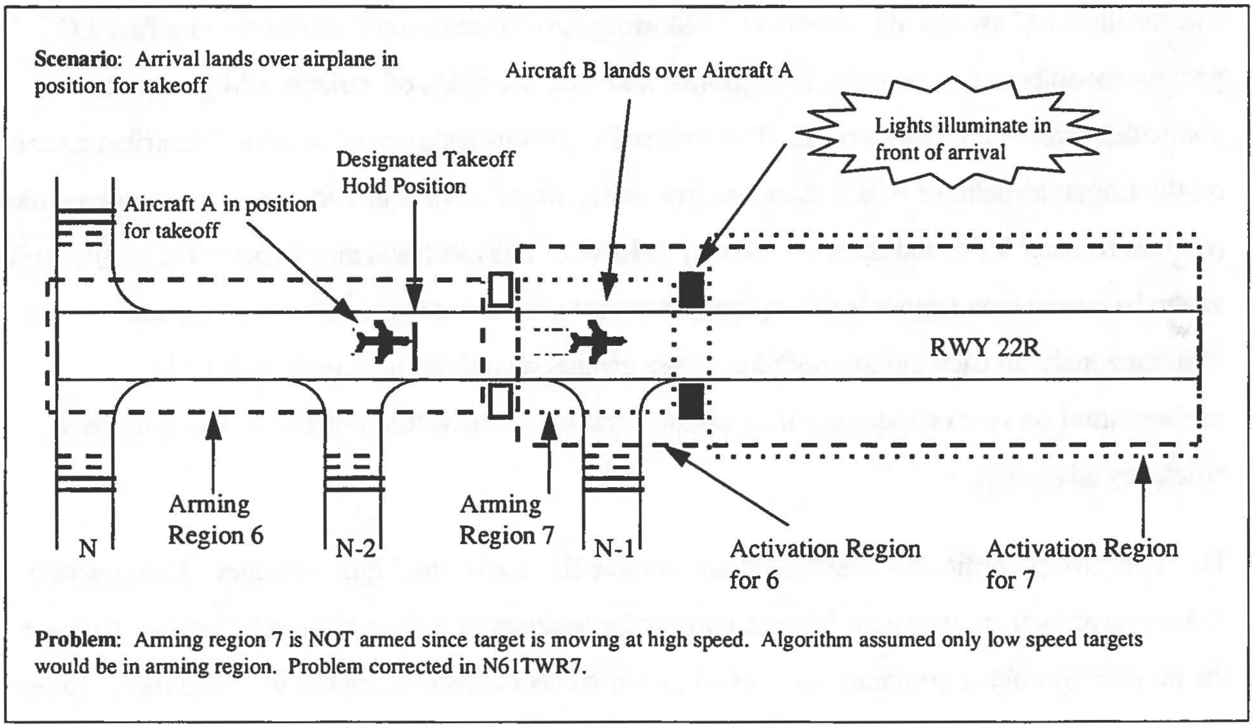


FIGURE 4-8. FAILURE CONDITION #1

The second failure was noted during testing of scenario #13. In this scenario, aircraft A is in position for takeoff and arriving aircraft B lands over the top of aircraft A. When aircraft B touches down on the runway, the THLs facing aircraft A are expected to illuminate. In the test implementation of this scenario, aircraft B touched down after the first set of THLs and before the second set of THLs (see Figure 4-9). The first set of THLs did not illuminate while aircraft B was in the arming region associated with the second set of THLs and the second set of THLs did illuminate. An analysis of this problem revealed that the algorithm for controlling both sets of lights independently was not functioning correctly when a high speed target was in the second arming region. The algorithm was checking to see if the second arming region was armed and determining that it wasn't because aircraft B was moving at high speed and only slow speed targets can cause the region to arm. This problem was corrected by modifying the algorithm to take this scenario into account.



Scenario: Arrival lands over airplane in position for takeoff

Problem: Arming region 7 is NOT armed since target is moving at high speed. Algorithm assumed only low speed targets would be in arming region. Problem corrected in N61TWR7.

FIGURE 4-9. FAILURE CONDITION #2

4.4.4 Light Group Verification Testing

The Light Manager light control commands are not communicated directly to the Light Computer, but instead are communicated to an intermediate computer, the Light Control Computer, which converts the LM-format light commands into a format acceptable to the LC.

This separation of the LM operation from LC operation allowed considerable flexibility in establishing light groups and communication methods used by the LC. To ensure the LC receives commands that match the intent of the LM, the LCC mapping of LM light groups to LC light groups was tested. The method and results of the testing are presented below. In summary, no mapping errors were detected.

There are multiple conceptual representations used to manage the runway status lights. In the Logan assessment system, there are 187 lights. The Light Manager is concerned only with the position of the lights along the runway, not the lights themselves, and so views the lights as 46 LM groups. The LC and smart transformer system directly controlling the lights allow lights to belong to multiple groups so that many lights can be efficiently controlled with a single command from the LC. Nearly 250 LC groups were defined for the lights in the assessment system, of which the LCC is configured to use 148. A light typically belongs to three or four LC groups. The smallest LC groups are identical to LM groups, so by extension, all but the smallest LC groups encompass two or more LM groups, allowing the lights of multiple LM groups to be controlled with one LC command. The largest LC groups encompass an entire electrical circuit on the Logan airfield, of which there are five on the two runways instrumented for the assessment (two on runway 9/27, and three on runway 22R/4L). The electrical circuit was used as the largest group because some vendor's LC equipment would send commands independently and simultaneously on each circuit; defining larger groups would require commands to be retransmitted on two or more separate circuits and would therefore not confer any command efficiency advantage.

The light group verification testing did not involve the use of the Light Manager. Using actual LM commands from the Light Manager would have severely limited the test coverage, because the number of unique combinations of LM group states is severely limited in actual runs. Except in certain highly active situations, lights are typically turned on or off in rather consistent and mundane patterns, exhibiting a ripple pattern in the case of RELs as all lights in front of a landing or departing aircraft illuminate and then are turned off as the aircraft passes, or following a single group on, single group off behavior for THLs as a plane enters a takeoff hold position and the runway becomes safe for departure. When more than one runway is active at a time or planes arrive or depart closely following one another, these patterns may become slightly more interesting, for instance exhibiting a double ripple pattern when the hot-zones of two arrivals are almost but not quite overlapping, but even the exceptions vary only slightly from the norm.

Instead, the test vectors were applied by an automatic vector-generating subroutine added to the scripting capability of the LCC. These subroutines algorithmically created the test vectors and formed a valid LM command message. Normal LM command processing was triggered, so that the processing performed was identical to that which would have been performed had the command message been received from the LM through serial communication.

Validation was performed by an automated log analysis tool. The LCC logs all LM command messages received and LC command messages sent. The LM command log and the LC command log were compared for discrepancies using an Excel Visual Basic tool. The Visual Basic tool was developed independently from the LCC. The LC group information used by the tool was derived independent of the LCC configuration file.

The test of the LCC was applied in two parts. In the first part, each circuit was tested independently from all other circuits. In the second part, all circuits were tested together, but in a far more limited way. The LCC formed commands for the LC in Broadcast Mode, the command mode used at Logan Airport during operational testing (see Appendix A for a complete description of LCC command modes), and test vectors were applied at a rate of one per second.

In testing the circuits, every possible ON/OFF combination of LM groups in the circuit under test was applied. While a circuit was being tested, all lights in other circuits were off. The test validation indicated no errors.

To test all circuits together, pseudo-random test vectors were applied for over four hours. It was found that random test vectors generated a high number of communication errors, due to the limited size of the LC command message. The LC command message allows for up to thirty commands per second, but fewer than twenty percent of the randomly generated LM commands could be translated into thirty or fewer LC commands. To ensure a higher ratio of usable vectors to unusable vectors, the randomly generated vectors were adjusted to eliminate single LM groups that conflicted with both neighboring LM groups. In concrete terms, the algorithm would randomly decide to eliminate all occurrences of either 010 or 101 (but not both). All bytes in the

LM commands were then scanned for occurrences of either 010 or 101 and the middle bit would be changed to match the other two. The random test generated 14,513 test vectors, of which 12,379 produced valid LC commands. The test validation indicated five errors, which occurred at shut-down and are directly caused by the shutdown algorithm. At shutdown, the LCC ignores the LM commands it receives and instead commands all circuits off for six cycles. The last cycle did not have a corresponding LM command, possibly due to the termination of logging, and so only five discrepancies were detected.

4.5 RECOMMENDATIONS FOR FUTURE IMPROVEMENTS

The following changes to the existing RWSL would result in significant performance improvements.

1. ***Modify the REL processing algorithms to include an REL arming region.*** The revised concept of operation for the RELs would include the addition of an REL arming region, similar to the concept of an arming region for controlling the operation of the THLs. The REL arming region would be used to only illuminate RELs when an aircraft is in the taxiway and the RELs are visible to a pilot. An analysis of this algorithm enhancement has shown that REL illumination events are reduced by 90%, significantly reducing the number of light command messages that need to be sent to the lighting system on the airfield.

2. ***Connect the ASR-9 directly to the AIU.*** The AMASS ARTS Interface Unit currently receives radar data from the ARTS host connection (i.e., the MDBM interface). There are two drawbacks with this approach: (1) there is a delay in receiving the target data since it is first processed by the ARTS host computer and, (2) the ARTS host computer drops tracks prior to reaching the runway threshold, degrading the performance of the ARTS to ASDE-3 hand-offs. To compensate for these deficiencies, the AMASS AIU must estimate target arrival at the runway threshold. A poor estimate by the AIU often results in missed hand-offs (i.e, an ARTS track is not associated with an ASDE-3 track) which in turn results in incorrect operation of the runway status lights. To eliminate this performance problem, the ASR-9 radar data can be directly connected to the AIU via the SCIP interface, providing a direct feed of radar target data to AMASS. Appropriate algorithm modifications to the AIU software would be required to take advantage of this higher fidelity surveillance input.

3. ***Tune ASDE-3 radar to reduce runway edge clutter.*** The ASDE-3 radar at Logan Airport is currently tuned to show runway edges. This has been done to improve the controller's display of the airport surface area map (i.e., runway edges are well defined on the AMASS map display). This causes more radar clutter and increases the likelihood that a clutter return will be classified as a target return during AMASS surveillance processing. False targets appearing on a runway edge cause incorrect operation of the runway status lights.

4. ***Tune AMASS tracker so rapidly accelerating targets are not dropped.*** Small business jets can accelerate so quickly that the alpha-beta tracking algorithm used in AMASS does not adjust quickly enough. The alpha-beta tracking algorithm should be modified to take into account the growing error in the predicted versus actual position.

5. LIGHT SUBSYSTEM

5.1 INTRODUCTION

The Light Subsystem embodies the Light Control Computer, the communications link with the Lighting Vault, and the Smart Transformer Subsystem. Light Commands are received by the Light Subsystem from the Light Logic implemented in the AMASS computer located on the 19th floor of the Logan Tower. These commands are processed and the resulting output of the Light Subsystem is the illumination of lights contained in elevated and in-pavement light fixtures on the airfield. Sections 5.2 through 5.4 presents the equipment used to implement the Light Subsystem and the associated interaction of these system elements.

Because the SX Subsystem represents a major development effort associated with the RWSL System deployment at Logan, it is instructive to review (Section 5.5) its chronological evolution to the final configuration used for hooded and dry run testing. This discussion needs to be prefaced with a note that the SX Subsystem is comprised of off-the-shelf equipment, with the exception of the software used in the Light Computer. None of the vendors identified herein specifically developed their SX equipment to support the RWSL Program requirements. The equipment was originally developed by the vendors to support remote control and monitoring of runway lighting, not necessarily the highly dynamic requirements of the RWSL System. Therefore, adapting the available equipment for RWSL has been a learning experience for both the development team and the equipment vendors. The vendors identified herein worked closely with the RWSL development team to develop a mutual understanding of the real requirements. This process has resulted in a significant understanding of the SX technology and associated limitations, along with a significant demonstration of system capabilities in the operational environment. Any inability of the identified vendor's available equipment to meet the desired RWSL performance should not necessarily be viewed in a negative light.

5.2 LIGHT CONTROL COMPUTER

The LCC is the maintenance and control station for the Logan implementation of RWSL. Light commands produced by the Light Logic implemented in the AMASS computer are received by the LCC on the 16th floor of Logan Tower over a hard-wired, short-haul modem link operating at 9600 bits/sec. These light commands are processed into light group commands by the LCC and transmitted to the SX Subsystem. System status information is returned by the SX Subsystem to the LCC for display and logging.

5.2.1 Hardware and Software

A 90 MHz Pentium computer with a large-screen 19-inch monitor provides the LCC hardware platform. FactoryLink (COTS software from U. S. Data Corporation) running under Microsoft Windows NT is used to implement the LCC application. FactoryLink was selected prior to system testing in the Volpe Warehouse, consistent with the Program directive to employ COTS hardware and software for RWSL. A warehouse version of the LCC was developed and employed in support of warehouse testing. This initial version provided an evolutionary development path for the Logan system by exploiting the reuse of a significant portion of the warehouse software.

FactoryLink is a high-level application environment that is intended for factory automation and process control; as such, it embodies the required functionality for the LCC application: real-time data interfaces, data processing, interactive display, and data logging. Although satisfactory LCC performance was eventually achieved with the product, the associated development effort exceeded original expectations. FactoryLink has considerably more features and functionality than is needed by the LCC and is evidently intended for applications with slower response and data handling requirements than is required by RWSL. Considerable effort was required to enable the required data handling within the basic one-second command cycle, including the use of special "C" code to implement selected time-critical data handling/processing. The final configuration achieves a processing duty cycle that ranges between 50% and 75% of the one-second command cycle.

5.2.2 Operating Modes

Two fundamental modes of LCC operation are available: Light Manager (operational) and Manual (test) commands. In the Light Manager mode, light commands received from AMASS each second are converted into light group commands, packed into the Command Table (Appendix F) and transmitted to the Light Computer located in the Lighting Vault and is part of the SX Subsystem (Appendix G). In the Manual mode of LCC operation, light groups are commanded through manual selection of the desired group from the screen with a click of the mouse, or a script may be run to sequence specific groups on and off for the specified time intervals identified in the script. Brightness level of the lights is also controlled with the script by controlling the current level (one of five steps) of the Constant Current Regulators in the Lighting Vault. The ability to run scripts is a valuable capability used extensively to support system test and evaluation (Section 7.4). Test coverage is easily controlled with the script and the LCC functionality is the same as in the Light Manager mode of operation. Light groups are predefined groupings of lights (and associated SXs) that respond as a logical unit to on/off commands issued to the group number. The advantages and use of light groups, along with the specific groups used at Logan, are addressed in Appendix G and summarized in the following paragraphs.

5.2.3 Group Commands

Each SX is a member of up to 20 distinct light groups; these predefined group numbers are stored in the flash EPROM of each SX on the airfield. The LCC commands an SX *on* or *off* by issuing a command to one of the group numbers contained in the desired SX. An original design goal of the Light Subsystem was to support both group commands and individual light commands. Although the ADB SX Subsystem employed at Logan for operational testing supports both types of commands, the Safegate SX Subsystem tested in the warehouse and initially deployed at Logan does not support individual light commands. Further, both SX Subsystems have insufficient communications bandwidth to support sending individual commands to all 170 lights every second. Groups commands are much more efficient since a single group command can control all of the lights on the airport.

A light on the field may be turned *on* with a one group number and then turned *off* with the same or a different group. Determination of the on-groups and the off-groups to be commanded each second is part of the LCC processing. Light commands from the AMASS are examined by the LCC to determine the desired state of all 170 lights on the airport. A group determination algorithm is used to optimally select available groups that will achieve the desired on/off light states using the fewest number of group commands each second. Minimizing the number of groups that must be commanded each second minimizes the communications requirements. Groups are defined on a per-circuit basis for each of the five lighting circuits serviced by the Logan SX Subsystem. Therefore, if all lights on the airport are *off* and are to be commanded *on*, one group command is issued by the LCC for each circuit, for a total of five commands. Generally there is a required mix of *on* and *off* light states, thereby requiring two or more group commands per circuit. The LCC group determination algorithm, in combination with the design of the Logan light groups, is designed to control all of the lights each second with (nominally) four groups per circuit. Note that the maximum number of groups that must be commanded on each circuit could be reduced to a minimum of two by defining a "sufficient number" of groups to encompass all of the required combinations and permutations of operational on/off states. This would minimize the communications requirements but may exceed the allowable number of groups that can be handled by each SX.

5.2.4 Command Mode

Every light on the airport is commanded by the LCC each second, not just the lights that are required to change state. This means that each light is commanded *on*, even if it is already *on*, until it is to turn *off*; then it is commanded *off* each second until it is to turn *on*. The SX simply ignores the command if it has achieved the desired state. This command approach is called the command *broadcast* mode and is used because it is self-correcting if a light command is not received or is executed incorrectly by an SX. This means that if a command is not executed correctly, the light will only be in the incorrect state for one command cycle (one second) before the command is reissued. The probability that two commands in a row will be missed due to communications errors (noise) is very small, unless there is a system failure. This serves to ensure system integrity — the system must not present false information to the pilots.

Other command schemes were considered, tested and rejected during system development. The *incremental command* mode, where commands are only sent to the lights when the Light Logic identifies a need to change state, minimizes the system bandwidth requirement but requires the highest command reliability to ensure system integrity. Some form of light-state monitoring is required each command cycle to determine if the desired light state is actually achieved. This monitoring must be fast enough to permit detection and retransmission of the command, or appropriate modification of the command to be sent the next command cycle. The bandwidth of the SX Subsystem used at Logan is insufficient to enable rapid monitoring in support of command retransmission (Section 7.4). Tests of the system using the LCC incremental command mode, without monitoring and retransmission, confirmed that missed incremental commands resulted in incorrect light states which could persist for extended time periods, thereby reducing system integrity to an unacceptable level. The associated reduction of the group command rate with the incremental approach does not justify the associated reduction in system integrity. A hybrid approach where the incremental command is transmitted several times in an attempt to insure its reception was also implemented in the LCC. Although performance reliability is better than the incremental mode, tests show that system integrity is still compromised with this approach.

The commanded state of each light is displayed in a graphical display window of the airport. Light fixture icons, located at their relative geographical positions on a graphical depiction of the runways, are colored red when the light is commanded on. This enables visual monitoring and direct comparison of the desired light states with a similar AMASS display located next to the LCC on the 16th floor of the tower. Lists of all the available light groups are also provided in windows and are displayed in red if a group is commanded *on*, or in black if commanded *off*.

5.2.5 Status Monitoring

Because the time required to collect the actual status of all 170 lights by the SX Subsystem and transfer this status to the LCC is on the order of 10 seconds, indicated status is not current enough to be used to modify subsequent LCC commands. Rather, the status information is used to indicate the health of the SXs, thereby enabling the detection of failures or anomalous performance. It was originally hoped that the time to collect a round of status information (status cycle) would be on the order of one or two seconds, or less, to provide timely indications in support of both testing and operations. As is indicated in Section 7.5 and Appendix G, this rapid status cycle is not supported by the SX Subsystem.

The status of each individual light is displayed in status windows (for the RELs and THLs) on the LCC screen. Each second, the LCC status display is updated based on information gathered by the SX Subsystem during the previous one-second interval. If the status report indicates that the light is *on*, the fixture identifier on the LCC screen is displayed in bright red; if the indicated state of the light is *off*, the displayed color is black. If the status of a fixture is not updated by the SX Subsystem in a given status transmission, a previously indicated *on* status for the fixture is displayed as light red; a previous *off* status is designated in gray. Changing color patterns on the LCC display provide an effective real-time indication of system health. Indicators are also provided for each fixture to identify a failed lamp and to identify if communications between the Lighting Vault and the SX associated with the fixture has failed. A failed lamp of SX is detected and displayed to the operator within 10 seconds of the event. A separate Alert and Warning window is also provided for the system operator on the LCC display to display all system errors associated with detected failures and detected communications errors. All commands, status and alert/warnings are time-tagged and logged in data files on the LCC hard disk for post-test analysis. The recording format is compatible Microsoft Excel for display and processing.

5.2.6 Light Masking

If there is an occasion during unhooded operations that particular lights are operating erratically or causing other problems such as interference with other airport operations or impeding traffic flow, the lights may be manually disabled or masked through the LCC. Lights are masked in the LCC on the group level. The most fundamental group level is associated with the SX pairs located at the hold lines. The group to be masked is selected from the masking screen using the mouse and the display indicates that masking is activated. Lights in the masked groups are then commanded *off* as long as masking is activated. This approach to disabling specific lights is intended to be temporary and is used during operations when rapid response to a problem during unhooded operations is required.

Long-term or permanent masking of individual lights is accomplished using remote access to the Light Computer in the Lighting Vault over a standard telephone modem link. A software package called ReachOut is installed in the LC in the Lighting Vault and in the Shadow Controller Computer on the 16th floor. The SX configuration file in the LC is accessible via ReachOut and the offending individual lights can be disabled by removing them from the configuration file (Appendix G). In addition to file editing, ReachOut also enabled full remote control of the LC. A third copy of ReachOut is installed at the ADB factory in Columbus, Ohio and is used by the ADB SX Subsystem engineers to configure the system parameters and diagnose performance anomalies. Strict access security procedures (including passwords, remote call-back and written procedures for all authorized personnel) are implemented in the LC to prevent unauthorized access to the system. This remote access capability has proven to be extremely valuable and effective by enabling rapid access to the system by the system operators and the development experts without having to go to the Lighting Vault (a rather inaccessible and undesirable working environment).

5.3 COMMUNICATIONS LINK

Reliable communications between the LCC located on the 16th floor of the tower at Logan and the LC located in the Lighting Vault about a half-mile away is ensured with a fiber optic link. A fiber-pair operating at a data rate of 19.2k bits per second is used for asynchronous, byte-level transfer of command and status tables (Appendix F) between the two sites. Error checking (table checksum) is provided at both ends of the link to identify bit errors if they occur. Fiber is essentially immune to interference or induced noise and high data reliability is achieved since the link bandwidth is considerably wider than the implemented data rate. Any errors that occur are most likely due to communications handling within the computers rather than due to the physical link.

A spare fiber contained in the fiber bundle running to the vault is used to implement an LC boot capability. (This use of a fiber optic link is one of convenience because it is available rather than out of need for the available bandwidth.) A simple momentary push switch is implemented on the 16th floor to activate a fiber transmitter and a receiver on the LC end of the link closes a relay that boots the LC in the same manner as the reset switch. The need for this remote boot capability is prompted by the fact that the LC software is not considered to be of operational quality that supports reliable unattended operation. There are infrequent abnormal conditions that may cause the LC to lose communications with the LCC, thereby requiring the communications and control application in the LC to be restarted. In order to meet certain cost and schedule constraints of the RWSL Program, the LC software is developed to support the needs of a test system. All of the necessary watchdog timers and other software bullet-proofing techniques normally embodied in fully-operational software are not implemented since the test system is intended to be operated with experience test personnel. Manual rebooting of the LC to clear infrequent LC software-related problems (mainly during start-up or associated with system testing) is acceptable for the Logan test environment, but not for a fully operational RWSL. Watchdog timers are implemented in the LC to ensure the shutdown of SXs in the event that communications between the LC and LCC are lost for more than 10 seconds.

5.4 SX SUBSYSTEM

The heart of the Light Subsystem is the SX Subsystem and represents the major part of the installed base of Logan equipment. A functional block diagram of the SX Subsystem is presented in Figure G-1 and the reader is referred to Appendix G for a detailed description of the SX Subsystem and its operation. All of the equipment in the Lighting Vault and on the field is considered to be part of the SX Subsystem: Light Computer, a Master Brite (series circuit modem) for each of the five circuits, a 15 kw Constant Current Regulator for each circuit, series circuit cables, isolation transformers, smart transformers and light fixtures. With the exception of the LCC, Master Brites, and the SXs, all other items are standard FAA-approved lighting equipment. The SX is designed to be used with available lighting circuits and may be retrofitted to existing circuits and fixtures. In the case of RWSL, new dedicated cables were installed so as not to interfere with the normal operation of the lighting circuits at Logan and to help ensure the best possible system performance. This is desired since the SXs are being used in a dynamic environment which is considerably more demanding than the nominal application for which they were designed: turn airfield lights on at dusk and off at dawn, while providing remote monitoring of the integrity of the lamp in the light fixture.

Light group commands received by the LC from the LCC are parsed and directed to one of the five ADB-ALNACO, Inc. Master Brites. Each Master Brite is connected to the series cable for the circuit and impresses an FSK-modulated communications signal with a 125 kHz carrier frequency onto the power cable. Two-way communication between the Master Brite and the SXs on the circuit is accomplished at a fundamental data rate of 9600 bits/second over the same underground power cables used to supply the 60Hz AC power to the lights. This eliminates the need to run separate cables to control the SXs. On the other hand, it is important to recognize that digital communications performance (i.e., bit error rate) is subject to the fundamental performance constraints and requirements of radio frequency communications: namely, signal-to-noise ratio (SNR) and bandwidth.

The SX communications environment is rather harsh with circuit noise and interference induced by the circuit CCR and by cross-talk or coupling from adjacent close-proximity cables in the raceways and conduits on the field. Many CCRs maintain a constant circuit current by controlling the conduction angle of the 60 Hz sinusoidal waveform with silicon-controlled rectifiers. This switching action introduces high-frequency noise that reduces the communications SNR. Cross-coupling between the five RWSL circuits limits the ability to simultaneously communicate on all five circuits. Signals from one circuit that are coupled into an adjacent cable for another circuit appear as interference to the desired signal. Further, the radio-frequency control signal experiences significant attenuation in the underground environment of the cables — many of the cables are actually submerged in water. All of these combine to limit the communications capability and reliability of the SX Subsystem.

Selected SXs are configured to operate as repeaters (in addition to controlling a light fixture) to extend the range of communications to the end of the circuit. A repeater receives the signal, amplifies it and then retransmits a stronger signal. Although this repeater action boosts the signal to improve the SNR, the associated penalty is the time it takes to accomplish this repeating action, which affects both the commands and the status reports. Communication delays become significant if a daisy-chain of multiple repeaters is required to reach the distant end of the circuit, as is the case at Logan. Appendix G contains a detailed discussion of repeaters and identifies the specific repeaters used at Logan.

All SXs "listen" for control signals from the Light Lighting Vault. When a group command is received, the SX turns its light *on* or *off* in response to the command if it is a member of the commanded group. The groups for each SX are stored in its flash EPROM and are loaded into the SX from the configuration file in the LC using a special configuration command available in the LC. This allows the SX groups to be modified without requiring the SX to be removed from the field. Also, replacement SXs do not need to be configured before installation other than programming its unique address — the address of an installed SX can be changed from the LC as long as the address is unique. In addition to group commands, each SX also listens for its unique address that is associated with a polling request. During the one-second command interval when the LC is not issuing group commands, it polls each SX, one at a time in a round-robin fashion, for status. Upon receiving a status request, the SX responds with the status of its lamp filament, even if the lamp should happen to be *off* at the time. If the SX does not respond to a LC polling request three times in a row, a communications fault is declared.

Each SX is installed on the secondary side of an isolation transformer, both of which are physically located in the base can of a light fixture. The primary of the isolation transformer is electrically connected to the series circuit cable. Therefore, the power cable goes from the CCR in the vault, through the isolation transformer primary for each fixture on the circuit and back to the CCR, like the old-fashioned series Christmas tree lights. However, if one of the field lights on the series circuit burns out, the rest of the fixtures continue to receive power due to the connectivity provided by the primary winding of the transformer, unlike the Christmas tree lights. The SX electronics "steal" a small amount of the power intended for the lamp and turn the lamp off by essentially placing a short circuit across the filament. Therefore, when the lamp is *on*, the constant current from the CCR flows through the filament, whereas when the light is *off* the constant current flows through the short circuit. Although the current is held constant by the CCR, the voltage measured at the CCR output depends on the total circuit load. Since each fixture at Logan has two 125 watt lamps wired in series, RMS voltage levels of each circuit at the CCR swing as high as 1-2 kv with all lights on a circuit illuminated.

Five light brightness levels are available. The desired brightness level is selected from the LCC and implemented by current step control commands sent from the LC to the CCRs. All five circuits are always set to the same brightness level. There is no positive monitoring of the achieved current levels sent back to the LCC, a feature that should be added to an operational system.

5.5 SX SUBSYSTEM EVOLUTION

It is instructive to review the SX Subsystem development leading to the system installation and testing at Logan. Development of a meaningful specification for procuring the SX Subsystem and the design of a RWSL System incorporating the SX Subsystem presented numerous challenges to the development team:

> *First*, application of the SX technology in the highly dynamic RWSL environment has never been done. Vendors had developed their SX Systems for the rather infrequent on/off control of airfield lights. The most dynamic application prior to RWSL was stop bar control, which is probably an order-of-magnitude less demanding than the RWSL System.
>
> *Second*, because SXs represent an emerging technology, there is no body of knowledge or quantitative field test data available to the development team. As with all communications systems, actual SX Subsystem performance depends on the specific filtering and processing techniques employed by the vendor, along with the fundamental engineering compromises made in developing the system. These design details tend to be proprietary or generally not available in a competitive procurement of COTS equipment. Because one of the RWSL System development ground rules is to use COTS equipment, the performance specification had to be developed at a system level.
>
> *Third*, the actual noise and interference environment at Logan International Airport was unknown and untested since the circuits didn't exist.
>
> *Fourth*, because of schedule pressure to install SXs before the '95-'96 winter set in at Logan, it was necessary to procure the SX Subsystem in parallel with the development of

the Light Logic that is used to drive the SX Subsystem. Therefore, available knowledge was incomplete with respect to specific expected command rates and allowable error rates. Schedule was driven by the fact that the airport installation has to be approved and coordinated with Massport which had another project that involved shutting down the runways for other lighting work.

Fifth, the focus of the project is on assessment of the RWSL concept in an operational environment, not the development of an operational system; engineering and experimental flexibility had to be retained in the specification and development of an assessment system.

Development of the SX Subsystem Specification was completed in the March, 1995 time frame with the goal of having an assessment system for installation at Logan in September, 1995 — an aggressive schedule for any system development effort. It became evident during the development of the specification that fundamental SX performance issues needed to be resolved to enable the team to develop the entire system. SX vendors were unable (or unwilling) to provide the required information due to the specialized nature of the RWSL application and proprietary elements of their system.

In order to acquire a fundamental understanding of the SX technology so as to reduce the risk associated with system design and development, the RWSL warehouse test facility was developed at the Volpe Center. Fifty SXs were purchased from Safegate Airport Systems, Inc. along with an available computer system to drive the SXs; 50 light fixtures were purchased from Crouse-Hinds Airport Lighting, Inc. Instrumentation was developed and installed in the warehouse to measure the actual response time and integrity of the SX Subsystem. It was known that these warehouse SXs were not suitable for operational use at Logan because they employ (for another application) an undesired logical "OR" of the group on-commands, but they were readily available to provide an initial basis for discovery and technology understanding. Safegate indicated that the OR-logic could be easily modified in future production runs to support the Logan needs. Warehouse testing commenced in late April, 1995 and continued through the summer in preparation for the Logan installation in the Fall.

To meet the aggressive RWSL development schedule, the SX Subsystem competitive procurement process was initiated in March as part of a Massport Contract awarded to Mass Bay

Electrical of East Boston for airport lighting system work. Three bids were received for the SX Subsystem. Vendor selection was based on qualifications and price since the system technical details were to be provided in shop drawings by the winning bidder. Mass Bay Electrical selected Safegate to supply the SX Subsystem for Logan. Although the Crouse-Hinds bid was lower, they did not meet specific installed-base qualifications; ADB-ALNACO, Inc. qualified but their cost was considered excessive for their proposed Brite I system. The original desire of the development team was to select two vendors and perform a technical run-off in the warehouse. Contract limitations and schedule demands did not support this desire.

Because technology assessment is a significant element of the Program, Volpe Center made the warehouse test environment available to the three vendors. Twenty-five SXs were purchased from Crouse-Hinds for evaluation in the warehouse. (This evaluation was never performed because, due to schedule conflicts, Crouse-Hinds personnel were unable to support the warehouse testing.) In mid-summer, ADB tested and demonstrated their pre-production Brite II SXs in the warehouse; Safegate also demonstrated their improved version of the SXs procured by Mass Bay Electrical under the Massport contract for Logan.

In mid-June, the third submission of the Safegate shop drawings was rejected because the proposed SX Subsystem for Logan did not meet the TS-20 specification. This was supported by the Warehouse test results that show a maximum command rate capability of only three commands/sec/circuit, and each SX can be a member of only four groups. As indicated in Appendix G, this combination is not sufficient to support the command broadcast every 0.5 sec, as specified in TS-20. It was becoming clear from the warehouse test results that planned software changes by Safegate were not going to overcome the inherent command rate limitation of the system. The Safegate system should not be viewed in a negative light since the system was not originally designed to support the highly dynamic RWSL environment. One of the RWSL Program goals is to utilize off-the-shelf equipment and learn the real requirements based on testing. In order to have some capability to demonstrate the system at Logan in the September time frame, the decision was made by the Volpe Center to drop back to the less reliable incremental command approach (since the Safegate units could not support the command broadcast mode requirements) and install the Safegate SXs to gain experience in the operational environment with the Logan circuits. Warehouse testing provides only limited insight into environment-specific error mechanisms and the potential to gain important insights into the technology in the Logan environment supported the RWSL Program's primary objective.

Although the incremental command mode (rather than the specified broadcast mode) used to implement the Safegate system at Logan reduces the number of groups that need to be transmitted each second, there was no assurance with the Safegate command rate limit of three groups/sec/circuit that there would be sufficient time within the one sec. command interval for the acquisition of timely status information. Reliable status and timely correction of erroneous light states are "musts" with the incremental command approach to ensure acceptable operational integrity of the lights. Without status-based error corrections, the required incremental command reliability needs to be 100%. This level of performance was not demonstrated in the warehouse tests and it is unreasonable to expect any communications system to achieve "perfect" performance in the real-world.

In early July, 1995 after the fourth submission of the Safegate shop drawings was rejected because the system did not meet the specification, it became apparent that the viability of the RWSL SX Subsystem was in jeopardy. The Safegate software improvements did not materialize in the warehouse and the RWSL development team did not have confidence that Safegate system response and integrity would be sufficient to eventually support unhooded operations at Logan.

In-mid July, Safegate demonstrated an improved version of the Logan SXs in the warehouse. The improved Safegate SXs support trickle current and increase the number of groups/SX from four to eight. Excessively slow luminance response of the lamps had been previously identified in the warehouse as a major problem (not the fault of the SX). Without trickle current, it takes three sec. at CCR Level 3 for the lamp filament to reach 50% luminance. Trickle current reduces this time delay to 1.5 sec., which is considered sufficient to enable unhooded testing. Tests of the improved Safegate SXs again demonstrated a maximum command rate capability of three commands/sec/circuit, which cannot support the specified command broadcast approach. The availability of additional groups has the desired potential to free-up time during the command cycle for status monitoring, but not enough time to guarantee RWSL integrity with the incremental command approach.

In the July 1995 time frame, ADB demonstrated their Brite II pre-production SXs which operate on the secondary side of the isolation transformer rather than the primary side of the Brite I system; the basic system communications and operation of the Brite II are essentially the same as the Brite I system. The Brite II price tag is also considerably lower than the Brite I Subsystem. Warehouse tests by the development team yielded a measured command rate of over 40 groups/sec/circuit with 10 groups in each SX, which ADB proposed increasing to 20 groups/SX for Logan. The tests also demonstrated stable reliable system status reporting and the SXs have the capability to provide a trickle current through the lamps to reduce the illumination response time due to lamp thermal characteristics.

Given the apparent inability of the Safegate system to meet the requirements for unhooded operation at Logan, the decision was made to procure the ADB SX System for installation at Logan since it appeared to meet all elements of the specification, with a healthy safety margin. In addition to meeting the TS-20 specification, the development team had a high overall confidence that the RWSL System operational assessment goals could be achieved with the ADB SX Subsystem. This confidence was based on extensive experience gained through warehouse tests and tests performed at Logan with both (ADB and Safegate) systems. The ADB system also supports the specified capability to issue single SX commands in addition to the group commands. Single light commands are desired to facilitate the masking of individual lights in the operational environment, although cost and schedule constraints precluded implementation of single-light commands in the LCC. Safegate SXs need to use one of the groups in each SX to support single light commands; this reduces the number of Safegate operational groups to three in the Logan units and to seven in the improved SXs.

The first submission of the ADB shop drawings was at the end of August and the second submission was approved at the end of October. Because delivery of the ADB SX Subsystem was projected for the end of November, there was a concern that the weather may prevent installation of the SXs at Logan before the winter shutdown period. A change order was prepared to purchase available improved Safegate SXs for installation in the fall; fifty of the improved Safegate units SXs were installed at Logan on Circuits 1, 2, and 3 for interim testing until the ADB units could be installed. This provided insurance for hooded testing through the winter months in the event that it was not possible to install the ADB SX Subsystem due to extreme winter conditions.

The ADB system was installed on Circuits 4 and 5 in December, 1995 before the winter shutdown. Initial testing of the ADB system occurred during the winter and Safegate continued to work on improving their software. It is interesting to note that simultaneous operation of both systems on different circuits did not present any identifiable cross-interference problems. In the spring of 1996, Safegate completed their software upgrades but it was still clear that the Safegate system could not support the command broadcast mode of operation. Also, status information was not reliable enough to ensure the necessary performance integrity (with the incremental command mode) for unhooded operation with the Safegate system. The Safegate system was removed and the ADB system was fully installed on all five circuits.

During the winter, the infant mortality of the ADB equipment was much higher than expected (see Section 7.4). The mechanical packaging of this first-generation SX equipment proved no match for the extremely harsh environment in the fixture base cans at Logan. Since many of the cans are filled with water due to the low water table at Logan, the water froze and crushed some of the SXs. Others leaked water, which was exacerbated by the ice. When the SX is turned off for an extended period under freezing conditions and then turned back on, the ice next to the package melts due to the heat loss from the electronics. If the SX is then turned off, the freezing action of the ice tends to force some of the water through the seal into the package. As a result of this experience, ADB provided an improved package for the replacement of failed units. A diode in the power supply was out of specification and accounted for several failed units and was replaced in subsequent production runs. ADB considers the SXs to be repairable items and as such are not potted. The Safegate SXs are completely potted and did not experience any leakage or ice problems.

The major surprise associated with the ADB Subsystem was the need to configure the system with a rather large number of repeaters. Although the repeater action permits communication with distant SXs which could not communicate directly with the Lighting Vault, the associated penalty is an excessively long status collection cycle. It takes about 10 seconds to poll for the status of all 170 fixtures. Although this is acceptable for system health monitoring, faster status response would be desirable. Given that the ADB system supports the command broadcast mode of operation, system integrity is not compromised by this rather slow status cycle, unlike the Safegate system which could not support the command broadcast.

The ADB Subsystem was used for all of the hooded and dry run testing reported herein. End-to-end testing indicates that the desired command reliability at Logan is nearly achieved (Section 7.4) by the ADB Subsystem. The primary reason for the performance shortfall appears due to an unresolved software timing issue in the LC and a need for additional circuit configuration (tuning). In any event, communications at Logan between the Lighting Vault and the SXs appears to be much more difficult than previously expected. The bottom line is that the technology is close to achieving the performance required for an operational system. It is believed that the demonstrated performance is close to what is needed and additional improvements can be made to the software and hardware by the vendor that will yield an acceptable operational system.

5.6 LESSONS LEARNED

Development of the Light Subsystem in combination with extensive testing yielded the desired understanding and quantitative insights into the applicability of the smart transformer technology to RWSL. Although warehouse testing provided significant contributions to understanding the as-built operation of off-the-shelf systems within the context of RWSL, testing at Logan provided major contributions to ascertaining the actual performance in the operational environment of a major airport. The Logan testing provides an important reality check on the somewhat optimistic system performance experienced in the warehouse environment. This is an expected result since the free-air cable environment in the warehouse is considerably more benign than the underground raceways and conduits, some of which are filled with water, at the airport. The true impact of the Logan airfield environment on system performance could not have been ascertained only from the warehouse testing. Although some operating problems were experienced with the SX Subsystems tested at Logan, it is expected that these problems are correctable in future system deployments. Viability of the SX technology in the implementation of RWSL is clearly demonstrated by the Logan installation. Additional testing and experimentation is recommended, however, to ensure the desired system-level performance improvements in future installations.

Both the Safegate and ADB SX Subsystems tested in the warehouse and at Logan employ carrier current technology to communicate with the SXs over standard series lighting power cables. Each system uses a proprietary communications protocol; performance of the two systems is quite different and the systems are not interoperative. Based on limited testing at Logan, it appears that both systems can operate simultaneously but require dedicated SXs and series circuit communications equipment in the Lighting Vault. Additional testing over the full range of operating conditions is required to verify that there is no mutual interference when operating both systems on the same circuit or on physically adjacent circuits.

Neither the ADB or the Safegate Subsystem is specifically designed to support the rather dynamic requirements of the RWSL. Both systems are designed to command lights on and off, and enable status monitoring of the SXs. However, the response time of these basic functions is quite different for the two systems. Both manufacturers recognize the communications burden associated with commanding lights one at a time and therefore incorporate the capability to command groups of lights. Clearly, if lights on the airfield operate as logical groups, as is the case with RWSL, group commands provide the most efficient use of the available communications bandwidth. The two most important parameters determining the time it takes to command the desired state of all the lights is: 1) the number of groups available to each SX, and 2) the rate at which group commands can be issued on each circuit. Either or both of these parameters need to be large to support satisfactory RWSL operation. The value of "large" depends on the fundamental command period (the time it takes for a full scan of the ASDE-3 radar) and the requirement to also monitor the actual state of the SXs within the command period. The Safegate system's maximum command rate capability of three groups/second/circuit with either four or eight groups (depending on the SX version) proved inadequate for RWSL. The ADB system with its order-of-magnitude higher (relative to Safegate) command rate capability and the availability of 20 groups for each SX proved sufficient to implement RWSL with 4 to 6 commands, or less, issued to each circuit during each one-second command period. These parameters enabled all 170 SXs to be commanded each command cycle while still allowing time to poll for status before the start of the next command cycle.

Smart Transformer monitoring is implemented by polling individual SXs for status in the ADB subsystem whereas the Safegate system returns the status of pre-programmed groups (not necessarily the same as the command groups) of SXs when commands are not being processed. In both systems, commands take precedence over the monitoring function so status can only be collected during the time remaining in the command period following transmission of the commands. Neither system demonstrated the capability to command and monitor all 170 SXs on all five circuits at Logan within the one-second command period used by RWSL. The total time required to refresh the status of all 170 ADB SXs at Logan is about 10 seconds. Communications cross-talk between the cables of adjacent circuits is a significant problem encountered at Logan but not observed in the warehouse. With the ADB system, mutual interference caused by the crosstalk between cables necessitated sequential status polling of the five circuits which increases the total time to acquire the status of all SXs by about a factor of five over that of simultaneous polling.

The excessive time required to acquire SX status precludes using the most current status to alter subsequent commands to correct for missed or erroneous SX command responses, which is the ideal command and control implementation. If an erroneous SX response could be detected and immediately re-commanded, this would minimize the time that the SX is in the incorrect state. However, the command broadcast scheme employed at Logan proved effective in circumventing the requirement for rapid status measurements while still maintaining system integrity. Commanding all of the SXs every second greatly reduces the probability that a light will be in the wrong state for more than a single command cycle. The 99% response reliability goal for the first issuance of a command was easily achieved in the warehouse and nearly realized at Logan with the ADB system. It is believed that a correctable software timing error in the LC may be a major contributor to the observed command response reliability. Additional understanding of the airport cable environmental parameters, and the effect of these parameters on command reliability, needs to be acquired so that the desired command reliability can be assured in other operational installations. Cable installation/routing requirements and procedures are needed that will enable the optimization of system performance in the operational environment. Further, improvements in locating and/or the design of repeaters is an area of investigation which has the potential to improve performance reliability.

Light Subsystem equipment reliability at Logan is considered satisfactory, except for the ADB SXs. Failure of a single SX does not necessarily present an operational problem since at least two independent lights are employed at each critical intersection. However, failure of a repeater renders inoperative all of the SXs serviced by the repeater. An excessive number of SX failures were experienced with the ADB SXs during the test period at Logan. Infant mortality associated with deployment of the first production version of the SX is the major contributor to the relatively poor reliability statistics at Logan. ADB considers the SX to be a repairable item so its mechanical housing can be disassembled; a major failure mechanism encountered at Logan is water leakage through the seal joining the two halves of the SX housing. The improved ADB package appears to have better reliability than the original package but some failures were still encountered. The Safegate SX package is fully potted and hardware reliability problems were not encountered. It is recommended that ADB consider a fully-potted package design that will eliminate water leakage problems and strengthen the package against incurring potential ice damage in the base cans during severe winter conditions.

The LCC proved to be an effective approach to providing system monitoring and control on the 16th floor, given the constraint that the Light Logic is implemented in AMASS on the 19th floor of the tower. It is recommended in future applications, however, that the LCC functionality and the Light Logic with its supporting processing of the radar data be consolidated in a single dedicated platform with a single display. The excess functionality of AMASS that is not needed for RWSL contributed to operational inefficiency and human interface-induced errors at Logan. The remote display for AMASS on the 16th floor suffered both quality and reliability degradation due to the excessive cable length between the computer and display. Dedicated radar data interfaces should be provided for the consolidated platform and all interfaces must be placed under configuration control to ensure data integrity. After considerable effort, the FactoryLink software used to implement the LCC function provided adequate performance for the assessment system. However, FactoryLink is not recommended to implement the consolidated functionality. Although the functionality provided by FactoryLink supports that needed for RWSL, the data handling performance at Logan proved to be marginally acceptable. It is expected that the added burden of radar processing and Light Logic operation in a consolidated application will not yield acceptable performance if implemented as a FactoryLink application.

6. AIRFIELD INSTALLATION

One of the most critical aspects of the project was the actual installation of the various RWSL subsystems at Logan International Airport. Careful planning and design were performed to maximize success of the test. The information learned from previous studies (e.g., warehouse testing) was incorporated into the construction documents to the maximum extent possible.

There were several reasons why testing was proposed to be performed at an actual airport. Most of these included the ability to perform a more realistic testing of the overall system within an actual airport environment. Some specific reasons included: possible weather impacts, input from actual airport users (pilots and ground vehicle operators), the use of real sensors to drive the system, the ability to test both elevated and in-pavement light fixtures, to test the placement and visibility of the elevated or in-pavement fixtures, the testing of "smart" transformers to control the lights, and overall field system tests.

Logan International Airport was selected as the airport to install the system for the following reasons: MITLL had done their initial system concept testing using Logan Airport, the airport had an ASDE radar and AMASS equipment from which the RWSL system would extract the necessary sensor information, a variety of aircraft use the airport, several confusing runway/runway or taxiway/runway intersections at the airport where the installation of the RWSL system would prove to be a valuable test in preventing runway incursions, and most importantly - Massport was willing to allow the system to be installed and tested on their airport.

6.1 CONTRACTING

The Volpe Center contracted the engineering firm of Parsons, Brinckerhoff, Quade & Douglas (PBQ&D) to prepare the construction documents. PBQ&D was helped by Dufresne-Henry, Inc. (DH), another consulting engineering firm during the preparation of the construction plans and specifications. The engineering firm of Edwards and Kelcey (EK), a member of the TASC/Volpe Team, also provided assistance during the design phase.

The team's initial work is documented in a report entitled, "Design Report RSLS Installation at Logan International Airport, Boston, Massachusetts," dated July 1994. In the report, they reviewed the scope of work to be undertaken, provided a general layout of the RWSL light fixtures, the different components of the RWSL system, and provided an estimated construction cost. In addition, they reviewed three possible alternatives on how to contract out the actual installation.

One alternative was for the Volpe Center to issue a separate construction contract for the installation of the RWSL system. Two other alternatives suggested that the installation of the RWSL system should be accomplished under an existing Massport airfield construction project. The difference between the alternatives depended on when the construction documents would be available to be included along with Massport's. Both the proposed Massport airfield projects included major electrical work tasks similar to those required to install the RWSL systems.

All parties agreed it would be better if the installation could be included as part of an existing Massport construction contract. The question was how quickly the construction documents could be prepared so that they could be included in the overall bid documents. A fast-track design was chosen whereby the final documents had to be completed by December 1994 so that the RWSL project could be incorporated with a proposed Massport project. This provided PBQ&D and DH approximately four months to prepare final construction documents.

During the preparation of the final construction documents, the Volpe Center began negotiations with Massport to establish a contract between the two agencies to allow funding the RWSL installation under an existing typical Massport construction contract.

The Massport portion of the project was named Schedule A, and the RWSL installation was designated Schedule B. The Massport project, under which the work was to be accomplished, was Massport Contract Number MPA 1.641F. Since EK was already working directly for Massport preparing the construction documents for the Schedule A work scope, they coordinated with the PBQ&D/DH Team to combine both Schedule A and B work scopes into a single construction package. A detailed construction phasing schedule was prepared for the entire project and contained in the construction documents.

The bids for the project were opened on January 25, 1995. Four contractors bid on the project. The following table summarizes the bid results:

TABLE 6-1. CONTRACT BID

Contractor	Massport Work Schedule A	RWSL Installation Schedule B	Total Bid
Mass Bay Electrical Corp.	$1,837,130.00	$1,650,350.00	$3,487,480.00
The Chappy Corporation	$2,789,495.00	$1,998,960.00	$4,788,455.00
J.F. White Contracting Co.	$3,200,800.00	$2,173,700.00	$5,374,500.00
HY Power, Inc.	$3,636,363.00	$2,727,272.00	$6,363,635.00
Engineer's Estimate	$3,353,100.00	$2,844,790.00	$6,197,890.00

The contract was awarded to Mass Bay Electrical Corporation (Mass Bay). The original scheduled start of construction was May 1, 1995. In part this was done to allow time to order long lead time materials so that they would be available when required. Also, it allowed for better weather. Because the spring had been mild, however, the contractor began the project on April 3, 1995, or approximately one month ahead of schedule. The RWSL installation was completed on September 5, 1995, which was on schedule and within budget.

6.2 EQUIPMENT

6.2.1 Airfield Infrastructure

The installation of the RWSL involved the installation of equipment on the two runways (Runway 4L-22R and 9-27) to be instrumented, the associated taxiways, within the airfield lighting vault, and the Air Traffic Control Tower. The following table summaries the locations and quantity of elevated and in-pavement lights installed.

TABLE 6-2. INSTALLED LIGHTS

Location	Number of Locations	Number of Fixtures Installed
Runway/Taxiway intersections (RELs) Elevated light fixtures	31	62
Runway/Taxiway intersections (RELs) In-pavement light fixtures	6	18
Runway/Runway intersections (RELs) Elevated light fixtures	8	16
Takeoff Hold Light positions (THLs) Elevated light fixtures	11	44
Takeoff Hold Light positions (THLs) In-pavement light fixtures	1	4
Runway/Perimeter Roadway intersections (RELs) Elevated light fixtures	4	4
TOTALS	**61**	**148**

The rest of this section provides specific information about each component installed.

6.2.1.1 Cabling - New cabling was installed for the RWSL installation. The FAA Technical Center in Atlantic City, New Jersey, reported problems had been encountered due to noise and grounding issues with control signals being degraded when using existing airfield lighting circuits at an installation at the Technical Center. They felt new dedicated cables would improve the reliability of the control signals to each of the light fixtures. Thus, to maximize the probability of success of the testing, it was decided that all new lighting circuits would be installed for the RWSL system. This design decision ensured that there would be no impact to any Massport circuits during the testing phase. At the same time, if the smart transformer set up did not work on the new circuit, it could not possibly work in a "dirty" environment.

The installation was subdivided into five (5) separate lighting circuits. This distributed the power requirements and helped reduce the size of the regulators required. This was critical because of the limited space within the existing airfield light vault to house all the necessary equipment. Looking at the number of lights on each runway, it was determined that Runway 4L-22R would be split into three separate circuits. Runway 9-27 would require only two circuits. This would allow the use of five 15 kw constant current regulators, one for each circuit. The design of the various circuits ensured that the same circuit provided power to all lights at same intersection, thus eliminating the possibility that fixtures at the same intersection were powered from multiple circuits. The use of multiple circuits also allowed the testing of possible crosstalk between the circuits and would more closely simulate the actual layout of airfield lighting circuits that occur at large airports.

The circuit went from the power vault via the home run to the airfield, then used the electric manhole/handhole system. In areas where no existing manhole/handhole system was available, existing two-inch conduit between edge lights was used. The cables stayed within the manhole/handhole system until they were within the vicinity of the proposed light location. From this point, new 1½-inch concrete-encased rigid conduit stubs were installed under the pavement from the manhole, handhole, or existing runway edge lights to the new RWSL lights. The following table summarizes the quantities of the conduit installed under this project:

TABLE 6-3. CONDUIT CABLE INSTALLED

Description	Unit	Quantity Installed
1½-inch conduit in heavy duty pavement	Linear feet	1,246.5
1½-inch conduit in shoulder pavement	Linear feet	8,448
1½-inch conduit in infield	Linear feet	2,180

Besides the airfield lighting cables, a fiber optic cable was installed between the airfield lighting vault and the 16th floor test center in the Air Traffic Control Tower. The installation of the fiber optic cable also followed the same technique of being routed through the existing electric manhole/handhole system until it reached the base of the Air Traffic Control Tower. Once the cable was within the Air Traffic Control Tower, it was routed via existing cable trays up to the 16th floor.

For this project, all airfield power cables were unshielded for use with runway and taxiway series lighting circuits and conformed to the requirements of FAA Specifications L-824, "Underground Electrical Cables for Airport Lighting Circuits." The cable was Type 'C', single conductor (1/C), seven strands, 5,000 volts (5kv), cross-linked polyethylene insulation, AWG size No. 8. The equipment ground wire that was also run in parallel with the power cables was a bare copper wire that conformed to ASTM Specifications B3 and B8, AWG size No. 8. A total of 104,402 linear feet of power cable and 37,802 linear feet of equipment ground wire was installed during the project.

Approximately 4,400 linear feet of Massport-provided eight-fiber, 62.5 micron core/125 micron clad, fiber optic cable was installed between the airfield lighting vault and the 16th floor testing center in the Air Traffic Control Tower.

6.2.1.2 Light Bases - The position of the lights, either elevated or in-pavement had been based on research performed by EK. EK reviewed the photometrics of various commercially available airfield lights during their research. In addition, different runway/taxiway intersection geometries were investigated.

The idea was to position the fixtures between the runway holdline and the edge of the runway to maximize their usefulness. All parties agreed that the closer the fixtures could be positioned to the edge of the runway, the greater the chance that an incursion could be prevented. The elevated lights were also located so as not to block the existing taxiway or runway edge lights.

The reason there was both elevated and in-pavement lights installed was to test the fixture's abilities to provide pilots and vehicle operators with the necessary visual information. One example is that the pilot's attention is normally focused directly in front of the plane. There was a question if the elevated fixtures would be picked up by the pilot at very wide intersections. Thus, the installation of the in-pavement fixtures placed, just offset the taxiway centerline to test this concern. In addition, the fixtures had to provide visibility over wide vertical and horizontal ranges to ensure that both parties (pilots and vehicle operators) would be provided with the necessary visual information.

The result of the investigation as to the various locations for the elevated and in-pavement lights (RELs and THLs) was summarized in a report prepared by EK entitled, "Test Runway Status Light System, Segment Specification for the Light Location," dated August 17, 1994, Document Control Number TRSLS-LLS-D10, Version 1.0. Within the report, exact equations were developed to place the elevated and in-pavement lights for any intersection geometry. This information was used during the design of the construction documents.

The light fixtures (either elevated or in-pavement) were installed on top of a light base. The type of light base depended on the location of the fixture. For all elevated fixtures installed outside the full strength runway or taxiway pavement section, the light base conformed to FAA Specification L-867, with a 16-inch outer diameter, an 11-1/4 inch bolt circle, and 24 inches deep. The depth of the can was standard for installations at Logan Airport. It allowed ample room for the installation of the isolation and smart transformers installed within the can. The light base was Class I (steel).

For all in-pavement fixtures installed within the full strength runway or taxiway pavement section, the light base conformed to FAA Specification L-868, Size C, with a 15-inch diameter, a 14-1/4 inch bolt circle and mounting ring, and 24 inches deep. Again, the depth of the can was Massport standard. The light base was steel.

The light base was installed by core drilling a hole, 24 inches wide, to the proper depth. The light base was installed at the proper orientation and the necessary connections to the underground conduit system were made. It was critical that the proper orientation of the bolt pattern of the light base was achieved to ensure that the light fixtures, especially the in-pavement lights, would be at the correct alignment after they were installed. The contractor used jigs during the installation of the cans to ensure that the proper alignment was achieved. Next, the contractor poured rapid setting concrete around the perimeter to anchor the light base. A solid steel cover (3/4 inch thick for elevated fixtures and 1-1/4 inch thick for in-pavement fixtures) was bolted in place during the installation procedures to keep foreign objects from entering the light base. The cover was removed any time the fixture was ready for installation. The cover was reinstalled during the winter shutdown periods or when the entire system was removed.

The water table at Logan Airport is very high. In fact, most of the electrical conduits and light bases are filled with water during most of the year. The airport has tried over the years to install drains within the conduit system with little success. Thus, the design had to accommodate the fact that the materials installed within the light bases will be under water most of the year. The RWSL system also experienced water-filled light bases and conduit. This was a problem during the winter months when ice damaged some equipment within the light bases. Refer to Section 6.4.3 for additional details.

6.2.1.3 Isolation Transformers -The isolation transformer was installed on the primary side of the cables. The output of the isolation transformer was connected into the smart transformer. The size of the isolation transformer depended on the lamp wattage of the fixture. For all elevated light fixtures, one (1) 200 watt, 6.6/6.6 amps, FAA Specification L-830-6 isolation transformer was installed. This single isolation transformer provided power to the two lamps within the fixture. For the in-pavement light fixtures, either two (2) 150 watt, 6.6/6.6 amps, or two (2) 200 watt, 6.6/6.6 amps isolation transformers were installed. The contractor was required to install only 150 watt transformers, but had some extra 200 watt units available left over from the installation of the elevated fixtures. The larger size transformer had no impact on the performance of the fixture. The reason for the two isolation transformers for the in-pavement lights was that the original smart transformers could only provide 250 watts. Each light had two, 150 watt lamps for a total load of 300 watts. Thus, two isolation transformers and two smart transformers had to be installed for each in-pavement fixture. It was later discovered that each ADB smart transformer could handle up to 500 watts. Thus, in the future, the in-pavement light can be designed with a single isolation transformer (300 watts) and single smart transformer.

6.2.1.4 Smart Transformers -The RWSL system needed to have control (turn on/off) of individual light fixtures. The sensor information collected was translated into specific light commands to turn fixtures to the proper state (on/off). The reliability of being able to turn on or off the lights is a primary system requirement. Further, timing of the light state (on or off) changes relative to Air Traffic Control instructions is critical. An excessive delay in the change of light state may be interpreted by the pilot or vehicle operator as an incorrect light state. These desired airfield states must be achieved quickly and correctly by the RWSL system.

A review of the existing technology to accomplish these requirements was under taken by EK. The most favorable technology discovered was the use of smart transformers. Other technologies were investigated, but were removed from consideration because either the installation would require excessive cable to be installed to each light or that the existing technology did not meet the major requirements of the system. The other technologies investigated included:

1. Fiber optic cables with programmable logic controllers
2. Individual control cable to each light
3. Coaxial control cable to each light

The summary of the investigation is presented in a report prepared by EK entitled, "Project Status Report on "Smart" Transformers (Light Controllers) for the Light Subsystem Specifications," dated August 29, 1994.

The smart transformer is an emerging technology for the control and monitoring of individual lights on a series circuit in the airport environment. Although the worldwide installed base of smart transformers is small, along with the number of available vendors, the RWSL Team decided that the technology has the potential to meet the RWSL system requirements. What is most important, the smart transformers are designed to be fully compatible with existing lighting installations and equipment.

The generic smart transformer system employs an electronic module (smart transformer) installed in the light fixture base can on the field and is electrically connected between the light and the isolation transformer. A Light Computer in the airfield lighting vault interfaces with communications modems connected to each power circuit near the constant current regulators. The series circuit modem superimposes a control signal on the power cable (besides the normal 60 Hz current for the lights provided by the regulator) that contains the unique smart transformer address and action to be taken by the desired smart transformer. When the addressed smart transformer received the control signal, its light is turned on or off in response to the command.

Each smart transformer also sends status information back to the series circuit modem in the airfield lighting vault reporting the state (on/off) of the lamp, including if the lamp is burnt out. Therefore, two-way communications are enabled between the LC in the airfield lighting vault and each smart transformer on the airfield. Numerous integrity checks and safeguards are built into the system, including power-up default settings (i.e., all smart transformers power up in the off state) and time-out defaults if communications between the smart transformer and the vault are interrupted for some specified intervals (i.e., smart transformer defaults to the off state). The operational status of each smart transformer is available in the LC.

Many design issues were addressed during the development of the specifications for the procurement of the smart transformer system. These included:

1. The application of the smart transformer technology in the highly dynamic RWSL environment had never been done before. Vendors had developed their smart transformer systems for the infrequent on/off control of airfield lights. The most dynamic application prior to the RWSL was "stop bar" control, which is probably an order-of-magnitude less demanding than the RWSL system.

2. Because the smart transformer system represents an emerging technology, there was no body of knowledge or quantitative field data available to the development team.

3. The actual noise and interference environment at Logan Airport was unknown and untested since new circuits were to be installed for the RWSL system.

4. Due to the schedule pressure to install the smart transformers before the winter of 1995, procuring the smart transformer system in parallel with the development of the Light Logic used to drive the smart transformer system was necessary.

5. The focus of the project is on assessment of the RWSL concept in an operational environment, not the development of an operational system; engineering and experimental flexibility had to be retained in the specification and development of an assessment system.

Taking into account the above items, a smart transformer system performance specification was prepared and included within the construction documents. To acquire a fundamental understanding of the smart transformer technology to reduce the risk associated with system design and development, a warehouse test facility was developed at the Volpe Center. Refer to Section 5.4 for additional details on the warehouse testing.

Initially, Mass Bay Electrical Corporation was planning to use the smart transformer system manufactured by the Safegate Group. A series of shop drawings were submitted by Safegate about how their system compared with the performance specifications. During the review of the shop drawings, testing of the Safegate smart transformer system was being conducted in the warehouse. After multiple submissions, a July 12, 1995 letter was sent to Mass Bay informing them that the Safegate system could not meet the requirements contained within the contract documents. In particular, the warehouse testing showed that the maximum command rate capable for the Safegate system did not meet the performance specifications.

Mass Bay then began to investigate other smart transformer vendors. At this time, ADB demonstrated their Brite II smart transformer system. While only in the pre-production stages, the warehouse testing performed on the Brite II system indicated that it met the specified command rates. ADB submitted the required shop drawings on their system's performance. The conditional approval of the ADB system was provided within an October 25, 1995 letter to Mass Bay from Edwards and Kelcey.

The problem with accepting the ADB system was the estimated delivery schedule near the end of November 1995. There was concern that the water within the light bases would freeze and not allow the installation of the smart transformers; thus, reducing the possibility of testing the system over the winter months as originally scheduled.

Meanwhile, the Safegate Group had been performing modifications to their smart transformer system. The improvements were focused on the number of groups available (8 vs. 4) plus the system now supporting the trickle current. The improved Safegate smart transformer system was available for installation in the fall of 1995. Thus, a change order was issued to the construction contract for Mass Bay to purchase a full Safegate smart transformer system. The change order was executed to allow the installation of 50 of the "modified" version of Safegate's smart transformer along with the necessary airfield electrical vault equipment. A limited test period was conducted with the Safegate system before it was removed.

As mentioned above, after a very short test period of the Safegate system, the ADB smart transformer system was installed. This changeover in smart transformer systems took place during the early winter of 1995. All the smart transformers were installed with shorting caps on the output side. The shorting caps simulated the load of the fixture. This allowed testing of the ADB smart transformer system over the winter of 1995-96.

Each ADB smart transformer can handle a maximum load of 500 watts.

6.2.2 Light Fixtures

A light test station was constructed at Logan International Airport to select the elevated light fixtures. Refer to Section 5.3 for additional details on this testing. The selection of the in-pavement light fixture was based on a study of commercially available fixtures and their associated photo-characteristics. This included reviewing the wattage of the lamp, available lens colors, and beam spread (both horizontal and vertical). The recommendations from these two activities were factored into the technical specifications for the construction documents.

6.2.2.1 Elevated Runway Entrance Light/Takeoff Hold Light -The type of fixture selected for the elevated light fixtures was a modified version of the current FAA Specification L-804, Wig-Wag light. The fixture complied with the requirements contained within FAA Advisory Circular 150/5345-46 with the following modifications:

1. The fixture was equipped with two (2) 115 watt quartz lamps.
2. In front of both lamps were aviation red filters meeting MIL Specification No. 25050.
3. Both lamps were steady burning.
4. The background face and lens visors were painted flat black.
5. The fixture was designed to operate on a current driven (6.6 amps) series lighting circuit.
6. The fixture's frangible coupling was originally designed to withstand 200 mph wind loads and fail at 270 mph.
7. The fixture was equipped with removable black "hoods" to block the light during the initial hooded test period.

8. All fixtures were installed with one metal tether (1/8 inch diameter, galvanized steel stranded cable) to hold them in place in case they were knocked down.

The reasoning behind the increased wind loads was based on the latest FAA recommendation contained in the design criteria for guidance signs (FAA Advisory Circular 150/5345-44E).

The installation of the elevated fixtures was a simple process. After the contractor had installed the cable, isolation transformer, and smart transformer within the light base, they would make the necessary connection from the output of the smart transformer to the fixture. The connection was a typical FAA Specification L-823 plug-in type connection. After the connection had been taped with electrical tape, the fixture was mounted via bolts directly to the top of light base. At this point, the contractor adjusted the horizontal and vertical orientation of the fixture to comply with the aiming angles set forth in the construction documents. Once the fixture had been properly aligned, all bolts would be tightened to secure the fixture in place.

The "hoods" were also installed during this process and remained in place until authorization was given to remove them.

6.2.2.2 In-Pavement Runway Entrance Light/Takeoff Hold Light - The specified in-pavement fixture complied with requirements set forth within FAA Advisory Circular 150/5345-46, FAA Specification L-850E. There were two lamps for each fixture. Each lamp was 150 watts with aviation red filters installed in front of the lamps. Each lamp was also equipped with film disc cutouts. The fixtures were designed to be current driven (6.6 amps) powered by a series lighting circuit. Each fixture was equipped with two cord sets.

Based on discussions with the light manufacturers, there was no way to install some form of black "hood" that would prevent light from being seen during testing. The manufacturer was concerned that the black filter would cause excessive heat generated within the internal portion of the fixture. This would damage the fixture. Therefore, no "hoods" were provided for the in-pavement lights. Instead, after the initial installation of the fixtures, they were tested for proper operation and then disconnected from the circuit. Shorting caps were installed on the smart transformer in the light base to simulate the actual lights.

The in-pavement units were installed using a similar technique to the elevated fixtures. There were three differences however. First, for each in-pavement light, two connections had to be made within the light base because of the two smart transformers per in-pavement light. Second, a steel mounting ring was installed to simplify the installation of the fixture to the light base. The fixture bolted to the mounting ring that was bolted directly to the light base. The last difference was that the in-pavement light beam could not be adjusted vertically. The light beam's vertical angle was preset at the factory.

6.2.3 Airfield Lighting Vault

During the design phase of the project, there were questions if Massport would allow the RWSL project to house its equipment within the existing airfield lighting vault. There were discussions about installing a prefabricated building next to the existing vault to house the test equipment. In the end, Massport allowed the RWSL test program to use part of their existing emergency generator room. One spare concrete pad (18 feet by 5½ feet) for a future emergency generator was made available for the program by Massport. This greatly simplified the installation and operations of the test program. Most of the equipment installed within the vault was mounted on the pad. A telephone and a new distribution panel were mounted to the wall beside the pad. The original design called for the regulators to be vertically stacked (three on the bottom and two on top). This was modified during the installation because the regulators were very large (43 inches tall by 32 inches wide by 36 inches deep). If the regulators were stacked on top of each other, performing any type of troubleshooting on the top units would have been difficult. The five regulators were installed side-by-side along one side of the pad. While the installation was done according to NEC, additional spacing between the regulators would have been helpful during troubleshooting procedures. A vertical rack was constructed off the pad's foundation to support the modems and series circuit filters. The two different smart transformers' light computers were installed at the northern end of the pad.

6.2.3.1 Constant Current Regulators - For the installation, five constant current regulators were installed within the airfield lighting vault. Each regulator provided power to a single lighting circuit. Each regulator had the following characteristics:

1. Conformed to FAA Advisory Circular 150/5345-10, Type L-828.
2. Input power was 480 volts - single phase.
3. The regulators were dry type - air cooled.
4. Each regulator was rated for 15 kw capacity.
5. The regulators were Class 1, Style 2, five brightness steps.
6. The regulator was equipped to provide 120 VAC, 60 Hz control power whenever the input voltage was on.
7. Due to the space constraints within the vault, each regulator could not exceed 47.5 inches tall by 35.6 inches wide by 36 inches deep.

The type of regulator installed was of the shunt type ferro-resonant. Two types of regulators were tested within the warehouse test program (ferro-resonant and solid state SCR). It was discovered during the warehouse testing that the type of regulator used to provide power to the circuit may affect the performance of the smart transformer system. Refer to Section 5.4 for additional details.

The contractor installed the regulators in a single row along the concrete pad. The power and control cables entered the regulator from the right side. After leaving the regulator, the power cables extended to the series circuit modems. Once the cables had left the modems, they ran through the S1 plug cutouts and into the field. The control cables ran directly from the regulators to the light control computer enclosure.

To isolate the regulators from the field, all that was required was to pull the plug cutout for the specified circuit. Whenever the contractor was working on the system in the field, they would begin the work shift by disconnecting all power to the regulators and then pulling the plug cutouts. At the end of the work shift they would reinstall the plug cutout and re-energize the regulators.

6.2.3.2 Light Computer Equipment Rack/Enclosure - As mentioned previously, two different types of smart transformers were tested during the program. The Safegate system had very limited testing, but their light computer equipment rack was installed within the vault to support the testing. The basic components of either the ADB or Safegate light computer were:

1. A modem to connect the airfield light vault and the testing center on the 16th floor of the Air Traffic Control Tower.
2. A computer (i.e., monitor, keyboard, and computer) with all the software that received the light tables from the test center and then issued the specific instructions to the series circuit modems.
3. Uninterrupted power supply capable for 30 minutes power supply.
4. A computer rack to support all equipment. For the Safegate system, there were no sides or top to the enclosure.
5. Connections to the constant current regulators to be able to remotely monitor and control the regulator's intensity.

After the limited testing of the Safegate system, their light computer equipment was disconnected and the ADB equipment was installed. The ADB system was installed within a sealed enclosure that had its own air-conditioning unit on the top of the enclosure. All cables that entered the enclosure did so through gasketed entrances.

Both light computer equipment racks/enclosures were installed on the north side of the concrete pad directly next to the regulators. Cable trays were used to run cables between the light computer and the regulators or the series circuit modems.

6.2.3.3 Series Circuit Modems - The series circuit modems were the units that “impressed” the various light commands onto the power circuits. They received the various light commands from the light computer. The output cables from the regulators passed through the modems before the cables went into the field.

During the project, both the Safegate and ADB modems were installed. Special metal enclosures were installed at the beginning of the project on a vertical plywood backing to house the modems. The Safegate units were installed within the metal enclosures and wired into the appropriate light circuit. For the ADB modems, the metal enclosures were removed because they were manufactured with their own enclosures. Five modems were installed, one for each circuit.

6.3 TESTING

Extensive testing was conducted during and after the installation of the system to ensure proper operation. The following sections outline the types of tests performed.

6.3.1 Inspection

Edwards and Kelcey provided full-time construction inspection services while the system was being installed. The inspector prepared daily reports that detailed the contractor's activities and the work completed during that work shift.

6.3.2 Troubleshooting

The installation of the system was accomplished during the nighttime hours. Typically, the quality of work is reduced due to the limited visibility, especially within electric manholes. Some errors made by the contractor were not noticed until the full system had been installed. Many of these problems would not have occurred if the contractor was allowed to perform their work during daylight hours or provided longer periods to work within critical areas. At larger airports however, nighttime construction is typical. During future installations, measures would be taken to reduce these errors.

1. The contractor had not made the final connections to certain sections of the lighting circuit. During the installation, the contractor had connected the main homerun cables back on themselves and did not connect some cables running off the homerun. This was because of the poor lighting within the electric manholes. Although the RWSL cables were tagged, identifying the proper cables with all the other cables running through the manhole is difficult. In addition, the contractor might not have

had enough time to make the proper connections before having to open that section of the airport up to traffic. This resulted in some lights not having any power and therefore, not operational. The contractor traced the extent of the power and made the necessary connections within the electrical manholes or handholes. Most of these situations were corrected quickly, but some connections were tough to troubleshoot.

2. Each of the smart transformers had been programmed with a specific "address." As such, it had to be installed at the proper location or else the light may go on or off at the wrong time. During some testing, it was discovered that some smart transformers had been installed in the incorrect locations. The contractor moved the smart transformers to the proper locations.

3. Errors were made in the remote control wiring of the constant current regulators within the airfield electrical vault. These regulators were connected to the light computer that allowed the test director in the 16th floor testing center to remotely change the regulator's intensity. A couple of the regulators had been wired incorrectly and would not allow remote control of their intensity. The wiring problems were traced and corrected.

4. Troubleshooting was done in respond to status reports from the smart transformers. This required the replacement of burned out bulbs, failed smart transformers, or knocked over fixtures.

5. The last major item dealt with the fiber optic cable between the Air Traffic Control Tower and the airfield electrical vault. Some existing fibers were found nonfunctional and adjustments had to be made to locate operational fibers. Once the final connections were made, the cables were tested to ensure their reliability.

6.3.3 System Level Testing

Once the entire system was working properly, system-wide testing was conducted. The scope of the testing involved end-to-end system operation that completely checked circuitry and proper operations.

The end-to-end testing was done after each segment of the RWSL system had been successfully tested. The end-to-end testing involved sending a specific light command and recording the time it took for the fixture to respond. During the installation of the elevated lights, the contractor had drilled a small hole on the bottom of the "hood." The purpose of the hole was to allow a light probe to be inserted to test if the lights were operating properly. The full system testing consisted of the following items:

1. A person in the field went to each elevated light location on the airport and inserted the light probe into the small hole within the "hood."
2. Once the probe was in place, the person contacted the test center on the 16th floor of the Air Traffic Control Tower via a cellular phone and reported the light number.
3. The people in the test center ran a script file that commanded that specific light to turn on and off in three-second intervals for each lighting group that it had been programmed to respond.
4. The light probe was equipped with an audible tone to register when the light went on. The person in the field held the probe's speaker to the cellular phone so that the response could be recorded in the test center.
5. The people in the test center recorded the response time for each light command to ensure that the proper number of group commands were performed.
6. Once the testing was complete, the person in the field went to the next light. This procedure continued until all the lights were tested. For the in-pavement lights, the contractor reconnected them to the lighting circuit because they did not have "hoods." Once the testing of the in-pavement lights was completed, the contractor disconnected them from the circuit and reinstalled the shorting caps on the output side of the smart transformer.

6.4 OPERATING EXPERIENCES

During the project, many unexpected situations occurred that required the team to modify the original design. Some more critical aspects are noted within this section. The following table summarizes the more common situations that occurred:

TABLE 6-4. SUMMARY OF PROBLEM SITUATIONS

Explanation of Problem	Number of Events
Elevated fixtures blown over	20 (14 initial and 6 with strengthen kits)
"Hoods" blown off elevated fixture	2 (1 had the entire face of the fixture blown off)
Damaged in-pavement fixture	5 (snow plowing operations damaged fixtures)
Smart transformer replacement	34 (failed units or communications problems)

6.4.1 Elevated Fixture Problems

From an airfield perspective, most of the problems encountered during the project were attributed to the mechanical failure of the elevated fixtures. Due to the close proximity of the fixtures to the runways and taxiways, they were subjected to severe jet blast. The original design requirements of the fixture did not anticipate the forces that the jet blasts would impose on the fixtures. As a result, the fixture had to be strengthened to be able to function properly in the proposed locations. Edwards and Kelcey worked with the fixture's manufacturer, Crouse-Hinds Airport Lighting, to come up with modifications to the original design.

6.4.1.1 Fixture Rotation - One of the first problems noted was that the fixtures did not maintain the proper horizontal alignment. The jet blasts would force the fixture to move out of alignment. The jet blasts were so strong that the fixture unscrewed from the base and would then fall over.

Several options were tried. A “threadlocking” material was applied to provide a greater bind between the threads. Another option was to install a locking nut to prevent the fixture from unscrewing. Both options were unsuccessful.

To solve the problem, an anti-rotation plate was designed by Crouse-Hinds. The plate provided additional resistance to hold the fixture in the proper horizontal alignment after it had been aimed. While this solution worked the best, this problem still needs to be reexamined. Some fixtures in critical locations would still have to be re-aimed and the anti-rotation plate re-tightened regularly to ensure proper alignment of the fixture.

6.4.1.2 Catastrophic Failures - Following the initial installation of the fixtures, 14 units blew over due to jet blast within a matter of a few days. The fixtures that were being blown over were found in the areas where high jet blasts occur (i.e., at the ends of a runway where takeoffs occur, points of rotation on the runways, at entrance taxiways, etc.). In some situations, the tethers installed to prevent the knocked over fixture from being blown over the airport broke. Thus, a potential safety hazard was created at the airport. In another case, the jet blast caused the fixture's housing to vibrate so much that the clamps that held the door closed came loose and the entire “face” of the fixture was ripped off. A third type of failure occurred at the “knuckle” where the support pipe and the fixture's enclosure were bolted together. On at least two occasions, the “knuckle” failed which allowed the entire top part of the fixture to be torn off. Because of these problems, Edward and Kelcey instructed the contractor to remove all the lights until the problem could be solved.

6.4.1.3 Strengthening Kits -The elevated fixtures were designed to withstand 200 mph wind loads and break at 270 mph loads. When the first of the elevated fixtures blew down, a series of tests were conducted that found the originally supplied couplings did meet the specifications.

Crouse-Hinds mentioned that the design standards for the strength requirements of the frangible coupling of the L-804 fixture had been increased since the initial construction documents had been prepared. They suggested that the couplings be strengthened based on the latest recommendations from the Requirements and Technical Concepts for Aviation Special Committee 184 (SP-184) that was studying modifications to the FAA Specifications for the L-804 light fixture. This special committee recommended that the frangible coupling strength be increased to withstand 350 mph wind loads and break at 450 mph loads because of problems of the fixtures being blown over. This was a significant increase in the strength of the coupling. As a result, new frangible couplings were manufactured to these higher limits.

Besides the stronger frangible couplings, several other modifications were made to the original design to stiffen the entire fixture. Some more significant modifications included:

1. A stiffener plate installed on the bottom of the enclosure to prevent the pullout of the bolts from the "knuckle" and increase the overall rigidity of the enclosure.
2. Better clasps (cam operation) were added to hold the face of the fixture closed under all conditions.
3. A stronger tether to prevent the fixture from blowing away in case it did get knocked over. The diameter was increased from 1/8" to 1/4".
4. An anti-rotation plate was designed to prevent the fixture from rotating out of alignment due to jet blasts.
5. A triangular brace was designed to transfer more of the loads on the face of the fixture down into the support pipe and the stronger frangible coupling.

Once the final aspects on the strengthening kit were completed, the contractor was instructed to order sufficient numbers and install them on all elevated fixtures. The cost to order the kits and install them onto the fixtures was covered under a change order to the original contract.

After the strengthened lights were reinstalled, only five lights were damaged over the next seven months (May - November 1996). Figuring out exactly what cause the fixture to fail was difficult at times.

6.4.2 In-Pavement Fixture Damage

Usually in-pavement lights are not as susceptible to damage as elevated fixtures; however, they did get damaged during routine snow removal operations. The tops of the fixtures were cracked, dented, and scraped from the plow blades passing over them. Some lenses within the fixtures were cracked or otherwise damaged. Concerns were raised that the sharp edges on the top of the fixture may damage an aircraft's tire passing over top. Five of the in-pavement fixtures had to be replaced due to the amount of damage. The contractor was ordered to remove all the fixtures and install steel plates on the light bases during the rest of the winter months. The damaged fixtures were sent back to the manufacturer to be rebuilt. Because of the removal of the in-pavement lights, no light visibility testing was conducted during winter months with snow and/or ice on the fixture.

6.4.3 Smart Transformer Failures

During the life of the project, 34 smart transformers failed and were replaced. As mentioned previously, the location of the smart transformers is within the light base. Most of these bases were filled with water that had an impact on the reliability of the smart transformers. This was particularly true during the winter months when the water within the base would freeze. This harsh operational environment was a good test bed for the smart transformer vendors. The failed units were shipped back to the manufacturer to figure out the cause of the failure. Both Safegate and ADB made modifications to their smart transformer units because of the failed units returned to them. Over the life of the installation, ADB had three different versions of the smart transformer enclosure. With each improvement, the failure rate decreased.

The following is a list of some reasons why the smart transformers failed:

1. The seals within the units did not work properly and allowed water to enter the unit. The ADB unit consists of a metal box that opens in half to expose the circuit boards and other electronic components. Screws are used to hold the two pieces of the housing together. A rubber gasket is found between the two halves. In addition, rubber gaskets are installed where the cables exit the enclosure. The Safegate smart transformers are fully encapsulated so that their units were not as susceptible to water entering the actual unit. In a couple examples of the ADB smart transformers, the water had entered the unit and then froze. The freezing of the water caused the entire enclosure to expand — expanding out the sides. ADB made several improvements to

their smart transformers to improve on this aspect. While improvements were made, additional work is needed to ensure a water tight enclosure.

2. The rough nature in which the contractor handled the units during the initial installation was blamed for damaging the electronic components inside. The basic problem was that during the handling of the units, some components within the unit would be shaken loose from their circuit boards. Thus, the circuit boards and other connections within the unit have to be hardened to withstand typical abuse by the contractor.

3. A general failure of the electronics within the units was encountered on several Safegate smart transformers. They had claimed that a bad batch of parts was the cause of the problem and that they were working to improve the reliability of the electronics within their smart transformers.

During the final removal of the system, corrosion was noticed on the outside of the smart transformer metallic housings. The units had only been installed for approximately one year, and the corrosion was a concern. Based on discussions with a representative from ADB, they had already taken steps to correct the corrosion problems on future smart transformers.

6.4.4 Airfield Lighting Vault Hardware Reliability

The equipment installed within the airfield lighting vault had good reliability. Except as noted under Section 6.3.2, concerning the remote control of the constant current regulators, there were no failures of the equipment within the vault. This includes the regulators, computer, and series circuit modems.

6.5 FUTURE INSTALLATION RECOMMENDATIONS

Extensive field experience was gained during the project related to the installation techniques and the type of fixtures that should be used. The following sections present the results and make recommendations on future installations.

6.5.1 Cable Routing

It is recommended that whenever possible, a new dedicated airfield light circuit be installed for each Runway Status Lighting circuit. This will ensure the integrity of the cable and the ability of the smart transformer system to communicate with little interference caused by old cable, weak insulation, poor grounding, or other lighting fixtures connected to the circuit. Also, try to reduce the length the homerun cables are installed within the same conduit to reduce the possibility of crosstalk between the different circuits. While the installation of new cables increases the cost to install the system, it also increases the overall reliability.

With the continued advances in the smart transformer technology being able reliably to communicate on "dirty" or "noisy" circuits, installing the system onto an existing airfield lighting circuit may be possible. This would allow the installation of the system with minimal impacts to the airport operations and significantly reduce the overall cost to install the system.

6.5.2 Fixture Type and Placement

From the brief unhooded testing completed, all parties agreed that the in-pavement fixtures provided the best visual clue. This was because the in-pavement fixtures were installed directly in front of the aircraft or vehicle. Thus, the pilot or vehicle operator did not have to turn their heads to see the lights. The in-pavement lights were especially effective within confusing intersections or at takeoff hold positions. Thus, it is recommended that the same type of fixture (L-850E) and lamp size (150W) be used on future installations.

In addition, many problems were experienced with the elevated fixtures. In particular, the fixture was exposed to severe jet blasts that required extensive modifications to the original design. Even with the strengthening kits installed on the units, they are still susceptible to jet blast or snow plow damage. Therefore, it is recommended that the future installations concentrate on in-pavement type fixtures.

The in-pavement fixtures were still prone to being damaged during snow removal operations, but not to the extent of the elevated fixtures. A newer style of in-pavement lights has recently entered the market that is almost fully flush with the adjacent pavement surface. This type of flush in-pavement light might not be as susceptible to being damaged by snow plows. These fully flush units still provide the necessary illumination by using lenses. These units also do not have the small depressions in front of the lights that normal in-pavement lights have that can fill with dirt or snow and reduce effectiveness.

Generally, the layout of the in-pavement lights should follow the guidelines used for the Logan project. A minimum of three lights at each runway/taxiway intersection and four lights at each takeoff position should be installed. However, additional work needs to be done to explore other layout options because only one layout of in-pavement RELs and THLs was installed at Logan Airport. Other light spacing patterns may provide better visual information to the pilots and vehicle operators. In particular, none of the in-pavement lights were tested from the cockpit of a large aircraft (Boeing 747). The height of the cockpit on these larger aircraft may warrant a wider spacing of the lights.

6.5.3 Smart Transformer Installation

During the project, the project team saw great advances in the development of the smart transformer technology. The use of smart transformers showed great promise on future installation because of its flexibility to meet the overall system's requirements. The reliability of the system greatly improved over the life of the test program.

It is recommended that the smart transformer be installed on the secondary side of the isolation transformer. This allows the smart transformer to be much smaller so it can easily fit inside the light base. In addition, it allows for safer installation because it is installed on the low voltage side of the circuit. The standard FAA L-823 connectors on the smart transformer are very familiar to the standard airfield electrical contractor and make the installation procedure quick and simple.

Still, improvements need to be made with the smart transformers such as improving the waterproof seals, addressing the corrosion problems, and toughening the overall packaging of the unit to allow for rough handling by the contractor.

7. SYSTEM TESTING

7.1 TEST PROGRAM

7.1.1 Objectives

The objective of the RWSL Test Program was to evaluate in an operational environment the performance of Runway Status Lights from the perspective of its users in meeting its intended purposes of: (a) reducing the incidence of runway incursions, and (b) increasing pilots' situational awareness while on the airport surface. The users that would be most impacted by the installation of RWSL are pilots, who can directly observe the operation of the system, and tower controllers, who indirectly observe its effects by the way that it affects traffic flow, communications with pilots, and other airport operations. The operational assessment of RWSL at Logan provided the first opportunity in a fully operational environment to evaluate the integrated system in terms of its effectiveness in improving safety and the degree to which it interfered with normal airport operations. It is emphasized, however, that the system implemented in this Test Program was intended to meet the stated objective of evaluating RWSL performance in an operational environment, and was not intended nor designed to be a system ready for full operational use.

Formally, RWSL assessment objectives were to:

1. Demonstrate that RWSL design risk was minimized before integrating the system into the AMASS production program.
2. Establish product utility:
    (a) Assess the performance of RWSL from users' and stakeholders' perspectives in an operational environment. Performance would be assessed in the following areas:
        (i) Effect on airport safety.
        (ii) Impact on normal airport operations.
    (b) Increase users' confidence in the RWSL concept.
3. Evaluate the compatibility of the RWSL concept with connecting systems. In particular, assess the suitability of RWSL for inclusion in FAA's

overarching vision of airport safety improvement systems and, more specifically, incursion prevention systems such as AMASS.

4. Identify and resolve critical operational issues.

5. Identify needed modifications and improvements.

6. Stimulate stakeholders' (and potential stakeholders') interest in the RWSL concept.

Based on these objectives, a set of requirements was identified [7-1] which

(a) identified the critical system characteristics and performance that would be required to obtain the pilots' endorsement of the system,

(b) allowed a more objective assessment of the system within the constraints which exist when testing any proof-of-concept system in an operational environment,

(c) allowed assessment of system operation from other users' perspective, particularly controllers and airport operators, and

(d) provided criteria for future integration of the RWSL concept with other elements of the FAA's incursion prevention and airport safety programs, particularly AMASS.

7.1.2 Test Elements

The RWSL Program was conducted in accordance with a well-defined test plan [7-2] that was designed to achieve the stated objectives. This plan hinged around the critical decision which would determine whether the system could be tested in a live, operational environment at a busy and complex airport such as Logan with lights exposed to users.

It was recognized that while the primary objective of the RWSL program was to determine the utility of the concept in an operational environment, and that this could be achieved in an Unhooded Test, an intermediate step would be required in which test data would be required *solely* to help decide whether or not the system was working well enough to be exposed to users. A series of test activities was therefore designed exclusively to support this critical decision. These activities culminated in a Hooded Test, whose objective was to demonstrate to decision-makers in as realistic environment as possible without actually exposing the lights to users that the RWSL system would not adversely affect normal operations at and around Logan airport if it were to be exposed in an operational environment. In this regard, two critical aspects of system performance were identified that would have to be demonstrated:

1. The system should not adversely affect airport safety.
2. The system should not adversely impact traffic flow on and around the airport surface.

To determine how to demonstrate these capabilities, it was necessary to analyze how RWSL could possibly affect airport operations in a negative way. The key criterion identified was that lights should not turn on or be visible in critical situations which might confuse pilots or contradict with instructions from the tower. This indicated that:

(a) the system itself should not turn on lights erroneously,

(b) lights which were switched on correctly (i.e., in accordance with the intent of the system) should not cause confusion and should not be visible from where they were not intended to be seen,

(c) lights which were switched on correctly should not confuse or distract pilots who were intended to see the lights,

(d) lights which were switched on should not conflict with instructions from air traffic controllers, and

(e) a pilot notification program would be needed to inform pilots of how the system worked.

It should be emphasized that the system concept as originally envisaged placed no meaning whatsoever on a light which is off. Whether a pilot would react to a light which is either off, or which suddenly turns off, is a different issue and was one of the key human factors which could not be satisfactorily resolved without exposing the system, at least on a limited basis, to pilots in a live, operational environment.

The RWSL Test program was therefore broken into four regimes:

a) Hooded Testing, including system and subsystem performance and functionality testing, integration testing, and reliability testing.

b) Human Factors testing, including precursory testing of how pilots would react to lights and the determination of regions of light visibility.

c) Unhooded Testing, following an affirmative decision to unhood (if forthcoming). This would include a dry run with lights unhooded but in a non-operational environment prior to exposure of the system to pilots.

d) Pilot notification program.

Although a detailed pilot notification program was planned, the FAA did not authorize its implementation because of apparent supposed shortcomings in the performance of the system. This section therefore describes only the three major test activities (a, b, and c above). Descriptions of unit testing of the performance and functionality of the two main subsystems, the Light Logic and the Light Subsystem are described in sections 4 and 5, respectively. Hooded Testing was further broken down into two major sections: (1) Testing of the light activation logic, including all parts of the system up to the point at which commands to switch lights are issued to the Light Subsystem, and (2) Integration and Reliability Testing of the Light Subsystem.

7.2 HOODED TESTING

7.2.1 Objectives

The objectives of the Hooded Test were to determine whether:

a) the system was working well enough to expose to users in an unhooded test, and

b) the system, if exposed to users, would adversely affect airport operations.

Both of these objectives had to be achieved before a decision could be made to unhood the RWSL lights. It should be emphasized that, although these objectives identified *necessary* conditions for allowing an unhooded test, they were not intended to be *sufficient* conditions - there were many other tasks that had to be completed before lights could be unhooded e.g., completion of a user notification program, development of approved procedures, etc.

7.2.2 Evaluation Methodology

7.2.2.1 Performance Criteria - To assess whether the Hooded Test would achieve its objective, a set of performance criteria was developed. It should be emphasized that these measures were not intended to be used for determining the success or failure of the overall RWSL Assessment

Program - they were solely provided as a means to support the decision to proceed to Unhooded Testing.

Two levels of performance criteria were defined. First, a set of essential criteria described the level of performance that had to be achieved if the system was to be exposed to users. These relate to the key issues of the system's potentially adverse effect on airport safety and traffic flow. The second set of desirable criteria provided a means of determining whether the system would be perceived as useful by users when the lights were uncovered.

Definitions

Missed Detection: A missed detection is a failure of a runway status light to illuminate as it should, as judged from the intent of the system and the state of the traffic on the airport and in the immediate airspace.

False Alarm: A false alarm is a status light illumination that should not have occurred, as judged from the intent of the system and the state of the traffic on the airport and in the immediate airspace.

Discrepancy: A discrepancy occurs when a status light is on, in accordance with the design of the system, while an apparently safe operation is under way that (a) contradicts an instruction issued by the tower controller and (b) lasts for more than three seconds[1] after the completion of the tower controller's instruction.

Observable Anomaly: An observable anomaly is a missed detection or false alarm that would be observable by a pilot or vehicle operator if the lights were not hooded. Note that discrepancies are, by definition, observable errors.

Operation: An operation commences when any of the following events takes place:

- an aircraft enters the immediate airspace from the far airspace (e.g., final approach).
- an aircraft taxis out of the terminal area and enters the active airfield (e.g., en route for departure).
- a vehicle leaves the terminal area or a perimeter road and enters the active airfield (e.g., for runway inspection).

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[1] From discussions with pilots, three seconds is approximately the time that a pilot would wait before calling the tower to report a conflict between the state of the lights and the controller's clearance.

An operation concludes when any of the following events takes place:

- an aircraft leaves the immediate airspace (e.g., transition to departure control).
- an aircraft taxis in from the active airfield and enters the terminal area (e.g., inbound after landing or return to terminal after departure abort).
- a vehicle leaves the active airfield and enters the terminal area or a perimeter road (e.g., after completion of runway inspection).

Only those operations which directly affected the state of the status lights on either one of the RWSL-instrumented runways were counted in the defined performance criteria (i.e., operations on either the instrumented runways or runways which intersect the RWSL-instrumented runways). Note that this definition of an operation encompasses both normal and aborted arrivals and departures.

It should be noted that the definitions contain reference to observability by pilots and vehicle operators. This is not easily determinable while the lights are hooded. However, the capability to determine whether or not a light might be observable was built into the performance analysis system.

With these definitions in mind, and recalling the objectives of the hooded test, the following performance criteria were established. These were derived primarily through discussions with representatives of the user community (pilots and tower controllers).

Essential System Performance Criteria

1. There should be zero discrepancies which would result in an adverse effect on airport safety.
2. In any four-hour period, there should be no more than one discrepancy.

Desirable System Performance Criteria

1. The average rate of observable false alarms should not exceed one in every 25 operations.

2. The average rate of observable missed detections should not exceed one in every 25 operations.

7.2.2.2 Processing Requirements - The performance criteria defined specific levels of performance that had to be achieved by the RWSL system. They also inherently dictated that the adopted method of processing test data had to be capable of *demonstrating* that the system had achieved the desired level of performance. The following data processing requirements were therefore also imposed:

1. The method of processing hooded test data had to be capable of demonstrating that the RWSL system could meet the specified performance criteria, with sufficient accuracy to convince users that the demonstrated performance was representative of how the system would operate with lights unhooded.

2. The data processing method had to support the timely and efficient analysis of hooded test data.

3. The data processing method had to address the interaction between the RWSL system and its users.

4. The data processing method had to support the identification of limitations in RWSL and the conditions under which RWSL would adversely affect airport operations.

7.2.2.3 Evaluation Approach - In formulating a method for processing data that would allow the Hooded Test objectives to be achieved, an approach to *validating* the system was adopted (in contrast to an approach of verification, which had already been conducted) that would ensure quantitative demonstration of system performance against the specified performance criteria. This section describes the method selected to process the hooded test data.

The design of the data processing method was driven primarily towards measuring RWSL system performance in terms of the measures delineated in the specified performance criteria i.e., discrepancies, missed detections, and false alarms. The basic pretext was that all of these types of anomaly could be determined by comparing the times at which lights *actually* changed state (as would be observable by pilots and vehicle operators) against the times at which lights *should* have changed state; these latter times being based on how RWSL is intended to operate.

Actual Changes in Light State

Measurement of actual changes in light states can be determined in several ways. Ideally, a sensing device placed on each light would indicate when light intensity reaches the threshold at which the required state would be observable as such by a pilot. Programmatic and implementation constraints deemed this approach inappropriate. There were, however, several alternatives:

- Measure times at which the Light Manager issues commands to switch lights on and off. Model, with supporting measurements, the delay between the time at which the command is issued by the Light Manager and the time at which corresponding lights turn on and off. By adding this delay to the time at which the command is issued by the Light Manager, it is possible to estimate, with a small degree of uncertainty, the time at which the lights change state.
- Similar to above, but instead of measuring the time at which the command is issued by the Light Manager, measure the time at which the command is issued by the LCC.

Attempting to measure the times at which commands are issued further downstream (i.e., by the Light Computer in the vault) was considered to be neither practical nor desirable because it would have required precise time synchronization between the LC and the upstream components of the RWSL system (i.e., LCC and Light Manager). Furthermore, the associated delays between the LCC and the LC are small (0.1 seconds) and highly deterministic.

Desired Changes in Light State

The determination of when lights *should* change state was derived from two inputs: (a) vocal instructions from the tower controller to the pilot, and (b) the traffic situation on the airfield, as observed from the RWSL test center under the same conditions as the tower controllers (i.e., by observation from the test center window overlooking the airfield under VFR conditions and by observation of the ASDE radar display under IFR conditions).

Vocal instructions from the tower controllers which were relevant to RWSL operation were not sufficient to determine the desired state of every light on the airfield surface, because relevant ATC instructions are limited to hold short instructions, clearances to cross or enter a runway, and clearances to take off. Most of these instructions give a clear indication of when specific lights should be OFF but are not as easily translatable to determining when lights should be ON[2]. The consequence of this was that discrepancies could be captured solely by using clearances from tower controllers whereas observable false alarms and missed detections were not as forthcoming.

To capture false alarms and missed detections, a set of "shadow" air traffic controllers (SATCs) was employed whose purpose was to:

- listen to actual ATC instructions and apply them to RWSL operation,
- interpret the prevailing traffic situation on the airfield,
- determine when lights are observable to pilots, and
- record, in real time, a commentary of events that are relevant to evaluating performance of the system using standard phraseology and under strict guidelines (see Appendix D).

In essence, the SATCs provided a record of aircraft and vehicle positions and intended actions. **This record was independent of any AMASS processing**, which clearly was a significant benefit in strong support of the objective of validation versus verification. By time tagging the SATCs' commentaries as they were being recorded, it was possible to subsequently determine the precise time at which lights should have changed state by the use of an appropriate translation from the standard phraseology of the commentaries to a set of desired light states, *for all lights on the airfield continuously.*

Other Considerations

To address the data processing requirements, the data collection and reduction was automated as much as possible. Distribution of a common reference time across almost the entire recording and instrumentation subsystem was automated[3]. A running verbal commentary on the airfield operations by the "shadow" air traffic controllers was recorded on audio and video tapes. Once this commentary had been digitized, subsequent processing of the data was entirely automatic.

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[2] It should be noted that it does not automatically follow from a hold short instruction that the lights corresponding to the controller's instruction should be off.

Where possible, models of user behavior were eliminated in support of the third data processing requirement. By using the tower controllers as the source of truth, the method inherently captured variations in controllers' techniques. This was considered essential if RWSL was to accurately reflect airport operations when the lights are unhooded. By procedurally forcing SATCs to interpret the traffic situation and account for aircraft orientation and position relative to the lights in their commentary, the method naturally addressed observability of the lights by pilots. The method did not, however, attempt to model whether a pilot would actually *see* the lights - instead, it was tacitly assumed that if a light was observable by a pilot, the design of the lights themselves would be sufficient to attract the pilot's attention at the appropriate time[4]. Conversely, strict measures were taken in the design of the lighting subsystem to ensure that the lights would not be observable by pilots where they shouldn't be.

The fourth data processing requirement was addressed by (a) the use of appropriate test procedures i.e., recording all ambient and environmental conditions which affect operation and use of the system, and (b) recording as much raw data as possible to allow subsequent determination of the fundamental causes of any problems encountered with the system. The data processing method also supported this requirement by allowing efficient, automatic reprocessing of data generated by different versions of RWSL software through the use of regression testing.

7.2.2.4 Data Processing Method - The data processing method is depicted in Figure 7-1. It comprises four main sub-processes:

1. Data Reduction
2. Data Collection
3. Performance Analysis
4. Interpretation

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[3] The only instrumentation device which was not being used in an automatically synchronized mode was the video camera. In the test equipment configuration, the video camera was synchronized manually to within less than 1 second.

[4] Note that evaluation of pilots' reactions to lights were, to some extent, addressed using NASA Langley's flight simulator (see section 7.5).

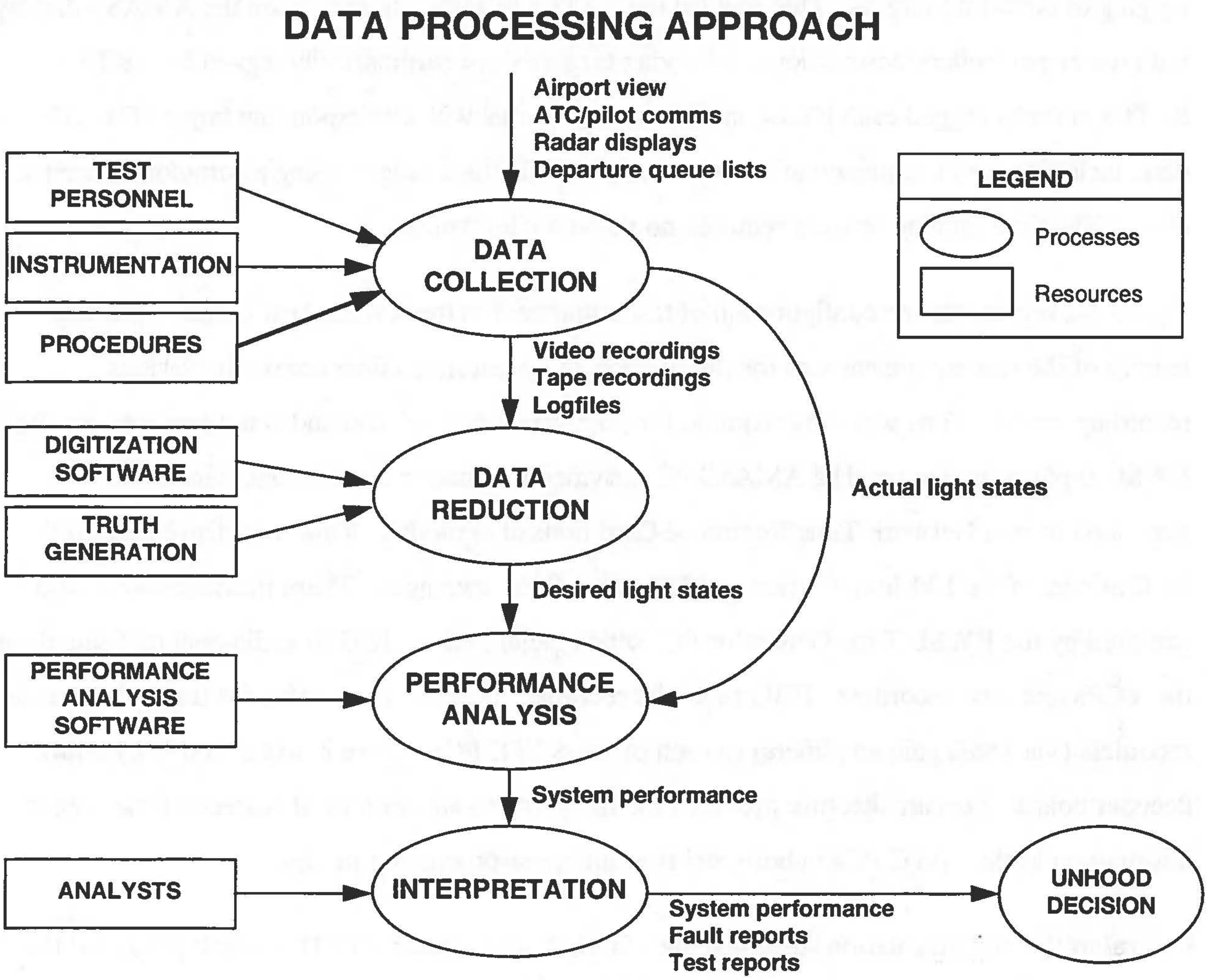

FIGURE 7-1. DATA PROCESSING APPROACH

7.2.3 Data Collection

The Data Collection process involved the recording of system and test data in real time. The two most important components of this data were (a) the content of light switching commands issued by the Light Manager and the times at which they were issued, and (b) verbal commentaries of events which might affect the state of the lights by the SATCs and exact times at which each individual phrase in the commentaries were made.

During the collection of data, the RWSL test center was set up in a way that mirrors operation in the tower cab. Two SATCs were used to mimic Logan's Local Controllers (East and West). Each SATC could hear the corresponding Local Controller via a radio receiver. A third test operator monitored the Ground Controller and viewed the departure queue list to allow manual tagging of departing targets. This enabled the SATCs to associate targets on the AMASS display with tower controllers' instructions. (Arriving targets were automatically tagged by ARTS.) SATCs verbally tagged each phrase in their commentaries with corresponding target IDs. All data, including SATC commentaries, were automatically time tagged using a common reference clock. The time tagging process required no manual intervention.

Figure 7-2 represents the configuration of test equipment in the RWSL Test Center. The key feature of the test equipment was the distribution of synchronous time across the various recording media. Time was only required for post-processing of data and is not required for the RWSL application *per se*. The AMASS PC provided the master clock signal, which was generated from a Network Time Reference Card housed in the PC. Time was distributed to the LCC as part of the LM Initialization and LM Light State messages. These messages were also captured by the RWSL Time Generator PC, which generated an IRIG-B audio-encoded signal for the VCRs and tape recorders. IRIG time was recorded on tape. It was also fed through the tape recorders (via 18dB gain amplifiers) to each of the SATC PCs, where it was decoded by a time decoder board. This architecture provided the flexibility to allow entry of correctly time tagged information in the SATC PCs in both real-time and post-processing modes.

Central to the instrumentation suite was the RWSL Time Generator (RTG) which produced the IRIG-B timing signal that was recorded on all analog tapes. This was a stand-alone i286 computer that received AMASS clock time and date over the RS-232 twisted-pair once per second at a rate of 9600 Baud. The received time had a resolution of 0.01 sec and was used to reset a stable clock (0.0005% stability) in the RTG with an accuracy of 0.05 seconds if the difference between the AMASS time and the RTG time exceeded 0.3 seconds. Because the AMASS time was derived from the same model stable clock, the relative drift between the clocks following synchronization was small and resets did not generally occur during a test period. The AMASS clock time was recorded in the AMASS log files and was displayed on the AMASS monitor.

An IRIG-B encoder card installed in the RTG also had a stable clock which was reset to the RTG clock if the difference between the two clocks exceeded 0.3 second. IRIG-B is an industry encoding scheme and utilizes a 1 kHz audio carrier that is modulated to encode the time. The resolution of the IRIG-B encoded time is 1 ms and time is synchronized with an accuracy of 0.05 second. This audio signal was recorded on one of the available audio tracks of the cassette recorders and the VCRs.

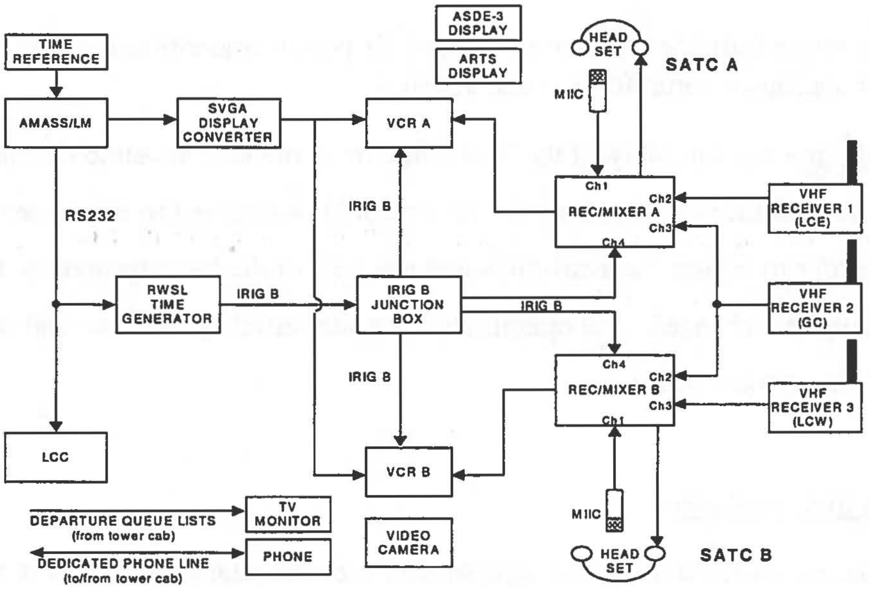

FIGURE 7-2 RWSL TEST SUPPORT EQUIPMENT

The Analysis Workstation (not shown in the figure), which was used for post-test processing, contained a time decoder card that was used to synchronize the data files. Playback accuracy is unaffected by tape speed variations as large as 2:1 and momentary tape dropouts can be interpolated by the decoder card. Timing accuracy was verified through end-to end testing. The maximum timing error relative to the AMASS reference time was 0.5 second with an observed RMS error on the order of 0.2 seconds.

In addition to system time, the following essential data were also recorded:

a) Communications between Logan tower controllers and aircraft pilots and ground vehicle operators. The ground controller and both local controllers were recorded. Each recorder/mixer could record any set of two controllers (although during normal operation, the ground controller and a single local controller were recorded on each of the recorders, as shown in the figure above).

b) SATC commentaries of pilot/tower communications and their interpretation of surface traffic movement as it applied to RWSL.

c) AMASS screen display on VCR. This was required to be converted from Super VGA to standard TV signal format for recording on the VCR. Recording the AMASS display on the VCR allowed control of TV frames (rewind, pause, etc.) when the data was being post-processed. The standard AMASS did not provide this feature, which was considered essential for post-test analysis.

d) Video of the airport surface. This was required for post-test identification of false targets, multipath, aircraft types and vehicles.

A Test Director Console (not shown) allowed the Test Director to monitor all audio channels on a non-interfering basis for real-time quality control. Audio could be directed to earphones or to two loudspeakers. In order to ensure the availability and integrity of the instrumentation, there was no need to make any cable changes. All operations were supported by switches and detailed check lists to ensure correct switch positions.

7.2.4 Data Reduction and Analysis

The Data Reduction process involved the digitization of SATC commentaries into a set of time tagged events and the translation of these events into a set of light states that reflect the events and the times at which they took place. Using the aircraft tags associated with each phrase, a flight log was created for each target and vehicle on the airport surface. Included in these flight logs were target locations (identified by taxiway and/or runway), aircraft intent, and time tags for each event. These logs were then translated into corresponding light operations.

The Performance Analysis process compared time histories of "desired light states" and actual light states (as extracted from recorded system data) and generated a list of potential errors i.e., times at which desired and actual light states did not match.

Finally, analysts investigated each of the potential errors, using additional test data if necessary, to produce a list of actual errors and their suspected causes. Problem reports were generated based on this analysis. Each of the actual errors was then further analyzed to determine its relevance to the specified performance measures.

7.2.5 Test Results

7.2.5.1 Tests Analyzed - Tests were conducted between February 22 and August 21, 1996. During the test period, there was a variety of adverse weather conditions, including several snowstorms, periods of poor visibility (down to 1/8th mile), high winds, periods of high and low humidity, rain (causing wet runways), and thunderstorms. All of these factors affected both local and national traffic patterns, flight profiles, and aircraft speeds while performing specific operations.

Tests analyzed are summarized in Appendix I. In summary, data from a total of 8,298 operations during almost 100 hours were used in the analysis of discrepancies. Data were typically collected from 8:00 a.m. to 5:00 p.m. daily, Mondays to Fridays. Significant is the fact that the system was being exercised during periods of very heavy traffic, with average traffic loads of over 85 operations/hour. Furthermore, there was a fairly even mixture of arrivals and departures (4,089 arrivals versus 4,209 departures). Testing was not conducted on Saturdays or Sundays, when traffic is typically somewhat lighter than weekdays.

7.2.5.2 Software Versions - Tests were conducted using LM software versions 13, 14, and 15. However, all data were processed post-test using version 16 of the LM software[5]. Subsequent to the Hooded Test phase, further versions of the LM software were developed. The last version, which was intended to be used for unhooded testing if such testing had ever taken place, was version 20. A limited amount of data was analyzed using version 20. Results of this testing are included in this section of the report. Full testing of Version 20 was restricted due to budgetary constraints.

7.2.5.3 Presentation of Results - The emphasis of the analysis was on detecting discrepancies and determining their causes. While the rate of discrepancies was not the sole measure for declaring the system ready for the unhooded assessment, it was the most significant contributor to affecting airport operations and creating potentially adverse safety conditions. However, results of analysis on missed detections and false alarms are also provided since these are considered "nuisance" factors as might be perceived by pilots.

Results are split up by the type of anomaly: discrepancies, missed detections, and false alarms. For each anomaly type, results are further broken down by the type of light (REL/THL).

Discrepancy results are presented as a function of runway configuration and instrumented runway (4L/22R and 9/27). Also shown for the RELs are the number of times that the controller issued an instruction to cross or to taxi into position on an instrumented runway. For the THLs, the corresponding number of take-off clearances that were issued on each runway and in each configuration is shown. Also shown are:

a) the percentage of controller-issued clearances (clear to cross, taxi into position, and take-off) in which RWSL was in agreement with the controller (i.e. lights were off when they should have been). In Tables 7-1 and 7-2, "Percentage in Agreement" is defined as (1-R) x 100%, where, for RELs, R is the ratio of the number of REL discrepancies to the number of clearances issued by the controller, and for THLs, R is the ratio of the number of THL discrepancies to the number of THL exposures. The number of THL exposures is the number of times pilots would have been exposed to a THL pair during take-off operations. This is not the same as the number of take-off clearances issued by the controller because a pilot is exposed to several pairs of THLs along the departure runway during the take-off operation. This measure takes into account the fact that all THLs should be off along the departure runway - each time a pilot passes a THL can be interpreted as an implied clearance through that THL.

b) discrepancy counts that would be expected in an unhooded test, if unhooded test procedures were to be followed. These counts are shown in parentheses in Tables 7-1 and 7-2.

c) the mean time between discrepancies (MTBD). MTBD is defined as the ratio of the total time that an instrumented runway was active during the tests to the number of discrepancies that occurred in that time. MTBD is intended to measure how often a controller could be faced with a report from a pilot of a conflict between the lights and the controller's instruction.

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[5] It should be noted that the AMASS software provides the option for selecting one of two inputs: real-time data from the ARTS Interface Unit and the Sample Processor or recorded data in the same format.

7.2.5.4 REL Results

TABLE 7-1 REL DISCREPANCY SUMMARY

RUNWAY CONFIG	TEST DURATION (hrs)	RUNWAY	NUMBER OF ATC REL CLEARANCES	NUMBER OF DISCREPANCIES	PERCENTAGE IN AGREEMENT	MTBD (hrs)
4/9	48.84	4L/22R	3164	51(31)	98.4%(99.0%)	1.0(1.6)
		9/27	1545	6(0)	99.6%(100%)	8.1(∞)
		BOTH	4457	51(31)	98.9%(99.0%)	1.0(1.6)
33/27	7.65	4L/22R	6	0	100%(100%)	∞
		9/27	228	1	99.6%(99.6%)	7.7(7.7)
		BOTH	234	1	99.6%(99.6%)	7.7(7.7)
27/22	31.36	4L/22R	2540	36	98.6%(98.6%)	0.9(0.9)
		9/27	19	0	100%(100%)	∞
		BOTH	2557	36	98.6%(98.6%)	0.9(0.9)
15/9	8.81	4L/22R	40	0	100%(100%)	∞
		9/27	373	0	100%(100%)	∞
		BOTH	377	0	100%(100%)	∞
ALL	96.67	4L/22R	5750	87(67)	98.5%(98.8%)	1.1(1.4)
		9/27	2165	7(1)	99.7%(100.0%)	13.8(96.7)
		BOTH	7625	88(68)	98.9%(99.1%)	1.1(1.4)

TABLE 7-2 CAUSES OF REL DISCREPANCY

	4/9 CONFIG		33/27 CONFIG		27/22 CONFIG		15/9 CONFIG		ALL CONFIGS	
CAUSE	4L	9	4L	27	22R	27	4L	9	4L/ 22R	9/27
ARTS Handoff	43	6	0	1	5	0	0	0	48	7
Early Departure	8	0	0	0	23	0	0	0	31	0
Vehicle	0	0	0	0	7	0	0	0	7	0
Target tracking	0	0	0	0	1	0	0	0	1	0
TOTAL	51	6	0	1	36	0	0	0	87	7

The tables also show the total time that the system was tested in each runway configuration. Combined totals showing the corresponding results for both instrumented runways together and for all configurations are also shown. It should be noted that in the 4/9 configuration, the totals given for both runways are not linear additions of the totals for each individual runway. This is due to the fact that there is one set of lights (on taxiway Bravo) which is common to both instrumented runways.

Missed detection (MD) and false alarm (FA) performance is also shown in tabular form. The number of MDs and FAs are tabulated for each runway configuration as a function of the reason they occurred.

Discussion of REL Discrepancy Results

One of the most significant features of the results is the high proportion of time that the RELs were in agreement with how the airport was operating (see "Percentage in Agreement" figures in the tables of results). Agreement between RELs and the controllers' clearance instructions was in excess of 98%.

REL performance is markedly different between the two instrumented runways. During almost 100 hours of testing and more than 2,000 clearances from the tower controller, only one discrepancy occurred on runway 9/27 (excluding the six discrepancies which occurred during crossings from the Bravo holdpoint[6]). In contrast, there were 87 discrepancies in almost 6,000 clearances onto and across runway 4L/22R.

Notwithstanding the limited amount of data collected in 33/27 and 15/9 runway configurations (7.65 and 8.81 hours respectively), REL performance in both of these configurations was excellent, with only 1 discrepancy occurring out of 600 clearances onto or across the instrumented runways.

The bulk of the data was collected during 4/9 and 27/22 configurations and the focus of the analysis was on these configurations. The results show that runway 9/27 REL performance in both of these configurations is excellent. The primary cause of the REL discrepancies on runway

9/27 in the 4/9 configuration was the handoff from ARTS tracking to ASDE tracking in the AMASS software. This caused six discrepancies at the Bravo holdpoint for aircraft taxiing out for departure on runway 4R or 9. It should be noted that the RELs at this location are not protecting an active portion of runway 9/27 - they are adjacent to the runway 9 overrun.

All discrepancies arose due either to problems in the AMASS software or to a lack of information. Knowledge of aircraft altitude and aircraft/vehicle type would eliminate almost half of the discrepancies, while improvements in the ARTS tracking filter and the handover to ASDE tracking would eliminate the remainder of the discrepancies.

REL performance on runway 4L/22R was not as good as that for runway 9/27 in either of the two major configurations. However, the primary cause of discrepancies was different for the two configurations. In the 4/9 configuration, the ARTS-to-ASDE handoff problem was the leading cause of discrepancy whereas the uncertainty in determining the exact time at which it would be safe to cross an aircraft ahead of a departing aircraft (referred to as the "Early Departure" problem) was the main source of discrepancies in the 27/22 configuration.

The reasons for this are twofold. Firstly, in the 4/9 configuration, a large proportion of aircraft landing on 4L approach from the channel and curve around into a final approach. The low update rate of the ARTS radar caused the ARTS tracker in the AMASS software to wrongly predict the runway which was intended to be used for landing. These types of approach to runway 22R are not as prevalent in the 27/22 configuration. Secondly, almost all arrivals in the 27/22 configuration are to runways 27 and 22L. As a consequence, on completion of landing roll-out, almost all landing aircraft have to cross 22R (usually at E, S, or W taxiways). In this configuration, almost all departures are from 22R. A potential conflict therefore arises at the E, S, and W taxiways between almost all arrivals waiting to cross 22L and almost all departures lifting off on 22R. In contrast, in 4/9 configuration, there are significantly more arrivals to 4L than there are to runway 22R in the 27/22 configuration. Furthermore, there are fewer arrivals to runway 4R in the 4/9 configuration than there are to runway 22L in 27/22 configuration (i.e., there are less crossings of 4L/22R in 4/9 than in 27/22).

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[6] RELs at taxiway Bravo are primarily in place to protect runway 4L/22R and were located on the North side of the runway 9 overrun because of construction constraints.

The most significant difference in the impact on airport operations of the two major causes of discrepancy is in the duration of the discrepancy. Discrepancies which arise due to poor handoff from ARTS to ASDE typically last for about 20 seconds whereas discrepancies which arise due to the early departure problem typically last for 3 to 6 seconds. The consequence of this is that discrepancies in the 27/22 configuration are short lived and more likely to be tolerable to pilots and controllers than the discrepancies in the 4/9 configuration, which are probably unacceptable at the relatively high frequency (approximately one/hour on average) at which they occur.

The final point to note regarding the two main causes of discrepancy concerns the dependence on weather conditions. Early departure problems tend to be related to conditions of high humidity and low headwinds, which result in longer take-off rolls. Under these conditions, the early departure algorithm works very well. In contrast, under strong headwinds and on dry days, aircraft typically lift off much earlier, providing ideal conditions for early departure discrepancies further down the runway.

Discrepancies due to poor ARTS-to-ASDE handoffs, on the other hand, tend to occur in bursts, although the reason for this is not clear. This burst mode is exemplified by the fact that almost half of the 43 discrepancies caused by poor handoffs in the 4/9 configurations occurred in just three one-hour test periods, two of which were on the same day.

REL performance is affected by vehicle operations primarily during runway inspections. The distribution of discrepancies across the different runway configurations is entirely random and depends on the direction in which the vehicle conducts the inspection relative to the prevalent configuration. No emphasis should be placed on the fact that all vehicle-related discrepancies occurred during operation in the 27/22 configuration.

Included in Tables 7-3 and 7-4 are discrepancy counts expected for unhooded testing. These have been derived based on the difference in test procedures between hooded and unhooded testing. During the hooded testing, data collection continued regardless of the frequency of discrepancies. Thus, even on days when ARTS to ASDE handoffs were causing problems, data continued to be collected. This would not have been the case during unhooded testing. Prior to commencing each day's unhooded testing, the performance of the system would have been checked prior to allowing the lights to be turned on. If handoffs were causing problems, testing would not be conducted on that particular day.

The expected effect of these procedures would have been to improve the agreement between RELs and ATC clearances to about 99% for all four major configurations. Although performance in the 27/22 configuration is the worst of the four, it should be recalled that most of the discrepancies in this configuration are very short lived (less than about 6 seconds).

7.2.5.5 THL Results

TABLE 7-3 THL DISCREPANCY SUMMARY

RUNWAY CONFIG	DURATION (hrs)	RUNWAY	NUMBER OF ATC T/O CLEARANCES	NUMBER OF THL EXPOSURES	NUMBER OF DISCREPANCIES	PERCENTAGE IN AGREEMENT	MTBD (hrs)
4/9	48.84	4L/22R	620	1860	45(3)	97.6%(99.8%)	1.1(16.3)
		9/27	1254	2500	65(9)	97.4%(99.6%)	0.8(5.4)
		BOTH	1874	4360	110(12)	97.5%(99.5%)	0.4(4.1)
33/27	7.65	4L/22R	4	20	0	100%(100%)	∞(∞)
		9/27	199	789	0	100%(100%)	∞(∞)
		BOTH	203	809	0	100%(100%)	∞(∞)
27/22	31.36	4L/22R	1323	6083	21(3)	99.65%(99.9%)	1.5(10.5)
		9/27	0	0	0	-	∞(∞)
		BOTH	1323	6083	21(3)	99.65%(99.9%)	1.5(10.5)
15/9	8.81	4L/22R	0	0	0	100%(100%)	∞(∞)
		9/27	333	666	32(1)	95.2%(99.8%)	0.3(8.8)
		BOTH	334	666	32(1)	95.2%(99.9%)	0.3(8.8)
ALL	96.67	4L/22R	1948	7963	66(6)	99.2%(99.9%)	1.5(16.1)
		9/27	1786	3955	97(10)	97.6%(99.7%)	1.0(9.7)
		BOTH	3734	11918	163(16)	98.6%(99.9%)	0.6(6.0)

TABLE 7-4 CAUSES OF THL DISCREPANCY

	4/9 CONFIG		33/27 CONFIG		27/22 CONFIG		15/9 CONFIG		ALL CONFIGS	
CAUSE	4L	9	4L	27	22R	27	4L	9	4L/ 22R	9/27
False Targets	34	56	0	0	18	0	0	31	52	87
Previous arr/dep	8	0	0	0	1	0	0	1	9	1
Vehicle	0	1	0	0	1	0	0	0	1	1
ARTS Handoff	1	7	0	0	0	0	0	0	1	7
Crossing a/c	1	0	0	0	0	0	0	0	1	0
Target tracking	1	1	0	0	1	0	0	0	2	1
TOTAL	45	65	0	0	21	0	0	32	66	97

Discussion of THL Discrepancy Results

Performance of the THLs was, in general, very good, particularly in light of the fact that hooded test procedures were in effect. The performance of the THLs under unhooded test conditions would be significantly better (see discussion below). Agreement between the THLs and ATC take-off clearances was in excess of 95% for all runway configurations and, in two of the three primary configurations, exceeded 99%. With unhooded test procedures in place, agreement between the THLs and the tower controllers would probably be close to perfect, mainly due to elimination of false targets, which account for 90% of the discrepancies.

There is not a significant difference between THL performance on the two instrumented runways. On 4L/22R, the mean time between discrepancies was about 1.5 hours versus 1 hour on runway 9/27. In unhooded testing, this performance would improve to about 1 discrepancy every 16 and 10 hours respectively.

THL performance in the 33/27 configuration was perfect. This is expected for runway 22R since THLs are not exercised in this configuration. However, unlike THLs on the other runways, the THLs on runway 27 were not affected by false targets and operated flawlessly through almost 8 hours of testing.

Performance in the 15/9 configuration is somewhat better than the results tend to suggest, primarily because, with one exception, all of the discrepancies were caused by false targets, 80% of which were caused by a single false target in one 1-hour test period. Performance for unhooded testing, albeit based on the limited amount of test data, is expected to be better than 1 discrepancy every 8.8 test hours for the runway 9 THLs in the 15/9 configuration.

Performance in the 27/22 configuration is again perfect for the runway 27 THLs because they are not exercised in this configuration. Although 21 discrepancies were observed during more than 31 hours of testing in this configuration for the 22R THLs, 18 of these were caused by false targets, 10 of which occurred in just two tests. Performance for unhooded testing would be no worse than one discrepancy every 10.5 test hours.

Performance in the 4/9 configuration was the worst of the three major configurations, with mean time between discrepancies at about 1 and 0.8 hours for runways 4L and 9, respectively. This was partly due to the fact that, in addition to false targets, which accounted for 75% and 86% of the discrepancies (runways 4L and 9, respectively), there were two other fairly significant discrepancy sources: ARTS to ASDE handoffs for runway 9 THLs, and previous arrivals for 4L THLs. ARTS to ASDE handoff problems cause THL discrepancies on runway 9 when arrivals to 4L are incorrectly predicted by the AMASS software to land on 4R, which crosses runway 9 just ahead of the THLs. Previous arrivals cause only minor (i.e., short duration) problems when controllers are clearing aircraft for take-off during periods of high frequency concurrent arrivals and departures, and they appear to be controller-dependent.

Performance for unhooded testing would be no worse than one discrepancy every 16.3 and 5.4 test hours (runways 4L and 9, respectively), the large improvement in 4L performance being attributable to elimination of (a) multiple handoff discrepancies and (b) discrepancies caused by previous arrivals/departures.

7.2.5.6 Missed Detections and False Alarms -The rates of occurrence of observable anomalies (i.e., missed detections and false alarms) are shown in Table 7-5. Observable anomaly rates are calculated based on an estimated REL anomaly observability ratio of 70% (i.e., 70% of REL anomalies would have been observable by a pilot had the lights been exposed). The corresponding anomaly observability ratio for THLs is assumed to be 100%, since THLs need to be observable before the logic will turn them on[7]. The causes of REL and THL anomalies are shown in Tables 7-6 and 7-7, respectively.

These results reflect only those anomalies which were classified by the automatic processing software as <u>definite</u> anomalies. Budgetary constraints precluded analysis of additional <u>possible</u> anomalies and restricted the number of tests analyzed to a limited sample, equivalent to about 42 hours of data.

7.2.5.7 Discussion of Missed Detection and False Alarm Results - Referring to Table 7-5, the rate of observable False Alarms meets the requirement of one observable FA per 25 operations. The rate of observable Missed Detections, however, does not achieve the requirement. However, almost all of both types of anomaly could be eliminated by some straightforward modifications to the AMASS software, most notably:

a) improvement of the ARTS-to-ASDE handover algorithm,

b) modifications to the target tracking filter,

c) improvements to the radar processing algorithms, including false target detection, clutter rejection, and multipath recognition, and

d) improvements to the slow target heading algorithm.

In addition to the anomalies arising from problems with AMASS, which accounted for over 90%, several anomalies appeared to result from erroneous RWSL logic:

1. In two tests conducted while the airport was operating in the 4/9 configuration, the RELs at the intersection of 15R/33L with 4L repeatedly blinked on and off during arrivals to, and rollouts on, runway 4L for no apparent reason, causing numerous Missed Detections.

2. On several occasions during 27/22 operation, targets entering runway 22R for an intersection take-off at taxiway T would fail to activate the THLs along 22R. This appeared to be only while the target was moving the wrong way (North) down runway 22R.

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[7] The only exception to this is the extremely rare situation in which a false target appears in the THL arming region and all other conditions are satisfied for illuminating THLs.

TABLE 7-5. OBSERVABLE ANOMALY RATES

	4/9			27/22			15/9			ALL		
	REL	THL	Both	REL	THL	Both	REL	THL	Both	REL	THL	Both
Missed Detections per hour	4.8	4.8	9.6	1.1	3.2	4.3	3.9	0.7	4.6	3.0	2.3	5.3
Number of operations per Missed Detection	19.3	19.4	9.7	79.3	28.5	21.0	23.7	134	20.1	30.9	40.1	17.5
False Alarms per hour	1.4	1.2	2.6	0.7	1.1	1.8	1.2	0.4	1.6	1.1	1.1	2.2
Number of operations per False Alarm	64.3	78.6	35.4	131	80.5	49.8	75.8	268	59.0	86.4	83.7	42.5
Anomalies per hour	6.3	6.0	12.2	1.8	4.3	6.1	5.2	1.0	6.2	4.0	4.8	8.8
Number of operations per anomaly	14.8	15.6	7.6	49.4	21.0	14.8	18.0	89.3	15.0	22.8	19.1	10.4

TABLE 7-6 CAUSES OF REL ANOMALIES

	4/9		27/22		15/9		TOTAL	
CAUSE OF ANOMALY	MD	FA	MD	FA	MD	FA	MD	FA
ASDE track drop while taking off	22	0	11	1	1	0	34	1
ASDE track drop while landing	2	0	2	0	0	0	4	0
ARTS-to-ASDE hand-off	74	34	11	9	15	2	100	45
False ASDE target	1	2	6	2	0	3	7	7
False ARTS track	0	1	3	1	0	0	3	2
ARTS tracking error	0	0	0	0	0	0	0	0
Reacquisition error	0	1	0	5	0	0	0	6
Erroneous heading estimate	0	0	0	2	0	0	0	2
Other, including RWSL logic	28	0	0	0	0	0	28	0
TOTAL	127	38	33	20	16	5	176	63

TABLE 7-7 CAUSES OF THL ANOMALIES

	4/9		27/22		15/9		TOTAL	
CAUSE OF ANOMALY	MD	FA	MD	FA	MD	FA	MD	FA
ASDE track drop while taking off	1	0	7	0	0	0	8	0
ASDE tracking error	5	0	1	0	0	0	6	0
ARTS-to-ASDE hand-off	63	3	2	0	0	0	65	3
False ASDE target	0	12	0	16	0	0	0	28
Crossing aircraft	0	5	0	6	0	0	0	11
ARTS tracking error	4	1	0	0	0	0	4	1
Reacquisition error	0	1	0	0	0	1	0	2
Erroneous heading estimate	4	0	0	1	0	0	4	1
Multipath	11	0	43	0	2	0	56	0
Dropped track in arming region	0	0	4	0	0	0	4	0
Other, including RWSL logic	1	0	8	0	0	0	9	0
TOTAL	89	22	65	23	2	1	96	46

7.2.5.8 Effects of LM Software Version 20

7.2.5.8.1 Introduction -This section provides a comparison of the performance of the RWSL Light Manager software versions 16 and 20. The most significant differences between the two versions were:

1. Approach algorithms were modified in an attempt to improve ARTS-to-ASDE handoff problems during curved approaches, particularly to runway 4L in the 4/9 configuration.
2. A new algorithm was implemented to identify false targets on active runways. The algorithm works by labeling static targets which appear on active runways outside of THL arming regions as false targets.
3. Algorithms were added to reduce the labeling of targets on taxiway N as multipath as they approach runway 22R in the 27/22 configuration.
4. Changes were made to the keyboard entry software to reduce the possibility of accidental interruption of AMASS/LM processing.

7.2.5.8.2 Tests Analyzed -Tests analyzed are summarized in Appendix I, Table I-2. In summary, data from a total of 1,824 operations conducted over more than 20 hours were analyzed. The data encompasses fairly diverse traffic conditions, covering times of day between about 9:00 a.m. and 8:00 p.m. The average traffic load was almost 88 operations/hour with a fairly even mixture of arrivals and departures (897 arrivals versus 927 departures).

7.2.5.8.3 Performance Measures - The intent of the algorithmic changes in the software was to reduce the number of discrepancies. This is therefore the key performance measure used in comparison of the two software versions. However, because of the way in which the false target identification algorithm works, there is a possibility that real targets on active runways might be labeled as clutter, thereby reducing the effectiveness of the safety logic. Such situations would be captured by the analysis software and would appear in the results as an increase in the number of MDs. However, the effect of the change made to reduce multipath effects on taxiway N would be to *reduce* the number of MDs. Budgetary constraints, however, precluded the analysis of MDs.

7.2.5.8.4 Results - Results of using LM software version 20 are shown in Tables 7-8 and 7-9.

Discussion

Clearly, the false target identification scheme significantly reduced the number of THL discrepancies. However, the price to be paid in terms of a loss of RWSL capability cannot be gauged without a full analysis of Missed Detections and possibly additional testing. The fix which was implemented was satisfactory for conducting the unhooded testing but is not a long term solution to the problem.

The change to the ARTS-to-ASDE handoff algorithm also had a significant effect, reducing the number of REL discrepancies on 4L approaches by 50%. This modification was, however, somewhat cosmetic, and would have sufficed for unhooded testing but a longer term solution is needed if RWSL is to be incorporated into a production program.

7.2.6 Validation of Data Processing Methodology

7.2.6.1 Objectives - A heavy reliance was placed on the data processing method which was adopted. Because the process was automated to the maximum extent possible, validation was needed to ensure that the approach and, in particular, the automation software, worked as required.

The objectives of the Methodology Validation effort were to:

a) determine the effectiveness of the adopted approach,

b) determine the accuracy and consistency of the results,

c) determine to what extent the method could be relied upon, and

d) identify limitations of the method.

TABLE 7-8. REL DISCREPANCIES - DIFFERENCE BETWEEN LM SOFTWARE VERSIONS 16 AND 20

RUNWAY CONFIG	DURN (hrs)	RWY	NUMBER OF ATC REL CLRNCES	NUMBER OF DISCREPS		PERCENTAGE IN AGREEMENT		MTBD (hrs)	
				V16	V20	V16	V20	V16	V20
4/9	13.97	4L/22R	961	18	9	98.1	99.0	0.8	1.6
		9/27	486	1	1	99.8	99.8	14.0	14.0
		BOTH	1373	18	9	98.7	99.3	0.8	1.6
33/27	0.96	4L/22R	0	0	0	-	-	∞	∞
		9/27	31	0	0	100	100	∞	∞
		BOTH	31	0	0	100	100	∞	∞
27/22	2.66	4L/22R	208	5	5	97.6	97.6	0.5	0.5
		9/27	0	0	0	-	-	∞	∞
		BOTH	208	5	5	97.6	97.6	0.5	0.5
15/9	2.72	4L/22R	2	0	0	100	100	∞	∞
		9/27	92	0	0	100	100	∞	∞
		BOTH	94	0	0	100	100	∞	∞
ALL	20.31	4L/22R	1171	23	14	98.0	98.8	0.9	1.5
		9/27	606	1	1	99.8	99.8	20.3	20.3
		BOTH	1706	23	14	98.7	99.2	0.9	1.5

TABLE 7-9. THL DISCREPANCIES - DIFFERENCE BETWEEN LM SOFTWARE VERSIONS 16 AND 20

RUNWAY CONFIG	DURN (hrs)	RWY	NUMBER OF THL EXPOSRS	NUMBER OF DISCREPS		PERCENTAGE IN AGREEMENT		MTBD (hrs)	
				V16	V20	V16	V20	V16	V20
4/9	13.97	4L/22R	624	25	11	96.0	98.2	0.6	1.3
		9/27	786	58	6	92.6	99.2	0.2	2.3
		BOTH	1410	83	17	94.1	98.8	0.2	0.8
33/27	0.96	4L/22R	0	0	0	-	-	-	-
		9/27	108	1	0	99.1	100	1.0	∞
		BOTH	108	1	0	99.1	100	1.0	∞
27/22	2.66	4L/22R	520	10	5	98.1	99.0	0.3	0.5
		9/27	0	0	0	-	-	-	-
		BOTH	520	10	5	98.1	99.0	0.3	0.5
15/9	2.72	4L/22R	3	0	0	100	100	-	∞
		9/27	186	29	1	84.4	99.5	0.1	2.7
		BOTH	189	29	1	84.7	99.5	0.1	2.7
ALL	20.31	4L/22R	1147	35	16	97.0	98.6	0.6	1.3
		9/27	1080	88	7	91.9	99.3	0.2	2.9
		BOTH	2227	123	23	94.5	99.0	0.2	0.9

7.2.6.2 Approach - The approach taken to validate the data processing method was to manually process test data and check manually derived results against automatically derived results. In addition, results from the process were compared against results derived from the RWSL Light Manager Analysis Tool. This is a tool that has been developed to verify the operation of the Light Manager logic as an independent software unit. It differs from the system data processing approach in that it makes extensive use of internal data (in particular, AMASS target tracks) to determine when inconsistencies in the logic occur. Comparing results against the LM Analysis Tool outputs raises the level of confidence in the process considerably.

7.2.6.3 Effectiveness of the Data Processing Method - By adopting the tower controller as "absolute truth," the process naturally captures the human variation associated with movement of traffic. This includes variations in the way tower controllers operate the airport and the observability of lights by pilots.

The analysis process proved to be highly effective in capturing errors. All discrepancies observed by analysts were captured. The process also captured almost all missed detections and false alarms which last for more than 3 seconds observed by analysts. Flicker detection software was also added to capture some of the errors which last for less than 3 seconds.

The process also captured several errors that may not have been captured otherwise:

- THL arming region problems on runway 27
- Split THL problem on runway 9
- Arming region on runway 9
- Early departure

Results generated by the data processing method were also compared against outputs generated by the LM Analysis Tool. This tool is highly efficient in capturing missed detections which are not readily captured by the automatic processing software (e.g., MDs due to track drops during take-off roll). From tests checked against the LM tool, the processing method has captured all RWSL Tool "Significant Events"[8].

There are, nevertheless, some known limitations to the data processing scheme, primarily involving targets moving at high speed for which the RWSL logic associates a t-second hot zone. Details of these limitations can be found in Appendix C.

7.2.7 Lessons Learned

Results of the hooded testing of RWSL have demonstrated excellent performance in most of Logan airport's four main runway configurations. Agreement between the light states (both RELs and THLs) and controllers' instructions were in agreement in more than 98% of the instances in which pilots/vehicle operators were instructed to proceed past locations of the lights.

The causes of discrepancies on the rare occasions in which light states and controllers' instructions were not in agreement were found to be caused by three primary contributors:

1. False targets, affecting THLs on runways 9, 15R, 4L, and 22R. Runway 27 RELS were not adversely affected by false targets.
2. ARTS-to-ASDE handoffs, causing REL discrepancies primarily on runway 4L in 4/9 configuration, but also to a lesser extent, RELs on runway 22R in 27/22 configuration, and THLs on runway 9 in 4/9 configuration.
3. Problems due to early departures, causing REL discrepancies primarily on runway 22R in 27/22 configuration.

Other performance anomalies in the form of Missed Detections and False Alarms were caused mostly by problems with the AMASS software:

1. ARTS-to-ASDE handoffs.
2. ASDE target tracking filter for rapidly accelerating or decelerating targets.
3. Clutter mapping.
4. Multipath rejection.
5. Slow target heading estimation.

The effects of most of these problems can be eliminated or reduced by improvements to the AMASS software.

There were, in addition, some problems associated with the RWSL logic:

1. Early departure.
2. Land and Hold Short operations.
3. Intersecting runways.

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[8] LM Tool Significant Events are operational anomalies, including situations in which aircraft cross through a light which is on.

4. Operations involving vehicles.

These could be eliminated by providing additional inputs, such as vehicle/aircraft classification, aircraft height, aircraft identity, and controller intent.

7.3 DRY RUN UNHOODED TESTING

7.3.1 Introduction

The Runway Status Lights installed at Logan Airport underwent extensive hooded testing. Data were collected and analyzed to assess system performance relative to the desired performance, as derived from experienced Shadow Air Traffic Controllers stationed on the 16th floor of the Control Tower. System performance results were presented to the New England Regional Office of the FAA for evaluation. Permission was granted by the FAA to conduct only limited nighttime testing with the light hoods removed using only dedicated test aircraft and surface vehicles. Unhooded testing that might interfere with normal airport operations was not permitted.

The goal of the original unhooded test program was to collect extensive human factors responses from pilots during normal operations for a variety of runway configurations, aircraft types and operational conditions. The plan was to collect sufficient data to enable the development of quantitative performance statistics with associated high levels of confidence. After the FAA's decision, it became necessary to down-scope the original extent of planned test activities to be consistent with imposed test restrictions. However, the overall goal of the unhooded testing remained unchanged: to acquire as much data as possible which is relevant to assessing the users' response to the RWSL System.

This section describes tests conducted during nighttime unhooded testing of the RWSL system at Logan Airport. Because of the test restrictions, the planned testing focused more on qualitative than on quantitative results.

7.3.2 Objectives

Quantitative test data were recorded with the lights hooded. Independent test instrumentation enabled the measurement and recording of system response and light illumination conditions, behind the hoods, for a broad spectrum of operational conditions. Based on an analysis of nearly 100 hours of operational data, quantitative performance statistics were generated and significant information was derived about the operational performance of the system. These data were presented to the FAA for evaluation and were used to identify both the strong and weak points of the system. Additionally, every attempt was made to correct the identified weak points. Certain fundamental limitations associated with the ARTS and ASDE radar sensors which are beyond the control of this project could not be corrected within the constraints of the RWSL program. From the system engineering point of view, these specific problems were associated with the existing test system implementation and could be avoided in an operational system design. Because the system limitations were well understood, it was possible to acquire meaningful test information under controlled operating conditions.

It was recognized from the beginning of the RWSL program that human factors issues needed to be addressed during unhooded testing. One of several human factors issues which needed to be evaluated was the possibility that pilots might misinterpret the lights, thereby introducing a possible safety problem. It was also necessary to validate key engineering assumptions/parameters that dictate system operation and therefore impact the information presented by the system to the pilots and vehicle operators. The primary nighttime test objectives were directed at obtaining human factors feedback in a pseudo-operational environment under controlled conditions. A secondary focus was on validating important assumptions made during the engineering of the system and during the hooded test analysis. Since most of the important engineering assumptions impact both pilots and surface vehicle operators, it was expected that meaningful data could be obtained by exploiting the use of surface vehicles in addition to a limited number of aircraft operations. This information would be valuable in completing the overall evaluation of RWSL at Logan and in understanding the real requirements for an operational system that might be deployed in the future.

The specific objectives of the nighttime testing identified were:

1) Determine pilot and (vehicle) operator reactions to normal operation of the unhooded lights in a pseudo-operating environment.

2) Validate engineering assumptions, made during system development, regarding expected acceptable human factors responses: a) assumed allowable three-second tolerance between the light transition and the Air Traffic Controller's directive, b) length of hot zones, c) state transition points (speed/trajectory).

3) Determine if the lamp response time, illumination level and visibility is suitable to the human observer; determine if the RWSL lights introduce any confusion with other lights on the airport and if other lights interfere with the RWSL lights or vice versa.

4) Determine if pilots/operators feel there is an "implied clearance" associated with a light turning off before clearance is given by the controller.

5) Validate the system instrumentation performance indications through human observations: a) indicated light state, b) state transition timing.

6) Obtain Air Traffic Controller reactions to voice traffic while operating with the lights unhooded.

7) Demonstrate system functionality/response not previously exercised during hooded testing: a) vehicle/aircraft stops for extended period and is incorrectly interpreted as a false target, b) mid-runway takeoff, c) late landing abort, d) vehicle/aircraft violation of hold position, e) wrong direction of travel on runway.

7.3.3 Methodology

The test period commenced on May 12, 1997 and lasted for one week. Testing was conducted during the midnight shift at Logan airport and utilized two surface vehicles and one light aircraft. The aircraft was piloted by experienced pilots, one having close association with the RWSL program and the other who was not familiar with the RWSL system. Vehicle operators were licensed by MASSPORT and briefed on the RWSL operation. Test observers were also present in the aircraft and vehicles to support data collection and to observe the reactions of the pilot/operator to specific RWSL conditions.

All airport operations during testing were under the control of the Air Traffic Controller in the Tower Cab. The controller was supported by an FAA Liaison who had both a detailed understanding of the RWSL system and experience with Logan operations. The FAA Liaison helped to coordinate execution of the Test Plan and had a direct telephone link with RWSL Operations on the 16th floor, thereby enabling rapid communication of any ATC directives to modify or suspend testing in the event of operational priorities. Logan midnight operations normally use runway 33L for landing and runway 15R for departures of normal traffic, subject to winds and weather conditions. The dry run unhooded tests used runways 9/27 and 4L/22R, subject to runway availability. The test runways were closed to normal traffic by the controller. All test operations were conducted in a manner that minimized noise.

The aircraft and vehicle observers were in direct radio contact with RWSL Operations on a MASSPORT maintenance frequency. All ATC communications were via normal ATC frequencies. RWSL System control was accomplished in the RWSL Operations Center on the 16th floor of the tower. Key operating positions in RWSL Operations were: Test Director, Shadow Controller and System Operator. Each of these test positions was staffed with experienced RWSL personnel. All tests were conducted in accordance with predefined test plans and procedures and in compliance with ATC directives throughout the duration of the tests. The following tests were identified in the test plan in support of the test objectives:

a) AIRCRAFT ON CROSSING TAXIWAY AHEAD
    i) Normal speed aircraft taxiing across runway ahead
    ii) Low speed aircraft taxiing across runway ahead
    iii) Aircraft halted in crossing taxiway ahead
b) AIRCRAFT ON CROSSING TAXIWAY BEHIND
    i) Normal speed aircraft taxiing across runway behind
    ii) Slow speed aircraft taxiing across runway behind
    iii) Stationary aircraft on runway behind
c) AIRCRAFT ON RUNWAY AHEAD

- i) Stationary aircraft ahead waiting to take off
- ii) Stationary aircraft ahead
- iii) Back taxiing aircraft ahead

d) PREVIOUS ARRIVAL ON RUNWAY AHEAD

- i) Previous arrival ahead, slow exit
- ii) Previous arrival ahead, high speed exit

e) DEPARTURE ON RUNWAY AHEAD

- i) Slowly accelerating previous departure ahead.
- ii) Rapidly accelerating previous departure ahead.
- iii) Slowly moving aircraft enters runway behind holding aircraft.
- iv) Medium speed aircraft enters runway behind holding aircraft.
- v) Rapidly moving aircraft enters runway behind holding aircraft.
- vi) Moving aircraft entering for take-off ahead
- vii) Departure abort (THLs)
- viii) Departure abort (RELs)

f) AIRCRAFT ON CROSSING RUNWAY

- i) Arrival on crossing runway
- ii) Departure on crossing runway
- iii) Landing abort on crossing runway
- iv) Departure abort on crossing runway

g) SPLIT THL OPERATION

- i) Normal
- ii) High speed departure ahead
- iii) Low speed departure ahead
- iv) Back taxi

h) LANDING AIRCRAFT

  i) Hot zone test

i) NORMAL DEPARTURE

  i) Departure test

A full description of these tests and supporting procedures can be found in [7-3]. These tests were executed on each of the four instrumented runways: 4L, 22R, 9, and 27.

7.3.4 Test Results

Due to budgetary constraints, results are presented only for tests conducted on runway 22R. Table 7-10 shows, for each of the tests conducted, how the system operated from an engineering perspective. It also shows specific comments received from three sets of observers:

A. Observer(s)[9] in vehicle A[10].

B. Observer(s) in vehicle B.

C. Observer in aircraft (C).

TABLE 7-10. RUNWAY 22R TESTS

TEST	ENGINEERING PERSPECTIVE	OBSERVER'S PERSPECTIVE
1a	System operated normally	C: THLs did not turn on
1b	System operated normally	C: THLs turned on late
1c	System operated normally	C: THLs turned off late
2a	System operated normally	C: THLs did not turn on
2b	System operated normally	C: THLs did not turn on
2c	System operated normally	C: THLs did not turn on
3a	System operated normally	No response
3b	System operated normally	B1,B2: THLs operated well

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[9] In some tests, there was only one observer. In others, there were two or more.

[10] Vehicle identifiers correspond to identifiers in the Test Procedures [7-3].

TABLE 7-10. RUNWAY 22R TESTS (cont.)

3c	THLs turned off when aircraft reached high speed taxi and turned off as aircraft slowed down	A1,A2: RELs did not turn on B1,B2: THLs operated well
4a	System operated normally	B2: THLs operated well
4b	Not applicable to this runway	N/A
5a	System operated normally	C: THLs on left hand side of runway blend in with VASI to the point where they are hardly noticeable. THLs do not turn on when vehicle enters runway ahead.
5b	System operated normally	B2: RELs turned on OK, turned off too early C: No THLs when vehicle in front. THLs flickered off and on momentarily
5c	Not applicable to this runway	N/A
5d	Not applicable to this runway	N/A
5e	Not applicable to this runway	N/A
5f	Not applicable to this runway	N/A
5g	System operated normally except for a faulty THL and the LC crashed.	C: One THL was not on. THLs did not turn on. B1: THLs operated OK.
5h	Departing target dropped on take off roll	A: RELs did not turn on B1: THLs operated well C: THLs operated well
6a	Test not conducted	N/A
6b	System operated normally	C: THLs turned on and off too early.
6c	System operated normally	B2: THLs turned on OK, but turned off early
6d	Test not conducted	N/A
7a	System operated normally	B1: THLs operated well B2: THL brightness level 5 better than level 4
7b	System operated normally	B1: THLs operated well B2: THLs came on a little late
7c	Test not applicable to this runway	N/A
7d	THLs did not operate correctly	B1: THLs operated well B2: No response
8a	System worked poorly. Aircraft was not tagged by ARTS	A1,A2,B1,B2: RELs failed to turn on

TABLE 7-10. RUNWAY 22R TESTS (cont.)

8a1	Target dropped on handoff from ARTS to ASDE	A1: RELs on when should have been off, and off when should have been on. A2: RELs off when should have been on. RELs stayed on too long after clearance from tower. RELs turned on much too late B1: RELs worked perfectly
9a	System operated normally	A1: RELs failed to turn on as expected B1,B2: Incorrectly positioned for this test

7.3.5 Discussion

In test 1a, the THLs did not appear to turn on for the following reason: The vehicle was crossing the runway at 30 kts. Because the RWSL logic implements anticipated separation for vehicles crossing a runway, the vehicle had no sooner entered the runway than the logic predicted that it would be leaving. The net result was that the lights were only turned on by the logic for 1 second. On average, the lights take about 1.5 seconds to reach full brightness and about 0.5 seconds to turn off after being on. As a result, the THLs did not appear to turn on to the observer. This raises two issues. Firstly, is the system really enhancing safety? It appears as though it probably is based on hooded test results. However, the extent of the THL activation regions is probably right at the threshold between enhancing safety and maintaining traffic flow. Secondly, it would appear that, based on our observer's comments, a real user would probably have doubts about the utility of the system if a similar situation were to arise in operational testing.

Another aspect of the same problem occurs in test 1b, in which the THLs turn on late, implying that the activation region might be too narrow. However, it was found during the hooded testing that the THL activation region had to be made narrower to circumvent the problem of previous arrivals on runway 4L, in which aircraft were being cleared for take-off before the previous arrival had apparently, entirely cleared the departure runway. One possible solution may be to adapt the width of the THL activation region according to traffic density and runway configuration. During periods of heavy arrival and departure traffic on runway 4L, the activation region can be made narrower than during light traffic. Also, since most arrivals in the 27/22 configuration are to 22L, the previous arrival problem does not occur as frequently, from which it follows that a wider THL activation region can be tolerated when operating in the 27/22 configuration.

To complicate matters further, in test 1c, the THLs were observed to turn off late, implying an activation region that is too wide. It should be noted that, in this test, the anticipated separation algorithm was not as effective due to the start/stop pattern of the crossing vehicle.

A final observation on the problems seen in tests 1a, b, c is that the observers were specifically looking for RWSL problems and a delay of 1 second (such as might be caused by inopportune timing between significant events and the ASDE radar scan) might be considered inappropriate performance. Pilots in an operational situation would not be as focused on RWSL.

Throughout the tests on runway 22R, observers noticed that one set of THLs blended with the VASIs at the approach end and on the left side of runway 22R. This problem was also noted during previous light observability tests on runway 27 (see Appendix E).

In tests 2a, b, and c, observer C (in the aircraft) noted that the THLs did not turn on in response to vehicles crossing behind while C was waiting in the THL arming region. This behavior is in accordance with the logic and is deemed appropriate because it would be legal to clear an aircraft for take-off while another aircraft or vehicle is crossing behind.

In test 3c, observers in vehicle A noted that the RELs did not turn on at all. This was due to a flag set in the RWSL logic which disables REL activations that result from high speed operations down a runway in the opposite direction to what is normal for the configuration in effect at the time. This option was adopted during hooded testing to eliminate some of the discrepancies resulting from runway inspections by vehicles. This decision was taken in accordance with the primary hooded test objective (which was essentially to do everything possible to get the system unhooded) and with the full knowledge that some RWSL capability was being sacrificed.

Also in test 3c, observers in the 22R arming region abeam taxiway N noted that the THLs operated well, despite the fact that they extinguished when the aircraft was approaching them at high speed. The anomaly in the observation is unexplainable. However, explanation of the THL behavior is as follows. The logic has a built-in feature which disables THLs from turning on if an aircraft appears to be taking off, even if the take-off is in the wrong direction for that runway at that time. This was designed to prevent pilots being faced with a red light at a critical point in the take-off operation. However, its applicability to THLs which are not facing the pilot is questionable, since they would provide some measure of protection against head-on collisions in such situations. The decision to operate the system in this way was made because of the tendency of the lights to rotate through 180 degrees, as was observed in test 5g for the THLs at the approach end of 22R during this test phase. Again, this philosophy may not be applicable to a production quality system.

In tests 5a and 5b, observer C reported that the THLs did not turn on even when vehicle B was directly in front of C's aircraft. This was due to the fact that both B and C were in the same THL arming region. Under these situations, the THLs were not designed to illuminate because this would confuse the pilot of the leading aircraft when given clearance to take off. Furthermore, under operational conditions, it is unlikely that two aircraft would be so close to each other. It should be noted that special logic is implemented in situations where the two sets of THLs are split by an intersection.

Also in test 5b, observers reported that the THLs flickered off and on. This was not observed on the AMASS display and the cause is unknown. An observer in a vehicle at taxiway C also reported that the RELs turned off too early, even though the RELs appeared to turn off as expected from observation of the AMASS display. (The same observation was made in test 9a by a different observer.) This raises a broader issue of whether anticipated separation for RELs is appropriate for vehicles waiting to cross a runway, since vehicles do not need time to spool up their engines. In a refined system, vehicle type would be available to the system and the duration of anticipated separation could be made adaptable to the type of vehicle waiting to cross.

In test 5g, observers reported that one of the THLs was not visible. This was found to be due to the light having rotated on its baseplate through 180 degrees. Later observations that none of the lights were working at all in this test were due to a Light Computer crash.

In test 5h, observers reported that the RELs turned off too early. This problem was caused by the AMASS tracker dropping the target as it commenced its take-off roll. Clearly, this problem, which was seen to cause numerous missed detections during hooded testing, invokes a negative reaction from observers as to the effectiveness of the system. In addition to the RELs not operating correctly, the problem also caused the THLs to momentarily flicker off, although this was not reported by observers. The fact that it was not reported was probably due to the short (1 second) duration of the anomaly, which may not be long enough for the lights to respond electrically to the point where they appear to be off.

In test 6b and 6c, which involved high speed operations on crossing runways, observers on the airfield generally noted that the THLs turned on and off too early. This observation might be expected since users on the ground cannot in general determine the location and speed of other aircraft on crossing runways. The same observers, however, noted during hooded testing when they were observing the system from the tower that timing was appropriate.

In test 7d, observer B1 reported that the THLs operated well, despite the fact that they did not operate as expected. The failure to perform as expected appeared to be due to two problems identified during hooded testing which caused the THLs to extinguish when they should stay illuminated. See section 7.2 for further details.

In test 8a, the RELs failed to illuminate in response to an aircraft landing on 22R because the aircraft was not tagged by ARTS. All observers noted that this was a highly undesirable aspect of system performance. In a subsequent repeat of test 8a (test 8a1), the aircraft was correctly tagged by ARTS but its arrival hot zone was very short due to its low airspeed (50 kts). Despite this, observers at taxiway N observed that the RELs worked very well. However, just after crossing the runway threshold, there was a problem with the handover from ARTS tracking to ASDE tracking and the target track was momentarily dropped. On reacquisition one radar scan later, because of its low speed, only those RELs immediately ahead were illuminated, which explains the comments from observers in vehicle A.

Conclusions

Despite the severe limitations imposed on the unhooded testing, it did provide some useful information, even though only a small subset of the test data could be analyzed in any detail and there were very few observers. Some, although not all, of the limited unhooded test objectives were achieved:

1. Reactions of pilots and vehicle operators were qualitatively assessed in a pseudo-operational environment. The general consensus was that the system was effective and easy to understand.
2. A brief analysis of the responses allowed some assessment of some of the assumptions made during development of the system, including the possible need for different anticipated separation parameters for ground vehicles and the extent of THL activation regions.
3. Lamp illumination characteristics, including response time and brightness, were assessed, but only under conditions of darkness. Some observers noted a possible confusion between THLs and VASI lights. It was also found that mechanical issues are extremely important and can have an adverse effect on safety if suitable care is not taken to ensure that light does not intrude into areas where it shouldn't (e.g., THLs rotated through 180°).
4. None of the observers reported feeling that there was an "implied clearance" when the lights turned off.
5. It was not possible within the confines of the testing to validate the system instrumentation performance.
6. Because of the way in which the testing was structured, i.e., with very little involvement from Air Traffic Controllers, reactions from the tower controllers could not be assessed.
7. The testing provided an ideal environment to exercise some of the rarer situations that did not occur during hooded testing, although a quantitative analysis could not be conducted within the constraints of the testing.

7.4 INTEGRATION AND RELIABILITY TESTING

7.4.1 Introduction

This chapter presents the results of specific engineering tests performed on the system during system integration and hooded testing. As elements of the system are integrated, tests are run to verify proper integrated operation. If a problem is detected, the first action is to analyze and correct the problem. The overall goal of integration testing is to groom the system to achieve the best possible performance with the available technology and off-the-shelf equipment used to implement the system. The test results presented herein represent the evolutionary performance of the system.

RWSL is an assessment system, not an operational system. Lights are used by some recently-installed systems (e.g., stop bars, SMGCS) to control airport surface traffic. However, RWSL is the first time that automated airport surface traffic control with lights has been attempted in a dynamic operational environment using surveillance radar rather than manual inputs. Since there is no precedence for RWSL, detailed performance requirements are not available from the FAA. Consequently, one of the important outputs of the RWSL System assessment is important requirements that will need to be achieved if and when RWSL is deployed as an operational system.

System integration is a process of achieving the overall system by making the individual elements play together. Each system element needs to perform as required and the interaction of the individual elements must satisfy the overall system requirements and objectives. The process of determining if a system meets its requirements is called verification. In the context of the RWSL System, verification answers the question:

Are the required *light states* achieved within the required *time*?

Clearly, key performance indicators for the RWSL System are *light states* and *time*.

RWSL is comprised of several elements or subsystems, illustrated in Figure 7-3, that must operate as an integrated system. During hooded testing, the RWSL lights are not exposed to the pilots and vehicle operators; operation of the RWSL is self contained and test instrumentation is used to measure system performance. Once the light fixture hoods are removed, the RWSL becomes part of the larger overall operational configuration illustrated in Figure 7-3; the end user (pilots and vehicle operators) now judge performance, which is the process of validation.

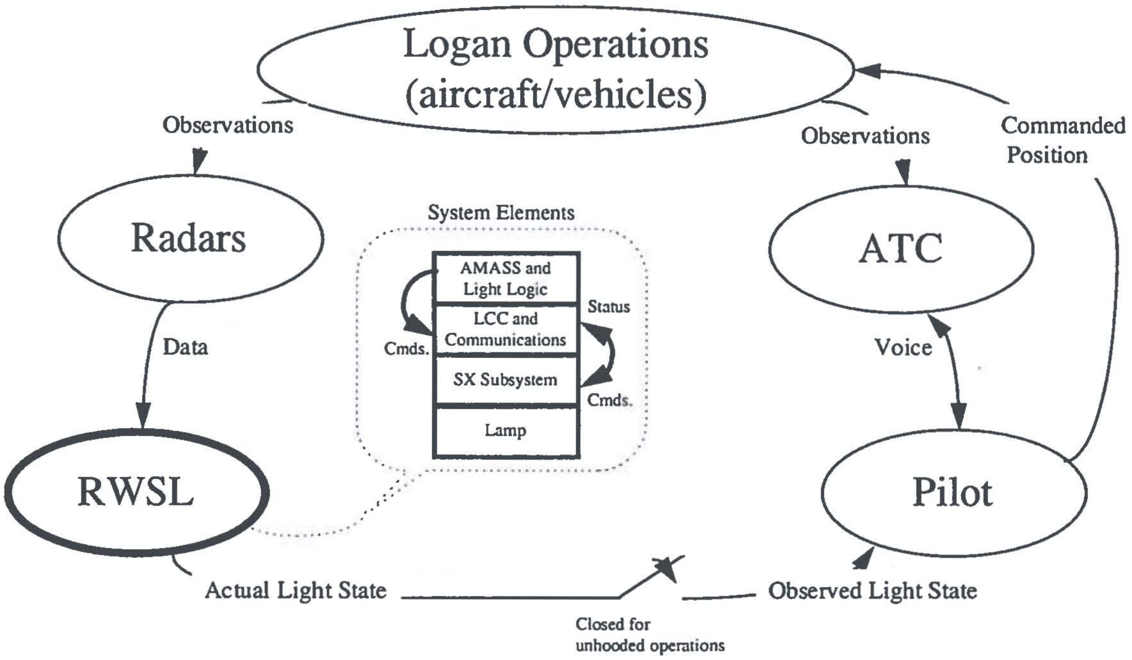

FIGURE 7-3. OPERATIONAL CONTEXT OF RWSL SYSTEM AT LOGAN INTERNATIONAL AIRPORT

Integration testing focuses on system verification. Tests are designed to identify problems or performance limitations that may result in incorrect light states due to errors or produce excessive time delays. System reliability is also addressed as part of integration testing. Two elements of reliability are evaluated: equipment reliability/availability and performance reliability. The first address issues that are typically associated with failures that deny normal system operation whereas performance reliability focuses on the stochastic nature of light state timing due to communications errors.

7.4.2 Integration Verification Testing

System integration testing was initiated during warehouse testing at the Volpe Center, prior to RWSL deployment at Logan. The warehouse provides convenient end-to-end instrumentation in support of performance testing and is an ideal environment for software verification. However, there are significant system and environmental conditions at Logan that limit the effectiveness and coverage of testing in the warehouse: topography and environment of the power cables on five circuits, actual interfaces with the ARTS and ASDE-3 radars, and communications links used at Logan.

Primary performance issues associated with the major system elements, and addressed during integration and reliability testing, are summarized as follows:

1. **Radar Processing**—Does the AMASS-processed radar data represent Logan operations with the required accuracy/fidelity?
2. **LM Light Logic**—Does the light logic respond as specified and is it "correct" for all operational situations?
3. **LCC**—Does the LCC transmit the correct light Command Table to the LC in the Lighting Vault and does the LCC correctly interpret the Status Table from the LC
4. **Communications**—Is command and status information transferred correctly between the LCC and LC?
5. **SX Subsystem**—Are Command Table light states achieved by the lamps within the specified time and is the correct light status sent to the LCC?

It is important to note that the above performance issues are not a testing afterthought! These issues were specifically addressed in the system design and at the subsystem development level. An underlying objective of the system design is to maximize the performance reliability and integrity of the system. Every reasonable attempt has been made with the commercially-available equipment to present accurate and timely runway status information to the end users.

Quantitative assessment of the first two performance issues is the focus of the hooded assessment and the observed performance is addressed in Section 7.2; the remaining issues are addressed in this section (see Section 7.4). The following paragraphs summarize important integration testing and qualitative observations associated with the identified system elements. Quantitative reliability and performance data is presented in subsequent sections.

Radar Processing—RWSL performance and availability is only as good as the availability and quality of the surveillance data. The radar data and associated interfaces at Logan are not dedicated to the RWSL program and are not under common configuration control. Consequently, ASDE-3 maintenance periods caused availability problems and an unexpected change in the format of the ARTS data to handle the TCAS down link information caused ARTS data to be unavailable to RWSL for about two weeks. At Logan, the RWSL interface with the

ARTS computer is implemented through the Maintenence Scope which introduces availability problems when the scope is used for its intended purpose. Although these problems are accommodated with assessment system procedures, these availability issues will need to be addressed with interface controls in an operational system.

During hooded testing, visual observations of experienced Shadow Air Traffic Controllers are used to assess the validity and reliability of the radar data at Logan. Aside from the above system availability problems, remaining radar data problems following integration testing are: false targets, dropped radar tracks and irregular handoffs of targets between the ARTS to the ASDE-3. These residual problems are fundamental to the sensors and the associated AMASS processing and are beyond the scope of the RWSL development and integration activities. These are issues that will need to be addressed and improved in a fully operational RWSL.

During hooded testing, a question was raised regarding the accuracy of the ASDE-3 indicated position relative to critical locations on the taxiways and runways, e.g., hold lines. Special tests were run on runway 9-27 and runway 4L-22R by positioning a vehicle at critical locations and observing the action of the Light Logic. These tests provide verification of the light logic map registration relative to the radar and the physical locations on the pavement, along with the response of the Light Logic at these critical positions. In summary, the worst case offset between the position of the vehicle when the lights changed state and the desired position at which the light should change state is 25 feet. In most cases the position offset error is less than 10 feet. These measured offsets are considered acceptable given the position of the hold lines.

LM Light Logic—The Light Manager and its associated Light Logic are hosted in the AMASS computer and can be viewed as the "brains" of the RWSL System. Surveillance data preprocessed by AMASS is used to identify the lights that should be on and off each one-second cycle of the input data. Extensive verification testing of the light logic and associated computer software was performed in a laboratory environment for over a year and used both simulated data (i.e., sprites) and operational log files recorded at Logan. These log files were also used to support integration testing in the warehouse. The full spectrum of potential situations have been evaluated, including operationally unlikely conditions such as simultaneous takeoffs or landings on the same runway. All runway configurations under which RWSL needs to operate have been tested. Identified errors or performance deficiencies have been corrected within the constraints of the AMASS system functionality. Based on the integration and hooded testing, the LM software in the AMASS computer is stable in terms of the discovery of new code errors and operating without failing. Several improvements were made to the AMASS-human interface as a result of integration and hooded testing. Most of these improvements are classified as bullet proofing to eliminate system failures due to erroneous keyboard inputs. There were no failures of the AMASS hardware in nearly two years of operation.

LCC—The LCC is the maintenance and control console. Light commands received from the LM in the AMASS computer are converted to light groups, displayed, recorded and sent to the Lighting Power Vault on the field. Status of all the lights is returned to the LCC and displayed and recorded. Lights are commanded in groups to reduce the required communications bandwidth (see Appendix G). A single group command can activate any number of lights, which is considerably more efficient than sending individual commands to every light. Further, group commands help to ensure that lights which should change state at the same time do so; e.g., turning *off* all runway lights.

An automated unit-test process is used to verify the LCC's transformation of LM light numbers into light groups. The combinations of light numbers of the automated testing software commands are then compared with the light numbers in the resulting groups output by the LCC. This process is run in the laboratory on all software releases for all realizable combinations and permutations of lights for 100% verification of the correct transformation. In the airport environment, the LCC and AMASS displays are in close proximity and visual comparisons made during hooded testing further confirmed the correct transformation and display by the LCC of the light commands received from the AMASS.

In addition to processing light commands from the Light Logic, the LCC has the capability to accept manual group commands and lights can be masked to disable their operation if operational problems are encountered during unhooded testing. The manual command mode has the capability to run a script of light group commands with specified on-off cycle times. This capability is used extensively during system integration and reliability testing since it provides a means to control the light commands and ensure 100% test coverage of all light groups. This is the primary command process used for the reliability testing reported herein. **Quantitative integration testing reported in this chapter primarily addresses the portion of the system from the LCC input of group commands to the light response on the field, and the display of light status on the LCC.** Because unit testing verified that the LCC presents the same light information as the AMASS display and log files, the combined test results presented in Chapter 7 verify the performance of the complete system.

The SX Subsystem is required to provide health status for all lights to the LCC within 10 seconds to enable the detection of lamp failures and failures in the SX Subsystem. This status is displayed by the LCC. Although it was initially hoped that status would be available for all lights within one or two seconds following a command, integration testing shows that the time to gather status for all 170 SXs at Logan is nine seconds or longer (see Section 7.5). End-to-end integration test results (Section 7.4.3) verify that correct status is displayed each status cycle. Command response and reliability test data (derived from end-to-end integration testing) is presented in Sections 7.4.3. Time response goals are achieved and the system is close to achieving its response reliability goals.

Multiple group commands are issued by the LCC each second. The entire system from the LCC to the SX must be fast enough to process all of the commands while allowing time to poll for status before the next set of commands must be issued. Tests in the laboratory using log files recorded at Logan show that the goal of four commands-per-circuit each second may be exceeded by 50% once or twice an hour. Integration stress tests (Section 7.5) show that a command rate of 100% over the goal causes no problems in system operation.

The LCC has operated continuously for nearly two years with no hardware failures. Initial timing problems with the LCC software identified during initial integration testing were corrected and the software runs with a duty cycle of between 50% and 75%. The LCC has sufficient timing margin to guarantee that all processing is completed before the next data set from the LM needs to be processed.

Communications—The LCC is located on the 16th floor of the tower and it is necessary to communicate with the LC in the Lighting Power Vault that is approximately a half-mile away. A dedicated fiber optic communications link operating at 19.6 k bits per second provides high communications reliability due to its wide bandwidth and noise immunity. Commands are transmitted by the LCC in a table format (Appendix F) every second. When the command table is received in the vault, the current status table is immediately returned by the LC to the LCC. This provides a positive indication that the command table was received and processed in the vault.

Each table includes a check sum for error identification. Detected errors result in the entire table being rejected and reported to the LCC in the associated status message. Because the command broadcast mode is used, the next command table will contain the desired state for all of the lights on the airport. The only consequence of a missed command table is a one-second delay in the desired change of light states if the change happened to be in the missed table. Detected communications errors encountered (although infrequently) during integration testing were traced to timing problems in the software and corrected.

If communications is interrupted for any reason, an alarm is displayed on the LCC within one second and recorded in the log file. If communications is not restored within 5 seconds, it has been verified that the SX Subsystem automatically turns all lights off. The probability of undetected communications errors is expected to be very small given the safeguards built into the system. There is no evidence from all of the integration testing that suggests the occurrence of any undetected communications errors. If an undetected error should occur, it is automatically corrected within one second as a result of the command broadcast mode of operation. The occurrence of two or more undetected errors in a row would probably be a result of a system failure which would be obvious to the system operator.

SX Subsystem—There is an emerging technology for the control and monitoring of individual lights on a series circuit in the airport environment which is referred to within the RWSL Program as Smart Transformers. Although the worldwide installed base of SXs is small, along with the number of available vendors, the RWSL engineering team decided that the technology has the potential to meet the RWSL System requirements. Most important, SXs are designed to be fully compatible with existing lighting installations and equipment. A detailed description of the SX Subsystem is presented in Appendix G.

Extensive unit testing and integration testing of the SX Subsystem equipment has been performed in the Warehouse, Factory, and at Logan. Warehouse test results are contained in the report *Assessment Runway Status Light System Warehouse Testing* (see Appendix J—Bibliography) and in the end-to-end testing (Section 7.4.3) which provides quantitative indications of performance at Logan.

The Logan physical and electrical environments are rather harsh, much worse than originally expected prior to the SX Subsystem deployment. SX hardware and electronics reliability is not as high as desired; an excessively high infant mortality rate prompted several improvements in the original packaging (first production run of the Brite II Remotes) by the vendor. Identified problems with the original units installed at Logan include: water leakage; electronic component failures; mechanical failures due to rough handling, ice-crushing damage, and assembly problems. Failed units were replaced with the new package which appears to have better mechanical integrity and corrected identified circuit component failures. Figure 7-4 illustrates the cumulative number of SX failures as a function of time. Initially there was a high infant mortality followed by a nearly linear failure rate over a period of about three months. From August, 1996 to May, 1997 the SXs were continuously powered on (CCRs provided power to the SXs) and there were only two recorded failures during this entire period. It is conjectured that supplying power to the SXs throughout the winter prevented ice in the base cans from crushing the units, as happened during the previous winter when the CCRs were shut down following testing. In May, 1997 during the one-week dry run test period there were four new failures. These failures are attributed to the fact that the CCRs were turned off each day when the unhooded lights were unattended to prevent any possibility of an unhooded light illuminating. The data suggests that SX reliability is best if the SXs remain on and the power is not cycled. Although the rather high SX failure rate experienced at Logan is tolerable for the limited assessment effort reported herein, SX reliability needs to be improved significantly by the system vendor for a fully operational system to achieve essentially continuous availability.

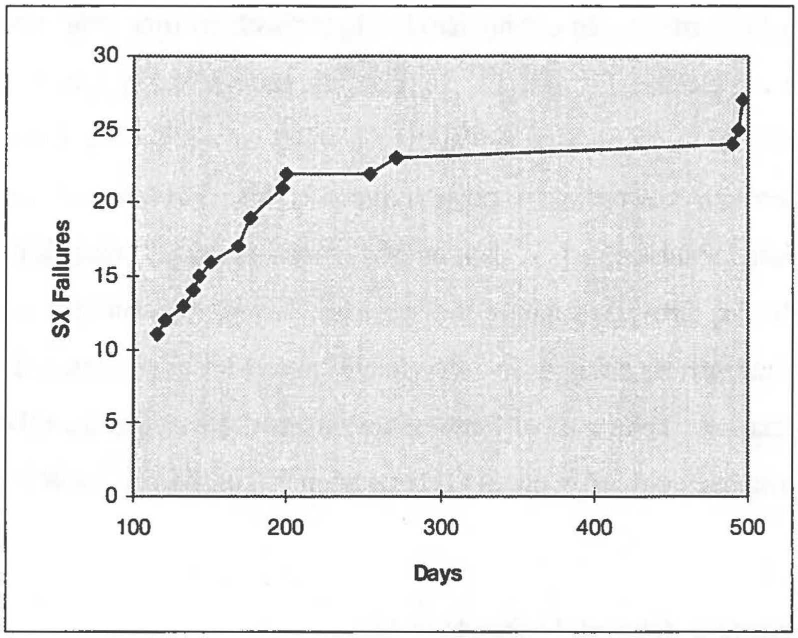

FIGURE 7-4 NUMBER OF SMART TRANSFORMER FAILURES AS A FUNCTION OF TIME

7.4.3 End-to-End System Testing

7.4.3.1 Objectives -The goal of end-to-end testing is to verify the overall operation of the light control system. This testing encompasses the LCC, fiber optic communication link between the 16th floor and the Lighting Power Vault, the entire SX Subsystem, and the light fixtures. Specific objectives of end-to-end testing are:

- Verify the correct response to all group commands at each fixture
- Verify that each SX is installed in the correct base can
- Verify the integrity of status reports at the LCC
- Measure the command response time
- Determine the command response reliability

End-to-end system tests were performed in the Warehouse as part of system development. However, it is critical that each light at Logan responds correctly to commands issued by the LCC and the reliability of the commands must be sufficient to support unhooded operation of the lights. Therefore, end-to-end testing is a necessary part of the Logan RWSL System integration effort.

A perfect system would illuminate (or extinguish) the lights with no time delay and there would be no missed commands or erroneous responses. In actuality, the SX Subsystem employs communications to control the lights (see Appendix G) and it is well known that all communications systems are susceptible to noise-induced errors. These errors can cause lost commands and/or missed status reports. Also, limited communications bandwidth introduces command response delays. Further, because the lights are driven by a constant current source they exhibit a significant turn-on delay due to the time it takes to heat the lamp filament to produce visible illumination. Taking all of these issues into consideration, the following light control system performance goals (Appendix G) have been established by the RWSL development team:

- Command response time delay of 3 seconds or less
- 99% probability of correct response to first try of command
- 99.9% probability of correct response after second try
- 100% probability of correct response after third try.

These are engineering goals for measured system performance which are based on engineering judgment and require validation by exposing the lights to pilots and vehicle operators.

Command response reliability is defined in conjunction with the broadcast mode of operation: Every light on the field is commanded every second, even if the desired state of the light has not changed since the previous command. This helps to ensure that a light is not in an unknown or undesired state. If noise or some other event causes an SX to miss a command and not respond, the light will be commanded again in one second. With a properly configured and tuned system, it is unlikely that two commands in a row will be missed. Barring a component failure, it is expected that a desired light state will be achieved within three command tries. Note that a light responding to the third transmission rather than the first try adds an additional two seconds to the nominal response time.

Because there are redundant lights (each with their own SX) at each intersection and takeoff hold position, it is unlikely that multiple lights at the same operational location on the field will miss the same command try. This serves to ensure that one or more lights will illuminate within the nominal time; it is expected that human observers will respond to the first illumination of a light within their field of view. Conversely, for turn-off commands, the pilot/operator is likely to wait for all of the lights at a position to extinguish; delayed/missed commands could therefore introduce a delay in the light relative to the clearance given by the tower ATC. Fortunately, the SX Subsystem has an inherently higher turn-off response reliability than the turn-on reliability; also, the turn-off response is faster and uniform for all five intensity levels. Clearly, it is necessary to evaluate system performance with both "on" and "off" commands.

7.4.3.2 Test Configuration - Before getting into the test results, it is useful to understand the end-to-end measurement process. As illustrated in Figure 7-5, Field Team personnel insert a custom-designed Light Sniffer probe into a 1/4 inch access hole in the hood of the elevated fixture.

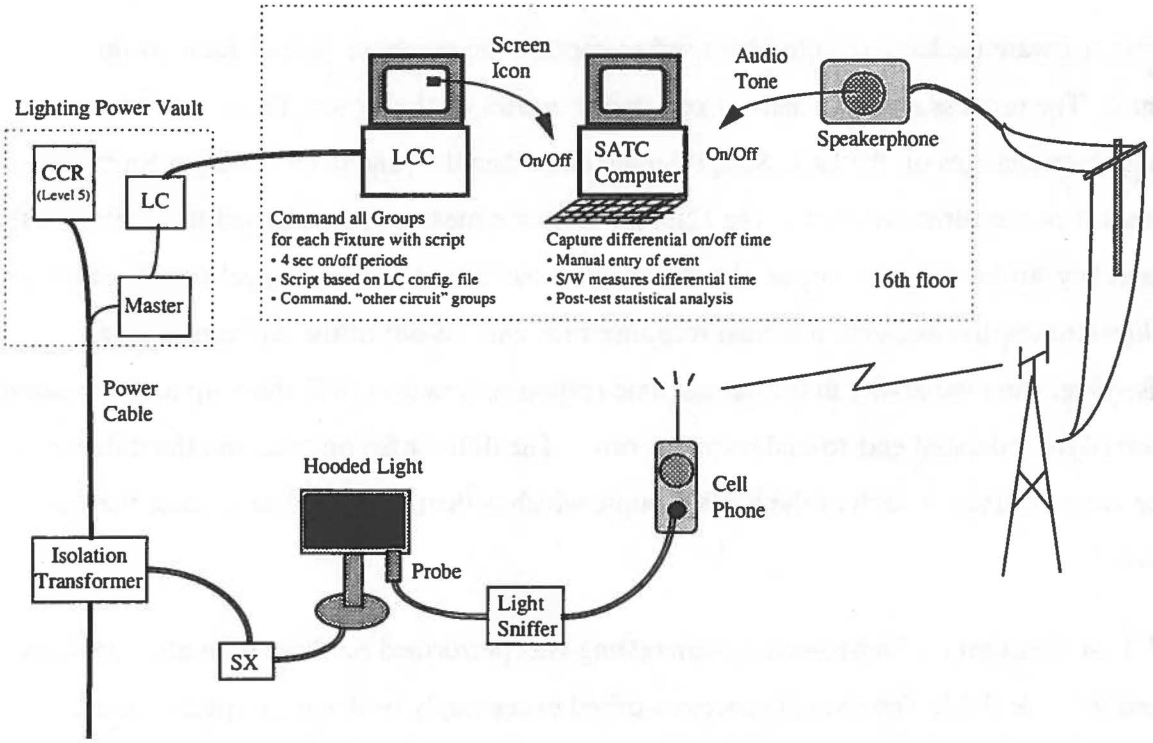

FIGURE 7-5. END-TO-END SYSTEM TEST CONFIGURATION

This eliminates the need to remove the hood and expose light to airport traffic. The probe uses a photocell to sense the lamp luminance and the Light Sniffer generates an audible tone when luminance is detected. A sound transducer couples the tone into a cellular telephone which, through the telephone network, is tied into the speaker phone on the 16th floor of the tower.

In the tower, the Tower Team personnel run an LCC script for each fixture that commands every group (Appendix G) that is supposed to be programmed into the SX. The LCC script for each fixture is automatically generated from the LC configuration file (Table G.2-2) to ensure that the test configuration matches the operational configuration. Each group is commanded *on* for four seconds and then *off* for four seconds using the broadcast mode of operation. Each script also sends initial on/off commands to all SXs on the four circuits that do not include the fixture under test so as to make sure that the SX is indeed on the correct circuit, and to ensure that off-commands are continuously broadcast to all of the lights not under test. All tests are run at CCR level 5 to achieve the fastest lamp luminance response. Lamp luminance response at all CCR levels (with and without trickle current) is known from previous Warehouse Test results and does not need to be measured at all CCR levels in the field.

A custom software package (Capture) is used to capture the response time of each group command. The process employs manual key-stroke entries by the Tower Team when the command icon changes on the LCC Script Screen and when the tone from the Light Sniffer heard on a speaker phone turns on or off. The Capture software measures the elapsed time between the command key stroke and tone key stroke. Given that the human response is relatively consistent for all key strokes, the associated human response time cancels out of the differential mean response time. Any variability in the human time response, however, will show up in the standard deviation of the indicated end-to-end response time. The differential on-time and the differential off-time are recorded for each of the SX's groups, which is then processed to address the test objectives.

7.4.3.3 Test Summary - End-to-end system testing was performed on three separate occasions identified in Table 7-11. The overall process worked exceedingly well and the quality of the recorded data is considered to be excellent!

The first end-to-end testing and supporting data analysis performed in May, 1996 was the most comprehensive of the three test periods. Because the data was collected during integration testing and a few problems were uncovered, the indicated system performance is not quite as good as with the final system configuration employed during dry run testing. Specifically, the following undesirable systems conditions existed at the time of the May 1996 end-to-end testing which were subsequently corrected, but serve to degrade the indicated performance:

TABLE 7-11. END-TO-END SYSTEM TESTING

Date	Summary	Significant Results
May, 1996	Tested 128 elevated fixtures; no trickle current; initial integration testing	• Determined response times/reliability • Discovered SX firmware error • Verified group commands
Nov, 1996	Tested 22 in-pavement fixtures with trickle current activated (36 SXs on Circuit 3 and 8 SXs on Circuit 1)	• Determined response times/reliability • Verified trickle current operation
May, 1997	Tested 49 elevated fixtures and observed selected in-pavement fixtures just prior to dry run operations	• Verified groups and operation of fixtures installed for dry run testing

1) Configuration of Circuit 3 (specification of repeaters) was not complete which means that the response reliability of certain SXs may be lower than desired due to unreliable communications; *subsequent system configuration activities produced a corresponding reduction in the observed communications error rate.*

2) An older version of LC software was used which exhibits an excessive number of communications collisions between commands and status reports; *a subsequent upgrade of the software virtually eliminated this problem.*

3) An SX firmware error discovered as a result of the end-to-end testing caused incorrect repeater action which reduced the communications reliability of several SXs; *this problem was subsequently corrected with a software patch in the LC.*

In spite of these undesirable system conditions during the initial end-to-end testing effort in May, 1996, the data set is valid and the indicated overall system performance is still quite good. Because the full test was not repeated after the indicated system problems were corrected, a quantitative before-and-after comparison is not available. However, selective testing was performed to ensure that the indicated problems were indeed corrected and new problems were not introduced.

In November, 1996 all of the in-pavement fixtures were tested. These units were not tested in May and the goal was to complete system integration testing prior to the winter shutdown period. All system/software modifications dictated by the May test results (Items 1-3 above) had been completed and verified, and all circuits were in their final configuration. Because unhooded testing was scheduled for the spring of 1997, the decision was made to repeat the full complement of end-to-end tests in the spring *if* unhooded testing is approved by the FAA. It is significant to note that most of the in-pavement fixtures are installed on Circuit 3. This provides valuable insight into the performance of Circuit 3 subsequent to configuration, thereby overcoming the restriction identified above in Item 1 of the May testing.

In May of 1997, a subset of the full set of lights was installed to support limited dry run testing of the RWSL, given that operational unhooded testing was not approved by the FAA. The 49 installed elevated fixtures were tested and all lights responded as expected to each of their corresponding groups. The firmware-based anomaly observed during May, 1996 was verified to have been corrected and the nominal response characteristics are consistent with the May and November, 1966 results. Detailed testing of the in-pavement lights was not repeated in May since there were no changes made to the SX Subsystem since the November test. Prior to the dry run testing, each of the in-pavement fixtures was observed by personnel located on the field in response to selected group commands to verify that the Lamp status reported by the LCC was correct and the fixtures performed as expected. No problems were encountered and operation of the lights was considered nominal relative to previous tests. This level of qualitative testing was considered sufficient to support the limited, non-critical use of in-pavement fixtures during dry run testing.

7.4.3.4 Response Time Analysis -Using the end-to-end test data recorded in May, 1996, the detailed **command response delay processing results for each circuit are given in Table 7-12.** A total of 1742 command responses (on plus off) are included in the full dataset and all mean values and standard deviations are given in seconds.

As part of the data processing process, the data are first analyzed to remove any obvious erroneous entries by the data collection personnel. Because of the excessively long status response cycle time (see Appendix G), it is not possible to identify from the indicated LCC status which command-try resulted in the successful execution of the command by the SX. Therefore, the response-delay for each SX group is examined relative to overall mean and standard deviation of the data set (and the population of responses for the particular SX) to ascertain that each response is the result of the first, second or a subsequent command try by the LCC. Because each SX group is commanded "on" four times, separated by one second, and then "off" four times it is relatively easy to identify "missed commands." The mean and standard deviation are then computed for the resulting data set using the data groupings indicated in Table 7-12. These data groupings provide insight into system response under various command/response conditions:

1. All Data—the complete data set for all elevated fixtures
2. No 1st on—the complete data set (1) less all data associated with the "on" command issued to the first group of each SX
3. No 1st on, 1st try—same as (2) but also less all data not responding to the first try of an on/off command
4. 1st on—the complement of (2), only data associated with the "on" command to the first group of each SX
5. 1st on, 1st try—same as (4) but only including data responding to the first try of the on command

Using All (valid) Data, the total (on and off) mean response time is 0.7 seconds with a standard deviation of 0.39 seconds. The on-response time is noticeably slower (0.88) than the off-response time (0.53) and the standard deviation of all the responses is dominated by the on-responses, consistent with the fact that there are more missed on-commands than missed off-commands. Warehouse test results also demonstrate an asymmetry in the SX on-/off-response time. The time required to illuminate a lamp is longer due to the luminance response of the lamp; also, the time to turn an SX on is a little longer than the time to turn it off.

Lamp illumination associated with the first on-command issued to a fixture consistently exhibits a slower response than subsequent on-commands in the group sequence. Excluding all data associated with these first on-commands from the total population reduces the mean on-response time from 0.88 to 0.82 second and the off-response time is unchanged at 0.53 second. Statistics for the first-on commands show a mean on-response time of 1.25 second and the off-response time of 0.51 second is essentially the same as with the full population. Clearly, there is a statistically-significant slower response associated the on-command issued to the first group in an SX. This is curious since all SXs are commanded "off" every second if they are not specifically commanded "on". There appears to be some mechanism in the SX or the LC that differentiates between "on" and "off" commands. Subsequent groups within a SX that are commanded on in the test sequence do not exhibit this additional delay.

It is instructive to look at the "No 1st on, 1st Try" results in Table 7-12 since these results provide the expected response delay *if* SXs respond the first time that a command is issued. Although this is an ideal situation, since it implies a system with no communications errors, it provides a lower bound on the expected time delays for the system at Logan. Based on this ideal data set, **the best performance expected with the system as configured at Logan is an on-time delay of 0.73 second and an off-time delay of 0.51 second.** The corresponding on/off standard deviations are 0.18 and 0.15 second. These relatively small standard deviations indicate that any variability in the data entry time delay (embedded in the measurements) is quite small and the computed mean values are statistically significant. This supports the validity of the database. It is also significant to note that the computed mean delays are consistent across all five circuits with this ideal data set. Although some circuit configuration changes were made to Circuits 3 and 5 after the data was collected, it is not expected that any of the changes have the potential to reduce this indicated lower bound; at most, the realizable system response time given by all of the data may have moved a little closer to this lower bound following circuit configuration activities.

TABLE 7-12. COMMAND RESPONSE TIME STATISTICS FOR ELEVATED FIXTURES (DERIVED FROM MAY, 1996 END-TO-END TESTING)

Condition	Circuit	Mean	Mean	Mean	Std.Dev.	Std.Dev	Std.Dev.
		Total	On	Off	Total	On	Off
All Data	All	0.70	0.88	0.53	0.39	0.42	0.25
	1	0.73	0.94	0.52	0.43	0.46	0.26
	2	0.65	0.78	0.52	0.24	0.26	0.11
	3	0.85	1.1	0.61	0.65	0.69	0.51
	4	0.64	0.81	0.47	0.3	0.3	0.2
	5	0.68	0.83	0.53	0.28	0.3	0.14
No 1st on	All	0.67	0.82	0.53	0.37	0.4	0.26
	1	0.7	0.87	0.52	0.41	0.45	0.27
	2	0.62	0.71	0.52	0.19	0.21	0.11
	3	0.83	1.02	0.63	0.65	0.68	0.55
	4	0.6	0.73	0.48	0.25	0.21	0.39
	5	0.66	0.79	0.53	0.26	0.29	0.14
No 1st on, 1st Try	All	0.62	0.73	0.51	0.25	0.18	0.15
	1	0.61	0.73	0.5	0.19	0.14	0.16
	2	0.61	0.7	0.52	0.21	0.18	0.11
	3	0.64	0.77	0.51	0.28	0.32	0.13
	4	0.57	0.7	0.44	0.17	0.11	0.09
	5	0.63	0.74	0.53	0.19	0.17	0.14
1st on	All	0.88	1.25	0.51	0.45	0.34	0.13
	1	0.9	1.3	0.51	0.49	0.39	0.14
	2	0.84	1.16	0.52	0.35	0.15	0.1
	3	1.01	1.53	0.49	0.67	0.58	0.18
	4	0.86	1.27	0.46	0.49	0.35	0.29
	5	0.85	1.13	0.56	0.31	0.12	0.14
1st on, 1st Try	All	0.85	1.18	0.52	0.37	0.21	0.13
	1	0.86	1.21	0.51	0.4	0.21	0.14
	2	0.84	1.16	0.52	0.35	0.16	0.1
	3	0.86	1.28	0.45	0.46	0.25	0.14
	4	0.83	1.2	0.46	0.41	0.22	0.11
	5	0.85	1.13	0.56	0.32	0.12	0.14

The lower-bound statistics are relatively consistent with *a priori* expectations. A major portion of the total end-to-end system response time is attributable to the lamp luminance response. Incandescent lamps convert electrical energy into radiant energy through heating of the filament. The electrical and mechanical characteristics of the filament dictate the time it takes to heat the filament to produce visible radiation, and the time for the filament to cool to extinguish the visible radiation. Type EVV 120 watt, 6.6 ampere lamps are used in the RWSL fixtures. Extensive testing of the luminance response of these lamps with an applied constant current was performed in the RWSL Warehouse and detailed results are reported in *Assessment Runway Status Light System Warehouse Testing* (see Appendix J)—this report also contains a discussion of why lamps respond much slower to a constant current than to a constant voltage, as most people are used to observing. A representative lamp luminance response at CCR Level 5 (recorded in the Warehouse) is given in Figure 7-6. The relative shape of the response is the same at lower CCR levels but the initial dead-time (no noticeable luminance) and run-up time (increasing luminance output) of the on-command are extended. A summary of the time to achieve a 50% luminance level at each of the five CCR standard current levels is given by the solid circles in Figure 7-7. The fastest on-response, achieved at the highest (Level 5) current level, is still quite slow compared to the constant-voltage response of an incandescent lamp.

It was recognized during Warehouse testing that lamp luminance response time is excessively slow relative to the total time-delay goal of three seconds for the entire system; it takes about three seconds to achieve 50% luminance at CCR current Level 2. A trickle current scheme was developed in the Warehouse and implemented in the SXs deployed at Logan to reduce this response time. A low-level trickle current through the filament is used to preheat the lamp filament to the temperature just below visible illumination; this cuts the time to achieve the 50% luminance level nearly in half, as shown by the solid squares in Figure 7-7. For example, the 50% response time at Level 5 with trickle current is about 0.5 second and about 1.5 seconds at Level 3, the lowest current level used at Logan. The 50% off-command response time is on the order of 0.2 to 0.3 second (Figure 7-6) and is essentially independent of the CCR current level.

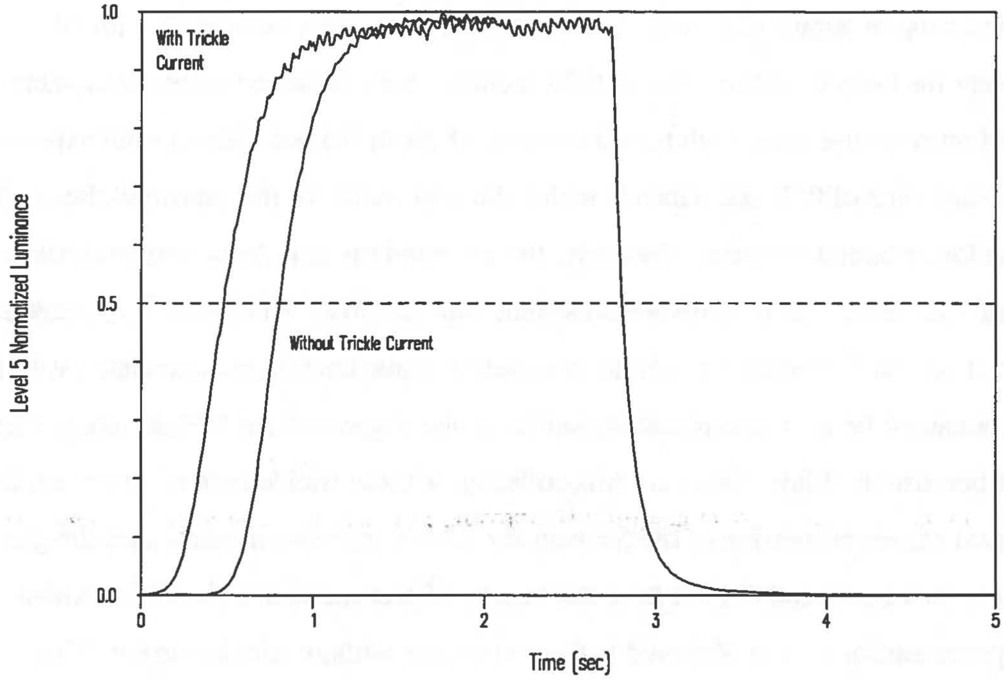

FIGURE 7-6. 120 LAMP LUMINANCE RESPONSE AT CCR LEVEL 5

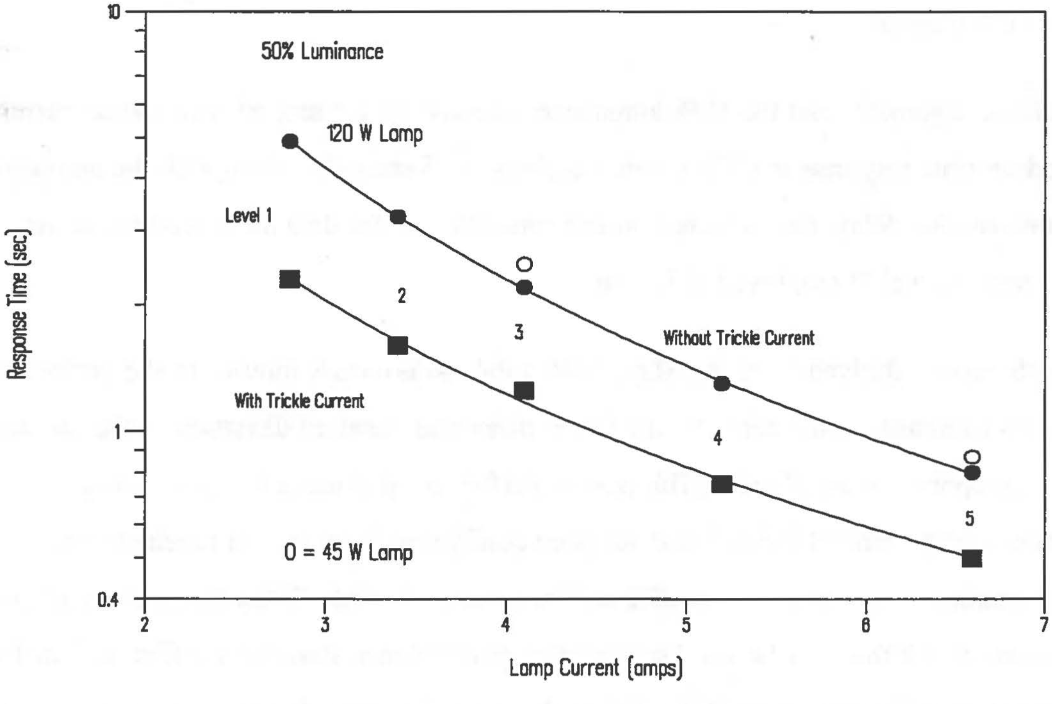

FIGURE 7-7. LAMP ON-RESPONSE TIME FOR 50% ILLUMINATION

With a measured end-to-end total system turn-off time of about 0.5 second and an expected time to extinguish the lamp of about 0.25 second, the command time delay associated with all equipment except the lamp is on the order of 0.25 second. Adding this estimated equipment delay to the indicated on-response time (with trickle current) of about 0.5 sec yields a total expected system on-response time of 0.75 sec which is within the uncertainty of the measured data (0.73 second) for the lower-bound statistics. Similarly, the expected on-time delay without trickle current is about 1.05 sec which is relatively consistent with the observed time of 1.18 seconds given by the "1st on, 1st Try" data set. (Note that there is some uncertainty associated with these numbers since it cannot be guaranteed that the sniffer probe triggers at the 50% luminance level.). It appears that because the May, 1966 data was collected without trickle current activated, the first on-command causes preheating of the filament for subsequent commands within the group sequence, but the first command did not have the benefit of preheating and therefore exhibits a luminance response similar to that observed in the warehouse without trickle current. This argument is also supported by the test results obtained from the November, 1966 testing which was run with trickle current activated. The implied equipment delay of 0.25 second is consistent with *a priori* calculations.

Given the above arguments and the 50% luminance response of 1.5 second with trickle current, the expected on-time response at CCR Level 3 is about 1.75 seconds. Even with the anomalous additional one-second delay, the expected on-response time is less than three seconds at the lowest light level (Level 3) employed at Logan.

Circuit 3 performance derived from the May, 1996 database is clearly inferior to the performance of the other four circuits, as indicated by the larger mean and standard deviation of the on- and off-command responses with all data. This poorer performance is blamed on excessive communications errors since Circuit 3 had not been configured (selection of repeaters for minimum communications errors) by the SX vendor prior to testing. This conjecture is supported by the observation that the "No 1st on, 1st Try" data performance statistics for Circuit 3 in Table 7-12 are consistent with the performance of the other four circuits; this is because any missed commands due communications errors are eliminated from the data set.

Analysis of the May, 1996 data identifying communications errors as the cause of poor Circuit 3 performance is confirmed by the data collected in November, 1966. As previously noted, most of the in-pavement fixtures tested in November are on Circuit 3. Performance statistics for the in-pavement fixtures (see Table 7-13) are consistent with the elevated fixture performance statistics shown in Table 7-12, other than Circuit 3. Note that the mean times for the "No 1st on, 1st Try" data set are essentially the same for the May and November tests. Configuration of Circuit 3 by the SX vendor subsequent to the May, 1996 tests appears to have brought its performance in line with the other four circuits. Note, however, that the previously observed additional delay associated with the 1st on command persists.

TABLE 7-13 COMMAND RESPONSE TIME STATISTICS FOR IN-PAVEMENT FIXTURES (DERIVED FROM NOVEMBER, 1966 END-TO-END TESTING)

Condition	Mean Total	Mean On	Mean Off	Std. Dev. Total	Std. Dev. On	Std. Dev. Off
All data	0.76	0.89	0.63	0.51	0.56	0.22
No 1st on	0.73	0.84	0.62	0.48	0.52	0.21
No 1st on, 1st Try	0.65	0.70	0.59	0.19	0.16	0.15

Based on close examination of the data, the 1st on delay problem is clearly characterized in the November data as a missed first command rather than what appears to be a somewhat random added delay in the May data. It is postulated that some form of timing problem in the LC is causing the first on-command following some unknown period of no on-commands to be missed, or delayed, one command cycle (1-second). This characteristic may also be present in the elevated fixture data but appears to be less prevalent. It is interesting that the first of the two SXs tested for each in-pavement fixture exhibits this first command delay, but the second SX tested does not exhibit the delay. The two SXs assigned to each in-pavement fixture are totally independent and drive separate lamps, but do contain identical light groups. The exact cause of the problem was not determined due to limited program resources and the fact that approval was not received for unhooded operations. The added one-second delay associated with this problem is not a showstopper for dry run testing of the system but would need to be corrected for unhooded operations. It is expected that the problem could be eliminated, thereby achieving a system on/of response of about 0.73/0.51 second, 99% Of the time.

7.4.3.5 Response Reliability Analysis - Command response reliability goals are given in Section 7.4.3.1. If these goals are achieved, all lights will always respond within three seconds. Using the expected "best" observed on-time of 0.73 second given in Section 7.4.3.4, the expected overall system performance if the goals are met is 0.74 second. Without even looking at response reliability data, the measured on-time delay of 0.88 shows that the reliability goals are not met. The off-command response reliability is much better with an expected "best" off-time value of 0.52 second compared to an observed off-time delay of 0.53 second.

Command response reliability statistics presented in Table 7-14 for each of the five circuits are derived from the May, 1966 end-to-end tests. The upper portion of the table shows the actual number of responses for the on- and off-command tries and the bottom half of the table presents the cumulative probabilities of correct response associated with each try. Note that there are four tries for each on and each off in the command sequence for each group programmed into the SX. Each command is separated in time by one second.

It is clear that the off-command response is more reliable than the on-command response, a fact that has been observed in previous qualitative tests and in the Warehouse environment. The exact reason for this performance asymmetry is not known and cannot be ascertained from the available test data.

Aside from Circuit 3, the other four circuits achieved the 100% response goal on the third try and are very close to the 99.9% objective on the second try—one or two responses either way can account for the observed short fall given the total number of commands evaluated. Only Circuits 2 and 5 achieved the first-try 99% response goal, but only for the off-command. Circuit 3 has the poorest across-the-board response reliability for both *on* and *off* commands; this is because Circuit 3 was not configured by the vendor at the time of the test, as previously noted. The overall on-response reliability of 93% for all five circuits is six points below the goal. Even excluding the data for Circuit 3, this only raises this overall value to 95%, which is still short four points of the goal.

TABLE 7-14 COMMAND RESPONSE RELIABILITY STATISTICS (DERIVED FROM MAY, 1996 END-TO-END TESTING)

				Number of Responses Evaluated					
Circuit	On/Off	On Resp.	On Resp.	On Resp.	On Resp.	Off Resp.	Off Resp.	Off Resp.	Off Resp.
	Total	1st Try	2nd Try	3rd Try	4thTry	1st Try	2nd Try	3rd Try	4th Try
1	218	197	20	1	0	214	3	1	0
2	177	172	4	1	0	177	0	0	0
3	100	81	15	2	2	96	1	1	2
4	124	120	4	0	0	120	4	0	0
5	252	241	11	0	0	252	0	0	0
All	871	811	54	4	2	859	8	2	2
				Response Reliability					
Circuit	Total	On Resp.	On Resp.	On Resp.	On Resp.	Off Resp.	Off Resp.	Off Resp.	Off Resp.
	1st Try	1st Try	2nd Try	3rd Try	4thTry	1st Try	2nd Try	3rd Try	4th Try
1	94.3%	90.4%	99.5%	100.0%	100.0%	98.2%	99.5%	100.0%	100.0%
2	98.6%	97.2%	99.4%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
3	88.5%	81.0%	96.0%	98.0%	100.0%	96.0%	97.0%	98.0%	100.0%
4	96.8%	96.8%	100.0%	100.0%	100.0%	96.8%	100.0%	100.0%	100.0%
5	97.8%	95.6%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
All	95.9%	93.1%	99.3%	99.8%	100.0%	98.6%	99.5%	99.8%	100.0%

Careful examination of the data reveals that communications errors associated with only a few SXs are pulling down the performance statistic for Circuit 1 and 2, which is due in part to the firmware error that was discovered as a result of the testing. Circuit 5 has three SXs that exhibit most of the command misses and appears to be due to communications problems. Communications is the most difficult on Circuits 1 and 5, requiring the most repeaters and having the furthest distance from the lighting vault. Based on the recorded data and general observations of system operation, it is not clear if the communications errors can be reduced to the level required to enable the response reliability goals to be achieved with the Logan configuration.

The command reliability statistics for the in-pavement fixtures tested in November, 1996 following correction of the firmware error and configuration of Circuit 3 by the system vendor do not show the expected/desired performance improvement. Measured command reliability values are summarized in Table 7-15. Given that 36 of the 44 in-pavement SXs are on Circuit 3, there is only a slight improvement in the on-command reliability relative to the elevated fixture test results in Table 7-14. The on-command reliability still falls short of the goals. Off-command reliability nearly meets the goals, only falling short of the desired 2nd try goal with 99.7% rather than 99.9%.

TABLE 7-15 COMMAND RESPONSE RELIABILITY STATISTICS (DERIVED FROM NOVEMBER, 1996 END-TO-END TESTING)

			Number of Responses Evaluated					
On/Off	On Resp.	On Resp.	On Resp.	On Resp.	Off Resp.	Off Resp.	Off Resp.	Off Resp.
Total	1st Try	2nd Try	3rd Try	4th Try	1st Try	2nd Try	3rd Try	4th Try
370	318	36	11	3	367	1	1	0
			Response Reliability					
Total	On Resp.	On Resp.	On Resp.	On Resp.	Off Resp.	Off Resp.	Off Resp.	Off Resp.
1st Try	1st Try	2nd Try	3rd Try	4th Try	1st Try	2nd Try	3rd Try	4th Try
92.6	85.9%	96.2%	99.2%	100%	99.2%	99.7%	100%	100%

As previously noted, "On-response reliability" falls short of the goals. The major contributor to this adverse performance is the first on command problem identified in the response time performance analysis (see Table 7-14). Out of the 52 misses occurring on the first on command try in Table 7-15, 22 of the missed commands are associated with the first on-command issued to the first group in the SX. Also as previously noted, each in-pavement SX has two SXs, one for each lamp, with the same groups. Out of these 22 missed commands, 18 on-commands are missed by the first of the two SXs of a fixture tested with normal response to the first on-command by the second SX of the fixture pair. This strong correlation is not expected with random communication errors and clearly suggests some type of timing or software problem. Even if this problem is corrected, there still remains a higher than desired number of misses associated with the 2nd try of the command broadcast. Most of the observed missed responses are associated with two fixtures (four SXs), thereby suggesting that further circuit configuration may reduce the associated communication errors to meet the system reliability goals.

Further circuit configuration efforts with additional repeaters may improve the response reliability but would further degrade the command response time and extend the status reporting cycle. Given that the off-command reliability is very close to the performance goals, understanding and improving the poorer on-command response reliability is a suggested area of research for the system vendor that could have the largest payoff in terms of achieving the overall reliability goals.

7.4.3.6 Command Stress Tests - In addition to command reliability tests, command stress tests were run to determine if the system can handle the required group command rate. The actual number of SX groups commanded each command cycle depends on the operational situation and the number of groups programmed into the SXs. As noted in Appendix G, at least one or two groups per circuit must be commanded when each one-second command cycle is two: one group that includes all of the SXs that are supposed to be on and one group for all of the SXs that are supposed to be off. Because each SX can handle a maximum of 20 predefined groups, operational situations may dictate that the LCC issue more than two groups to one or more circuits in a given command cycle if the required combination of SXs is not embodied in the available group definitions. The LCC analyzes the on/off commands from the Light Logic (implemented in the AMASS computer) and determines the most efficient combination (minimum number) of available groups for each circuit to achieve the required on/off pattern of lights on the field.

The achievable number of commands per command cycle is dictated by :

- SX communications bandwidth—fundamental data rate
- Repeater configuration—cascading of multiple repeaters
- One-second command broadcast cycle—require time to collect status
- Specific SX groupings—multiple groups per SX

The fundamental data rate combined with the cumulative delay introduced by repeaters between the LC and the SX limits the total number of groups that can be transmitted within the one-second command cycle. All commands need to be executed within the command cycle so the command stream will not fall behind, thereby introducing an additional command-response delay or possibly causing a system failure. Also, there should be sufficient time remaining in the command cycle after all commands are executed to poll for status. Because commands take priority over status polling within the command cycle, the polling cycle time to gather status from all 170 SXs increases proportionally with the number of group commands issued each second. The LCC group design goal is to limit the number of groups commanded each second to four groups per circuit, and to limit the total number of groups (entire system) to 15 each broadcast. This allows time before the end of the one-second interval to poll for status.

Operationally, the actual number of groups transmitted each command cycle is variable and depends on the specific operational conditions. Although extensive operational testing was performed, there exists the possibility of an abnormal situation. Therefore, the system must not fail if the design goal is occasionally exceeded. Verification of the system group command rate capability is a multi-step process:

1. Use operational data recorded at Logan in a simulation to measure the number of groups that must be commanded each second for all combinations of Logan runway usage and expected operational conditions—compute statistics for each circuit and for entire system.
2. Use special test software to verify that the group formation algorithm implemented in the LCC correctly transforms the Light Logic light states into the corresponding light groups—all physically realizable combinations and permutations are automatically tested by the test program.
3. Use the LCC test script capability to measure the system status response cycle time as a function of known command sequences—status cycle time provides observability into the time required to service the group commands each command cycle.

Group design testing using operational data recorded at Logan indicates that the circuit goal may be exceeded by 50% a few times in an hour, requiring six groups to be occasionally commanded on one or two circuits. The LCC group formation algorithm testing provides 100% test coverage and the final algorithm used to support system integration testing exhibits no transformation errors. Commands take priority over status polling in the LC during the one-second command cycle. After all of the commands are serviced, the system returns to polling for the remainder of the one-second interval. Table 7-16 presents the status cycle time for a representative increasing number of group commands in each command cycle. Notice that there is a nearly linear increase in the status cycle as the number of commands is incremented by four.

TABLE 7-16 LCC COMMAND STRESS TEST RESULTS

	Group Commands/Cycle					
Circuit 1 Commands	1	5	5	5	5	5
Circuit 2 Commands	1	1	1	1	5	5
Circuit 3 Commands	1	1	1	1	1	5
Circuit 4 Commands	1	1	5	5	5	5
Circuit 5 Commands	1	1	1	5	5	5
Total Commands	5	9	13	17	21	25
Status Cycle (sec)	9	12	14	16	18	20

Based on an analysis of this data, it is estimated that it takes an average time of about 0.1 seconds to execute a group command on a circuit and the maximum average command rate is nine group commands per circuit per command cycle, which is more than 100% over the goal. The test results indicate that system command rate capability has sufficient margin to support Logan operations, a result that is supported by extensive hooded testing. No system failures have been attributed to an inability to handle the required number of group commands.

The obvious down-side of excessively high command rates is that the status update cycle exceeds the 10-second cycle time requirement. This time could be improved through a software change in the LC that would enable “smart status monitoring” that puts the priority on polling SXs that are supposed to change state rather than the current sequential process. However, since status is only used to identify system failures (health), 15 seconds is nearly as good as 10 seconds and does not preclude unhooded operation.

An original desire was to try and achieve a status cycle time on the order of one second, thereby providing near real-time indication of the actual state of all SXs. In practice, the system status cycle takes at least nine seconds due to the rather large number of repeaters required for SX communications at Logan (see Appendix G), combined with the fact that status can only be polled on one circuit at a time due to excessive cross-talk between the Logan circuits. Note, however, that commands are issued simultaneously on all five circuits. It is fortunate that group commands did not need to be interleaved like status reporting; reducing the achieved group command rate by a factor of five could have been a system show-stopper. The command broadcast mode of operation mitigates the operational need for status to be reported in a fraction of a second.

However, based on operational system experience, rapid status reporting is still considered desirable, offering additional command and control options within the LC software and simplifying system testing.

7.4.3.7 Lessons Learned -The following summarize the important discoveries and results of the Logan reliability and integration tests:

1. Measured the end-to-end illumination response of all fixtures at Logan and verified that all groups programmed into the SXs are correct.
2. Verified the installation and operation of the SXs, LCC, LC, and all communications links.
3. Verified that the true light status is displayed by the LCC (accounting for the known delays, Appendix G, to receive status).
4. Identified an SX firmware error which degraded, and in some cases impeded, communication with some SXs—this problem was corrected with a software patch in the LC (see Appendix G) following the May, 1966 tests.
5. Discovered that the SX for fixture R16A1 was installed in the wrong base can.
6. Confirmed that the broadcast mode of operation ensures command integrity when commands are "lost" due to communications errors.
7. Identified an additional delay that is associated with the first time that an on-command is issued to an SX following some unknown period of off-commands; the exact cause remains unknown.

   Based on the available data, the mean time (with filament preheating at CCR Level 5) to turn a lamp *on* following a command from the LCC is less than 0.9 second and the mean time to turn a lamp *off* is about 0.6 second; the corresponding on/off standard deviations are about 0.5 and 0.25 second, respectively.
8. The mean time delay between when a command is issued by the LCC and received by a SX (excluding the time to illuminate the lamp) is about 0.25 second; this embodies delays through the following equipment: LCC; fiber link with the vault, LC; Master Brite, cable; SX.
9. Assuming that the observed problem identified in Item 7 is correctable and the command reliability goals are achieved, it is anticipated that the mean on-time delay in Item 9 would reduce from 0.9 to about 0.7 second with a corresponding standard deviation of less than 0.2 second.
10. Using the Warehouse test data for lamp luminance response at all CCR levels, the expected *on*/*off* times at the lowest usable light level (Level 3) at Logan are less than 2 seconds and 0.6 second, respectively, which are less than the 3-second goal.
11. The measured system on-command response reliability of 93.1% for the first try and 99.3% after the second try fall short of the respective 99% and 99.9% goals in Section 7.4.3.1; the additional delay identified in Item 7 along with communications difficulties associated with a few SXs are the primary reason for not meeting the on-reliability performance goals.

12. The measured off-command response reliability of the system following the November, 1966 testing appears to meet the response reliability goals within the associated test data uncertainty.

Overall, the measured light illumination response time delays to LCC commands (Item 9) are within the overall three-second timing budget. System response is considered sufficient to support unhooded operations at CCR Level 3 and above. As indicated in Item 11, it may be possible to shave about 0.2 seconds off of the overall mean on-time if the command reliability goals could be achieved. The total response time is dominated by the luminance response of the 120 watt lamps used in the RWSL fixture. Although the use of trickle current to preheat the lamp is instrumental in achieving this response time, any further improvement in the lamp response time requires non-standard lamps or extraordinary shaping of the current profile to force a faster lamp response at CCR levels less than 5. A slight reduction (less than 0.05 second) in the command response time could be achieved with fewer repeaters (Appendix G) but the associated below-objective command reliability would probably degrade even further—a counter-productive result. It may actually be productive to increase the number of repeaters, even at the expense of increasing the command and status cycle times, if communications with the several SXs experiencing missed commands can be improved, thereby improving the on-command reliability.

Item 7 appears to be the dominant cause of the system not meeting the on-command response reliability goals. Each test script issues between three and thirteen on/off command pairs, depending on the number of groups used by the SX. The first-on command (first broadcast of an "on" command associated with the first group in the test script) issued to a SX tends to exhibit a slower response than subsequent on commands in the group sequence in the May, 1996 test data. Although this slower response appeared consistent with the fact that trickle current was not active, subsequent tests with trickle current activated in November, 1996 exhibited an even more pronounced delay. For example, 52% of the first-on commands in November are classified as a miss (SX did not appear to respond to the first broadcast of the command) as compared to 18% in May.

RWSL Program resources did not permit a quantitative investigation of the first-on command problem. It is conjectured, however, that timing in the LC software may be the source of the problem and may have been exacerbated by software timing changes (subsequent to the May, 1996 test) made to reduce the command/status collisions. Although the problem degrades the system response time, this is not fatal relative to the system's ability to support unhooded operations. In the worst case, the problem may add one second to the expected response time; on average, this first-on command artifact adds about 0.2 second to the mean on-time response. In spite of the fact that the response time goal is achieved with the system as configured, this first-on command problem would have been corrected if the system had been approved for operational unhooded testing rather than limited dry run testing.

7.5 HUMAN FACTORS TESTING

7.5.1 Objectives

Light fixtures located on the airport surface provide the only interface between the RWSL System and the human (pilot or vehicle operator) end user. This interface is illustrated in Figure 7-3 where the Pilot views the Actual Light State (light *on* or *off*) and takes "appropriate action" to control the aircraft. The terminology "appropriate action" is rather complex to quantify since it encompasses all of the usual pilot actions and reactions in the absence of the lights, appropriately modified by the operation of the RWSL Runway Entrance Lights and Takeoff Hold Lights. The presence of an operational RWSL has the potential to influence overall traffic flow and related operations on the airport surface.

RWSL is intended to be used as an advisory system by pilots and vehicle operators. It operates independently of tower controllers, deriving traffic information from the ARTS and ASDE-3 radars. RELs that are *on* indicate that the runway ahead is not safe to enter. Similarly, THLs which are *on* indicate to aircraft waiting to take off that the departure runway is not clear of conflicting traffic. Lights that are *off* convey no meaning—the system is not, at any time, intended to convey clearance to proceed onto a runway or to start a takeoff. Pilots must operate on the airport surface as instructed by the tower. Pilots should normally stop when they see an illuminated status light. However, pilots should not stop, if by doing so, in their judgment, they would compromise the safety of their own or other aircraft. For contingency purposes, in the unlikely event of a conflict between the RWSL and instructions from the tower, pilots should contact the tower to report the conflict and wait for the tower to assess the situation and correct the anomaly. Pilots are not required to proceed through an illuminated status light.

Overall human factors considerations for RWSL are captured by the following operational questions:

1. Are the correct light states achieved by the RWSL System within acceptable time tolerances?
2. Are the light states visible, effective and unambiguous to pilots and vehicle operators?
3. Does the end user respond as expected to the observed light states?

Perfect operation of the RWSL produces the correct light states in precise synchronism with verbal directives from the tower controllers. In other words, there is no discrepancy between the information conveyed by the system and the tower, except in the unlikely event that the runway is obstructed and the controller and/or pilot happens to misinterpret the operational situation. It is this low-probability event that could result in an incursion; prevention of incursions is the expressed purpose of the RWSL System. In actuality, there will be some variability in the time between tower directives and RWSL state changes because each controller has a particular style/rhythm and is not "tied" to the radar data like the RWSL. Light Logic in the AMASS computer is designed to emulate the controllers' actions but is not tuned to each individual controller.

Human action and response depends on the specific operational situation. The first operational question (above) is directed at the "acceptable tolerance" in RWSL timing relative to the tower controller. Based on pre-test interviews of experienced pilots and Logan air traffic controllers, a maximum allowable time difference of three seconds is expected to be tolerable to pilots and vehicle operators and forms the timing goal for hooded test performance evaluation. Because this requirement is based primarily on the opinion of a few, albeit highly respected and experienced, personnel the validity and acceptability of this time-difference from a human factors perspective can only be assessed through extensive unhooded testing with a large population of users in the actual operational environment. Important insights can be obtained through simulator-based testing but cannot be viewed as sufficient validation of the requirement.

The second operational question (above) encompasses a broad range of human response and system physical characteristics and received the most attention during system design, deployment and testing. There are a number of related questions and issues, some of which support quantitative assessment whereas others fall in the category of qualitative human responses. The RWSL must be considered from two different perspectives. First, the lights must be sufficiently conspicuous and effective to draw attention when a pilot is at or approaching an intersection or takeoff hold line. RWSL will not be effective if the pilot does not observe the lights. Conversely, when the lights are illuminated, they must not be distracting or confusing to other operations occurring on the airport. This could result in a situation, for example, whereby a pilot may be confused by RWSL glow illumination that "spills" onto the runway which is meant for the aircraft waiting at the taxiway hold line. Also, the RWSL light must not obscure or be subject to misinterpretation for other lights on the airport, such as the VASI bar.

Critical variables that determine whether or not the human visual system will detect the light are: size, luminance, and contrast between the object and its background. Luminance (or photometric brightness) at the position of the pilot depends on the brightness of the light, distance from the light, transmission medium attenuation or reflection (e.g., clear air fog), visual angle and shape of the light beam, color and modulation (e.g., flash) characteristics. In addition, an observer's knowledge of the light position and the amount of time available to acquire the light can influence the human detection threshold. There also is the converse issue of excess brightness that overwhelms the human eye, particularly at night, causing discomfort or temporary loss of sensitivity. Light detection parameters can be measured and quantified. However, acceptable light levels and the actual probability of light detection by a pilot that is preoccupied with other important tasks prior to takeoff are human factors issues that need to be evaluated with a large population of pilots and a broad range of operational conditions.

Given that the pilot detects the light, there still remains the issue of human response to the information conveyed by the RWSL on/off characteristics, as identified in the third question above. Training and standard notifications (NOTAM, Jeppesen Bulletins, ATIS, etc.) convey the RWSL action and intended response of the pilots. However, there remains the issues of training coverage and effectiveness, and the fact that humans have a tendency to use systems in an unintended manner. For example, although an extinguished light conveys no meaning, there is the potential that an uninformed or "aggressive" pilot may interpret the light turning *off* as an implicit indication to proceed; or, the pilot may call the tower in the attempt to speed-up traffic flow, thereby increasing the verbal traffic burden placed on the tower controller. These are all human factors issues that need to be evaluated in the operational environment. All of these issues combine with the RWSL performance to establish the overall effectiveness of the RWSL System.

Human factors testing was an integral part of the RWSL System design and development process, with the end goal of validation through testing in the operational environment at Logan with the lights exposed to the end users. Initial human factors testing employed the NASA Langley TSRV Simulator to established the initial reaction of pilots to the system concept. A Light Test Station was installed at Logan in the Fall of 1994 to collect initial information on the visibility and effectiveness of candidate light fixtures for potential use by RWSL. Extensive testing of the system in the Volpe Warehouse focused on the luminance response of the RWSL light fixtures and lamps. Subsequent to system installation and integration at Logan, static tests of selected lights were run with a bucket truck at Logan during day and night to assess light visibility and possible confusion of the RWSL with other airfield lights. Following the static tests, dynamic tests were run to verify the static observations with a small aircraft operating at night and using selected lights on a closed runway. Finally, dry run testing was performed at night with most of the available lights exposed using a dedicated aircraft and ground vehicles. Each of these human factors test forums and the resulting important test results are summarized in the following sections.

Fully-operational unhooded testing of RWSL was not performed at Logan because the New England Regional Office of the FAA chose not to approve the system for unhooded testing during normal airport operations. As a consequence of this decision, many of the important human factors issues identified above that relate to the operational environment remain unresolved.

7.5.2 Simulator

Initial pilot opinion of the RWSL was obtained through a series of flight simulations performed with the Transport Systems Research Vehicle (TSRV) Simulator at the Langley Research Center.

The TSRV simulator consists of a modified B737 cockpit with out-the-window scenes provided by a computer-generated image system capable of rendering day and night scenes with complex weather effects. To perform an evaluation of the RWSL concept, REL and THL fixtures are depicted on the computer generated image of the Denver Stapleton airport. Testing employed an air traffic controller, acting as both the tower and ground controller, who communicated with the test subjects and emulated voice traffic with other aircraft within the test subjects' field of view. Ten simulated flight scenarios were employed to assess the pilots reaction to the system under a broad range of visibility and geometry conditions.

The primary goal of the study was to obtain pilot opinion on the potential usefulness of the RWSL. Secondary goals were to: 1) determine the impact (workload, confusion factor) of the system in a realistic cockpit environment, 2) provide suggestions on system design issues such as light size, directionality and location, and 3) acquire suggestions for operational procedures and areas of improvement. Twenty-one pilots participated in the simulation testing and completed the evaluation of the RWSL. Detailed test results contained in *Pilot Evaluations of Runway Status Lights* (see Appendix J*)* are summarized as follows.

Responses reveal that the test subjects unanimously support the concept of the RWSL System. If they receive conflicting information about the runway status, the RWSL can be used as a backup to prevent possibly proceeding into an incursion situation. Seventy-six of the subjects do not feel that the RWSL will add to the pilot workload. The remaining 24% feel that there will be an initial increase in the workload because of unfamiliarity and insufficient training, but once the habits are formed the residual workload will be negligible. Seventy-six percent of the subjects feel that the RWSL will improve their awareness of the other activity taking place on active runways which, in a manner, improves their awareness of the situation.

All of the subjects feel that RWSL will not add an unreasonable amount of clutter to their visual scene, assuming that the lights are hooded and pointed correctly. Ninety percent of the subjects feel that RWSL will not introduce confusion once it is fully operational. Confusion may occur in three situations: 1) during the training period, 2) if there is conflict between the information from the controllers and the lights, and 3) if the RWSL is not operating properly.

Because of the nature of the flight simulation environment, design issues such as light intensity, glow effects, and beam width could not be specifically evaluated. However, suggested system improvements were provided. Most suggestions relate to the type and location of the lights to catch the pilots' attention in all weather conditions. The most frequent suggestions relate to the consciousness of the THLs. As pilots begin to takeoff, they tend to get tunnel vision focused down the runway centerline. Nearly all crews passed an illuminated THL-pair after being cleared incorrectly for takeoff. Crews, not expecting an ATC misdirection, focused their attention on takeoff duties and did not observe the THLs. Recommendations for improvement included raising the elevation of the THLs to 2-3 feet off the ground, use in-pavement fixtures rather than the peripherally-located elevated fixtures, and possible flash the lights. Pilots have no problem monitoring the state of the RELs because they are more apt to do an out-the-window scan during taxi.

The authors of the report *Pilot Evaluations of Runway Status Light System* believe that pilot training is the most important aspect of the system to address, beyond the implementation issues. It must be ensured that the light states are not to be misinterpreted to denote clearance or additional incursion situations could be created.

7.5.3 Warehouse

Initial RWSL testing in the warehouse revealed the time required to illuminate the lights (luminance response) is excessively long compared to the three-second timing goal. This luminance response is illustrated in Figures 7-6 and 7-7. Dead time, the period of time between when the current is applied to the lamp and the filament reaches the temperature required for visible radiation, ranges from 0.4 second at CCR Level 5 to 3 second at Level 1. This dead-time is virtually eliminated by preheating the filament with a small trickle current to just below the level of visible radiation. Even with trickle current, response time of the lamp is still slow compared to the nominal human reaction time.

The precise time that a human identifies the light is *on* embodies complex psychophysical phenomena. It is not reasonable to use the time for the light to reach a steady-state luminance since the steady-state value is approached asymptotically and is therefore subject to excessive uncertainty in its determination. A human observer will generally identify the light as being "on" well before it reaches steady-state illumination. To enable a simple and meaningful characterization of the lamp response time, the 50% illumination level is selected as the timing threshold. Note that the total dead-time (when the human cannot view any visible light) and about one-half of the run-up time (the rising slope in Figure 7-6) is captured by this definition. Further, the rate of change of luminance is greatest in the region of 50% luminance. This selection of the measurable response time is consistent with human observations in the warehouse. If anything, this definition of response time is judged to be a bit pessimistic, particularly at lower light levels, in the warehouse. This is appropriate, however, since the human response to an expected event tends to be faster than the response to an unexpected or unknown event. A pessimistic estimate is preferred since the 50% response time is used as the nominal response in the evaluation of hooded test results.

Lamp off-response time is fast relative to the overall timing objective of three seconds. The 50% off-response time is about 0.2 seconds for all CCR levels and is below the 5% illumination level in less than 1 second. Based on warehouse observations, the 50% illumination decay time may be optimistic in quantifying the perceived off-response time. There appears to be a human tendency to wait until a lower luminance level before declaring that the lamp is off. This is also consistent with the fact that the nominal human response time to an event is on the order of 0.3 second.

These numerical values were subsequently confirmed during end-to-end testing at Logan (Section 7.4.3). Time response statistics of system response data measured with the same photocell used in the warehouse to measure the luminance response agreed within a couple tenths of a second with statistics derived from human observations of the on/off light states. This is considered sufficient confirmation of the selected 50% illumination level for hooded test evaluation given all of the other potential contributors to human response uncertainty.

The difference between luminance and brightness (as perceived by a human observer) is important since the eye is nonlinear in its response to luminance. The five current steps provided by the CCR attempt to accommodate this nonlinearity and provide a full range of usable light levels. The warehouse is not the best place to judge appropriate light levels for the airport environment since the background radiation and spacing are not representative. However, based on observations, Level 1 is identified as having too low a brightness to be effective (even at night) and Level 5 is judged to be too bright for nighttime operation, but may be satisfactory for daytime. Level 3 appears to be the most likely operational level.

Comparisons were also made in the warehouse between steady burning and flashing lights. A two-second flash cycle (one-second *on* followed by one-second *off* is judged to be nearly optimum. A shorter cycle does not allow the lights to fully extinguish at low CCR levels and a longer cycle tends to increase the response time uncertainty—the human response is to wait and see if the extinguished light is going to turn on again as part of a normal flash cycle or remain extinguished. This can extend the effective off-response time. A decision was made based on warehouse observations not to implement flashing at Logan. This decision was motivated by: 1) the perceived potential for distractions to other airport operations caused by the flashing lights, 2) flashing is implemented by each SX and there is no assurance that all lights in view of the pilot will flash in unison—the randomly flashing lights may produce a distracting "disco light" effect, and 3) the rapid on/off switching action of the flashing may introduce additional (unwanted) noise in the circuits, and/or degrade CCR performance.

7.5.4 <u>Static Tests</u>

As previously noted, light visibility depends on the background illumination. Warehouse testing provides important insights into the fixture lighting characteristics but is inadequate for assessing operational performance issues which may be encountered in the airport environment. Prior to the development of the RWSL warehouse test facility, a Light Test Station was implemented at Logan to test candidate light fixtures in the operational environment. Tests were run with several fixtures under various RVR conditions to measure the beam pattern and to assess the nighttime and daytime brightness so as to assess fixture suitability for the RWSL application. This approach to fixture selection supports an RWSL Program directive to utilize available off-the-shelf equipment and not to develop specialized equipment for the RWSL application unless absolutely necessary.

Based on the initial testing of candidate fixtures, the FAA standard L-804 Wig-Wag fixture outfitted with red lenses and two 120 watt lamps was selected (without the associated flash capability) as the elevated fixture for the RWSL System. This selection was motivated in part by the small beamwidth of about six degrees (measured from the centerline) since it provided sufficient brightness over the required range of cockpit heights while minimizing the light leakage onto the runway and in the horizontal direction. The installation contractor purchased the fixtures to be installed at Logan from the low-bidder, who is not the manufacturer of the fixture tested in the Test Station. Subsequent tests of this new fixture showed that the new fixture is built to conform to recently revised FAA specifications for the Wig-Wag fixture and exhibits a much wider beamspread of nearly 80 degrees on either side of the centerline. The pilots and human factors experts involved in the testing agreed that there is a high probability that pilots may see the RWSL light "spilling" onto the runway during takeoff. Subsequent experiments were run using various designs of baffles placed in front of the fixture to limit the field-of-view of the installed fixtures.

Following installation of the light fixtures at Logan and in support of system tests preparing for unhooded testing of the RWSL System, additional static tests were run at what are perceived to be critical locations on the airport. The so-called "bucket tests" employed a cherry-picker bucket truck to enable an experienced pilot and a human factors expert to view the REL and THL elevated fixture operation, with and without baffles, at all cockpit heights from the surface to that of a B-747 aircraft. Observations made on a clear sunny day and at night with 6 miles of visibility yield the following important conclusions:

Nighttime

- CCR Level 3 is the recommended minimum, and "best," level
- CCR Level 5 is too bright
- Light presentation to a pilot is adequate at all cockpit heights
- The VASI bar is in close proximity to the THLs on the left of 27
- From the tower (about a mile away), Level 3 RWSL is indistinguishable from normal field lighting, but is quite visible at Level 5

Daytime

- The RELs are effective at Level 5 in bright sun
- The THLs are not as effective as the RELs and a brighter light is recommended

- Light presentation is adequate at all heights although a bit cluttered by the background at a height of six feet.

The use of baffles on critical fixtures provides an acceptable human factors solution for RWSL testing at Logan. Light leakage is reduced to an acceptable level and there is no noticeable impact on the direct view of the light by the pilot. It is recommended, however, that baffles only be used operationally for particularly difficult viewing positions. The fixture lenses should be selected to provide the best field of view while minimizing the light leakage.

7.5.5 Dynamic Tests

The objective of the dynamic tests is to assess the visibility of the RWSL: at normal altitudes while flying over the airport, during landings and takeoffs, and during normal surface operations. During takeoffs and landings, the static test observations are to be confirmed under dynamic conditions. A secondary objective is to assess pilot reaction to the normal and abnormal (introduced by test personnel in the tower) operation of the THLs and RELs. The nighttime dynamic tests employed a Cessna 172 piloted by the same pilot who participated in the static tests, with a human factors expert and an experienced Logan Tower air traffic controller as passengers. The role of the passengers was to observe both the system and pilot reactions to the lights. Lights were uncovered on runway 27, east of 33L: RELs on taxiways D, D1, and D2; two pair of THLs on the end of 27. The runway was closed to normal operations, providing dedicated operation for the test. The weather was a high overcast with six miles of visibility.

The dynamic test results are best characterized by the following direct quotations provided by the experienced pilot of the aircraft. These comments are substantiated by the aircraft passengers.

1) While taxiing east on taxiway D, the RELs were manually cycled from the tower:

> *"At no time did the lights distract."*
>
> *"... did serve the purpose of advising us that there was an active runway to our right."*

2) At the hold line on D, REL Level 3 *"is best for nighttime operations"*

3) While holding short of RW-27 awaiting clearance:

Cycling RELs *"did not distract me nor be of any nuisance"*

"RELs going to the off-state did <u>not</u> convey the notion that it was O.K. to taxi onto the active runway"

Following clearance and before the light changed, *"... my reaction was to continue to hold short and advise the tower of the red light ..."*

4) In position and holding on RW-27, viewing the THLs:

"THL Step 5 is the most effective"

At Level 5, *"The THLs are clearly discernible from the VASIs"*

"... in-pavement THLs would be much more effective ...," compared to the elevated fixtures

Following clearance and with the THLs forced by the tower to stay on, *"... elected to remain in position"*

Following start of the takeoff roll, the THLs were forced back on by the tower test personnel, *"... continued my takeoff roll despite the THLs coming on because we had reached flying speed and the runway ahead was clear"*

5) Approach to RW-27 with the THLs on to determine if the THLs interfere with the normal operation of the VASI lights:

"... location of the VASI bar provided a clear indication of position on the glidepath (including above and below) during the entire approach ..."

"The THLs appear to more in line with the runway edge lights rather than any part of the VASI System."

6) During departures and arrivals:

"... unable to detect any visible light (beam light and/or glow light) emanating from the RELs"—no distraction

"Could see RELs during east taxi on 27."—this was subsequently eliminated by rotating the RELs

7) Bottom line from the pilot perspective:

"I found nothing that would compromise the level of safety."

"(RWSL) will enhance safety while providing significant improvements in situational awareness."

7.5.6 Dry Run Tests

The goal of the original unhooded test program was to collect extensive human factors responses from pilots conducting normal operations for a variety of runway configurations, aircraft types and operational conditions. The plan was to acquire sufficient data to enable the development of quantitative performance validation statistics with associated high levels of confidence. Because the FAA did not approve the system for operational unhooded testing, it become necessary to down-scope the original extent of planned test activities to be consistent with the test restrictions. However, the human factors goal of the dry run testing remained unchanged: acquire as much data as possible which is relevant to assessing the users response to the RWSL System.

Due to the rather restricted format of the dry run tests, relatively little new human factors information was added to the previous knowledge base derived from static and dynamic testing. For the most part, previous observations were confirmed during the dry run testing. The following paragraphs present the new findings.

While the aircraft was holding in position on Runway 22R, it was felt that the VASI lights have the potential to be confused with a THL. Part of the problem is that the VASI and THL are the same color. Also, the red runway edge lights marking the displaced threshold could present a similar problem. The pilot felt that the THLs do not attract enough attention and tend to blend with the other lights. A flashing format would be more effective in uniquely identifying the THL against the background of other red airport lights. These observations in concert with previous observations from the dynamic tests suggest that all of the critical geometries on an airport must be examined prior to commencing RWSL operations.

There were several occasions during the dry run tests when observers noted that pairs of lights at an intersection did not operate synchronously. It is expected that this aberrant operation of the lights is due to one of the SX-pairs missing the first broadcast of an on-command and illuminating on the second or subsequent command broadcasts. This issue is addressed in Section 7.4 and is a consequence of the fact that the SX Subsystem at Logan does not achieve the 99% command response reliability goal the first time a command is broadcast. Although this undesired differential delay in the lights does not convey extraneous operational information to the observers, the human factors response is a bit unsettling since it appears that the system is malfunctioning, thereby reducing the observers confidence in the system. It is expected that this problem can be eliminated in an operational system and the desired command reliability of 99% or higher will be achieved.

RWSL in-pavement lights were viewed by the pilot and test observers for the first time at Logan and are unanimously judged to be very effective. They appear to "give the illusion of being elevated" and command the pilot's attention immediately. Also, the color is more orange than the red elevated lights and less likely to be confused with other red lights on the airport surface. The in-pavement lights appear to be a much better format for the THLs than the elevated fixtures.

7.5.7 Conclusions and Recommendations

Human factors testing performed on the RWSL System suggests that the concept is viable, although available quantitative performance results are incomplete without comprehensive unhooded testing in the operational environment. Pilot and vehicle operator training is probably the most important action necessary to help ensure appropriate and safe operation of the RWSL System. As is true of any new system when it is first deployed, the effectiveness of training can only be measured through system use. Detailed informational materials and training courses developed under the RWSL Program in anticipation of unhooded operation were not utilized and their effectiveness cannot be evaluated or commented upon here. It is not possible to quantify if pilots will misinterpret the lights or attempt to use them in an unintended manner. Because the RWSL System shows significant promise in its ability to operate as a backup to air traffic controllers and possibly help to prevent incursions, it is recommended that the system be reinstalled at another, possibly smaller, airport for unhooded testing. This will enable unhooded testing to focus on the issues of training effectiveness without the associated concerns (or consequences) that the lights may be misinterpreted in a high-traffic environment like Logan.

The test results suggest the need for some changes in the placement and possibly the illumination color of the light fixtures. Limited testing strongly suggest the use of in-pavement rather than elevated fixtures, particularly for the THLs. Both the simulator and Logan tests show that steady-burning elevated THLs located on each side of the runway are not obvious enough to ensure capturing the attention of a busy pilot preparing for takeoff. Also, the color of the RWSL lights is judged to be too similar to the VASI and runway edge lights.

Although flashing has been suggested as a means to increase pilot awareness of the RWSL, the associated confusion that may be created for other operations on the airport is expected to preclude this approach, based on warehouse observations. The most promising solution appears to be the use of in-pavement lights with a different color (e.g., shade of red) than the background lights. Also, the in-pavement lights have a narrower beam pattern (compared with the excessively wide beam pattern of the elevated fixtures used at Logan) which provides a higher brightness level at the pilots' location. This may get around the need for higher wattage lamps to achieve the desired increased brightness in bright sun, daytime conditions.

Lamp luminance response with trickle current appears to be adequate from the perspective of observers during the limited testing with the lights exposed. However, quantitative validation of the overall timing goal of three seconds is not possible without the desired unhooded operational testing.

8. CONCLUSIONS AND RECOMMENDATIONS

The RWSL conducted an operational assessment at Boston's Logan Airport that evaluated the system performance of a rapid prototype proof-of-concept system whose purpose was to improve the situational awareness of pilots, ground vehicle operators and air traffic controllers and reduce runway incursions. The RWSL assessment program was conducted under fiscal and schedule constraints, with the consequence that some of the known deficiencies could not be corrected but instead had to be accounted for in the design of the system. The FAA decided at the outset that the implementation of RWSL as a production system would be significantly more likely if the light activation logic were integrated with existing AMASS software to the maximum extent possible. This resulted in a deviation from MIT Lincoln Laboratories' original architecture and from some of the parameters which they had selected to optimize the performance of the light activation logic. It was recognized that this decision would have a significant impact on the performance of the system.

This section describes some of the more significant results and deficiencies that resulted from the prevailing engineering, budgetary, and programmatic constraints and the recommended improvements in a production-quality RWSL system. Also described are changes identified during the extensive subsystem and system testing phases of the program which would improve the performance, robustness, and functionality of the system. The conclusions and recommendations are divided into the following categories:

- Surveillance data
- System architecture
- Hardware
- Light Logic
- Procedures

and are described in following subsections.

8.1 SURVEILLANCE DATA

Radar as the sole sensor

Primary performance deficiencies identified during the hooded testing at Logan Airport were related directly to the limitations of the radar surveillance sensor: false targets, dropped tracks/targets, clutter and clutter reduction aberrations, irregular hand-off of targets between sensors, inaccurate heading determination at low speeds and lack of altitude information. The surveillance performance reduced the choice between system effectiveness and interference with airport operations. Based on the criteria given by the FAA to conduct unhooded testing, the system was intentionally tuned to minimize false alarms, which can lead to discrepancies between illuminated lights and ATC instructions and subsequent adverse effects on airport operation, particularly traffic flow. The effect of this decision was an increase in missed detections leading to a reduction in the effectiveness of the system in performing its intended function.

A second negative effect of using radar surveillance data resulted from the specific way in which AMASS established its clutter map. It was found that moving targets contributed to the clutter map during the clutter collection process. The effect during normal operation was target drop-out in those areas of the clutter map which were heavily traveled during the collection of the clutter map, leading to a severe problem with failure to illuminate lights, particularly, although not exclusively, THLs[1]. Although this problem was circumvented procedurally (by collecting clutter only during periods of light traffic), this is not considered a long term solution to the problem.

The third surveillance problem was multipath, which manifested itself in two forms. Firstly, real targets classified as multipath by the AMASS multipath detection algorithm would lead to failure of the lights to illuminate. Secondly, true reflections which were not classified as multipath led to false light illuminations, particularly THLs. The effect of both of these problems can be reduced by improvements in the multipath classification algorithms.

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[1] It should be noted that, unlike RELs, a THL will only illuminate when a target is detected in its arming region. However, RELs will also fail to illuminate if an undetected target takes off.

The net result of making these improvements to the radar would be a reduction in the number of discrepancies and missed detections and a significant improvement in RWSL performance. However, feedback received from the regional offices of the FAA, who were responsible for making the final decision not to unhood the lights, indicated that any performance level less than 100% perfect would prohibit the system from being tested. Unless some relief from this stringent requirement is forthcoming, the use of a surveillance radar, *as the sole sensor*, is not adequate to fulfill the RWSL need.

Alternative sensors

An additional processing of the radar data may provide some improvement; larger performance gains on the system level may be achieved through the fusion of data from multiple sources of data. An alternative, or additional, system, such as a GPS-based ADS, magnetic loops or runway based microwave sensors could provide the necessary data quality. The synergy of multiple sensors while minimizing the associated deficiencies could provide a system level performance which would exceed the capability of any single sensor.

First, it would provide the medium for vehicle and aircraft tags under all conditions[2], which would enhance the target tracking algorithm. On several occasions during hooded testing, target tracks were dropped and subsequently reacquired. When reacquired, the target was treated as completely new with no prior history. By tagging vehicles and aircraft, recent history could be used to assist in target track association. In addition, knowledge of whether a target is a vehicle or an aircraft would allow RWSL to use parameter sets that are specific to vehicle or aircraft type (anticipated separation, take-off characteristics, acceleration and deceleration models, etc.) and to implement logic to handle activities which are specific to either vehicles or aircraft (e.g., vehicles are restricted to ground operations, runway checks are performed by vehicles, etc.).

Second, it would provide additional data which would be useful to RWSL, such as aircraft height and velocity. Height is useful in determining when an aircraft has lifted off the runway, which is a factor in deciding when aircraft can cross the runway ahead of the departing aircraft. Velocity information would be useful in the tracking filters, not only improving accuracy but also providing an improved track prediction capability.

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[2] In the system as tested, ARTS tags were only available for arriving targets.

Thirdly, the use of ARTS data as a means of projecting aircraft arrival data, such as hot zone lengths and arrival runway, contributed to the anomalous behavior of the RWSL. Targets viewed on the AMASS display often appeared to stop moving for several seconds near the runway threshold. This was primarily due to the low data rate and the need to predict aircraft location several seconds ahead based on relatively low quality data. A position/velocity update at a rate of once/second, as might be seen from a GPS-based ADS is much better suited to the RWSL function than a position-only update once every 4 seconds.

Arrival Runway

One of the problems associated with using AMASS as a data preprocessor is that AMASS, because of its objective of predicting potential collisions, attempts to predict the arrival runway based on target track data from ARTS. This technique, although suitable in the AMASS context, is not optimal from an RWSL perspective. Last minute sidesteps and curved approaches cause significant problems because AMASS has trouble changing the predicted arrival runway until damage has been inflicted on the RWSL logic. A somewhat better solution, from an RWSL perspective, is to use the arrival runway contained in the ARTS data stream. The only drawback is that tower controllers would be *required* to enter the arrival runway, including last minute changes. If this could be guaranteed, there would be no RWSL errors associated with wrongly predicting the arrival runway.

Target Extent

As used in the RWSL assessment, AMASS provided only the target centroid - it did not provide target extent. This information would have allowed more positive determination of whether or not an aircraft was actually clear of the runway. On several occasions, it was noted that clearance was given to take off while an aircraft was still apparently (as calculated using only the centroid) within the incursion space on a taxiway, even though visual inspection indicated otherwise. Use of target extent, together with centroid might eliminate these types of problem.

Target Tracking Filter

On many occasions, targets accelerating rapidly were dropped by AMASS, presumably because the acceleration exceeded tracking filter limits. Minor changes to the filter would eliminate this problem.

Slow Vehicle Heading Estimation

The estimation of heading for targets with small translational motion was found to be inaccurate on some occasions. Because one of the arming conditions for THLs is that a target is either stationary or moving slowly in approximate alignment with the associated runway, this problem led to several false illumination of THLs.

8.2 SYSTEM ARCHITECTURE

Computer Architecture

The computer architecture used in the RWSL assessment program was selected primarily for its implementation efficiency and ease of integration. From discussions with vendors, it was determined that the unique smart transformer control requirements of the RWSL application would dictate the use of some custom software. However, most of the SX system vendors were in a position to supply the SX interface drivers and lower level control functions. To avoid favoring or being restricted to a specific vendor, a standard interface was developed that would promote rapid integration with any vendor's hardware. This approach forced the use of at least two computers, the first providing the higher level light control functions, and the second providing the lower level interface to the lighting circuits and SXs.

New RWSL functionality was broken into two components. The first component was essentially an integration of MIT's light activation logic with existing AMASS software, while the second was the control of the fairly complex lighting hardware. Again for reasons of implementation efficiency, these two components were hosted on two separate computers.

As set forth by the FAA, the RWSL system incorporated the functionality of the AMASS system into its computer architecture. The AMASS software operates under a i486 DOS platform which did not support the desired real time multitasking environment which may have enabled the significant expansion of the AMASS functionality to support RWSL operations. The physical interfaces with the ASDE-3 and ARTS radar and the AMASS being three stories above the RWSL test center located at the Boston Tower, it was necessary to provide a means for operational control in the RWSL operations area. This operational control was provided by the LCC, which essentially repeated the information displayed on the AMASS. In a production system, where remote maintenance of the lighting system hardware and fault isolation and detection become issues, the recommended architecture would be to integrate the RWSL light activation logic with the AMASS software in the AMASS computer and to locate the light subsystem control and maintenance functionality into a single computer, which would include both higher and lower level control of the lighting system i.e., combine the functionality of the Light Computer and the Light Control Computer into a single computer.

The AMASS/RWSL computer monitor would be located in the tower cab, whereas the light control computer would be located where it is easily accessible to maintenance staff. One issue associated with this approach is that the AMASS monitor, as implemented in the RWSL assessment program, only had the capability to display <u>commanded</u> light status, whereas a more useful, and arguable essential, capability would be to display the <u>actual</u> light status in the tower cab. This would require a change to the interface between AMASS and the Light Control Computer.

Sensor Fusion

One of the main consequences of the FAA's decision to integrate the RWSL light activation logic with AMASS was that, in contrast to MIT Lincoln Laboratories' approach, AMASS does not perform sensor fusion on the surveillance data. Instead, ARTS data are used until ASDE data become available. The handling of surveillance data in this way was one of the main causes of REL discrepancies. Handovers from ARTS to ASDE tracking could be improved by adopting the sensor fusion approach. Ideally, this would make use of ASR data directly, a capability which the existing AMASS does not provide.

8.3 HARDWARE

Lamp Responsiveness

The time taken for lamps to respond to commands to switch on was originally found to be excessive, taking up to several seconds to reach visible levels. Filament response time was improved by the use of a trickle current by the smart transformer which was sufficient to keep the filaments warm without being strong enough to make the lights appear on. This approach should be adopted in a production system if constant current circuits are used.

Lamp Beamwidth and Color

The elevated Wig-Wag light fixture employed for Logan Airport exhibited a wider beam spread than the original fixtures procured because of the intervening change in the FAA specification for the standard Wig-Wag light fixture. The beamwidth of the FAA-standard lights was found to be excessive at some of the more acute angled intersections (such as intersection of taxiway E with runway 9/27), to the point where some light spill over from the RELs onto the runway was occurring. The problem was fixed by attaching baffles to the troublesome lights to limit the beamwidth to about ±20°. One of the problems with this solution lies in the susceptibility of the baffle to being blown off the fixture by jet blast. A more permanent solution would be to procure lights with a more appropriate beamwidth of about ±15°. It should be noted that this light is not FAA standard.

During the limited unhooded testing, the red color of the RWSL lights was judged to be too similar with the background of other airport lighting systems. The in-pavement semi-flush lights were judged to be outstanding in their conspicuity in differentiating from existing airport lighting systems.

Smart Transformer Subsystem Performance

Test results indicate that remote control of filed lighting by using control signal communications impressed on the power cable is viable for RWSL control. However, there is a need to improve the command response reliability observed at Logan Airport to achieve the goal of 99% response to the first issuance of a command in the broadcast mode. It is desirable to reduce the monitoring cycle time required to obtain the status of all lights. Both of these system performance factors are dictated by the performance of the carrier current communications link between the SXs on the field and the series circuits to enable SX communications due to the higher than expected signal loss, increasing the time to poll all of the SXs for their status.

Performance of the SX subsystem in the warehouse and the factory environments is considerably better than the performance realized in the installed environment at Logan Airport. The noisy electromagnetic environment at Logan airport impacted the performance of the SX subsystem. This, together with crosstalk between the lighting circuits themselves, led to the use of more repeaters than originally predicted and a consequent loss in communication bandwidth. The net effect of this was that, although commands to the SXs could be issued at a rate that could support the broadcast approach, the time required to collect status information from the SXs was severely degraded. Although status was not considered essential information that was vital to the correct functioning of the test system, its role in a fully operational system will have to be weighed against tower controller and FAA requirements. Status response time will therefore have to be considered in the design of the lighting network e.g., number of SXs per circuit. Alternate communication media and technologies should also be considered.

The SXs were prone to mechanical failure brought about by a combination of proximity to the ocean, which caused the cans to fill with water, and freezing temperatures, which caused the water to freeze, crushing the SX units in the process. Some form of pressure relief system in the can would be required to alleviate this.

Structural Issues

Due to a lack of published information on the effects of jet blast close into the runway, elevated lights at some locations suffered severe structural failure, despite customized strengthening kits. There was also a tendency for some lights to rotate, despite the use of anti-rotation plates. In future systems, location of elevated lights should take these factors into consideration. An alternative is to use in-pavement lights, although these tend to suffer from snow plow operations.

Light Intensity

During light visibility tests, it was noted by observers that the optimal intensity of RELs was different to that for THLs, particularly in darkness. It is recommended that the capability to control at least the two types of lights, and preferably each individual light, separately be built into an operational system.

8.4 LIGHT LOGIC

Intersecting Runways

The issue of how to control lights at intersecting runways was partially resolved for testing purposes by adopting a conservative strategy of disabling RELs on runways which: (a) are active in the prevailing runway configuration, and (b) intersect with other runways. Although this reduces the effectiveness of the system, it does prevent a light from illuminating in front of a high speed target. For THLs, the light activation logic was modified to disable THLs from illuminating in front of a high speed aircraft under any circumstances. Note that the solution for the two different types of light differs because RELs do not operate on the arming principle. This is probably an effective solution for situations which do not involve land and hold short operations. In these cases, again, a conservative approach was taken for test purposes. On runways in which land and hold short operations can take place, RELs beyond the crossing runway were disabled. This reduces the possibility of a discrepancy at applicable intersections at the expense of a loss in system effectiveness. Ideally, a means of incorporating controller intent would provide the necessary adaptive capability.

Automatic Reconfiguration

The test system did not have the ability to either detect changes in runway configuration or to change configuration on-the-fly. This is a capability that is considered necessary to minimize operator workload. To make the system more appealing to controllers, a production system should require minimal levels of manual control.

8.5 ADDITIONAL TESTING

Although the simulator, warehouse and Logan Airport testing of the assessment system yielded significant human factors information and lesson learned, system validation and testing is incomplete because the system was not exposed to the airport users during normal airport operations.

Logan Airport is one of the busiest airports with rather complex runway and taxiway geometry with a distinction of having an excellent safety record. These factors presented an ideal working environment for stress testing RWSL with a large cross-section of users under the most demanding conditions. Based on the hooded test results, the fundamental capabilities of RWSL have been established and the few identified technical limitations of the assessment system are considered correctable. However, the primary remaining uncertainty is the pilots, ground vehicles and air traffic controllers response and reaction in the airport operational environment. Simulator testing with the pilots produced high endorsement of the concept. However, there is no substitute for obtaining the actual feedback from the airport user in the operational environment with its associated pressures and distractions. It is recommended that RWSL be deployed at a smaller airport that does not have the operational complexities and demands of a major airport for the purpose of quantifying the airport users' response to the system. This information is necessary to establish the true viability of RWSL. A perfect safety record is the goal of all airports and the purpose of RWSL is to help achieve this goal.

APPENDIX B

LIGHT MANAGER LOGIC

The Light Manager function provides capabilities for automatically controlling the runway status lights. Two types of runway status lights are implemented, runway entrance lights (RELs) and takeoff hold light (THLs), with separate logic used for each type. Runway status lights may be in one of two states: ON, in which the lights are red, indicating that it is unsafe to enter the runway or unsafe to begin takeoff, or OFF.

The runway status lights function automatically in response to real-time surveillance and are designed to avoid interfering with controller clearances or impeding the normal flow of traffic. An overview of the REL and THL logic is provided in section 4.2.

B.1 Runway Entrance Light Capabilities

Runway entrance lights are placed at runway/taxiway and runway/runway intersections and when illuminated indicate that a runway is unsafe to enter. The algorithms for controlling the RELs are based on three fundamental concepts:

1. **Target Hot Zones** - an area ahead of a high-speed target that should be free of other targets. The length of the hot zone corresponds to a distance t seconds ahead of the target, where t is an adaptable parameter that is a function of target state.
2. **REL Activation Region** - an area on the runway at an intersection associated with a group of RELs. A condition applying to the region affects all RELs associated with the region. A region may control more than one set of RELs, but a set of RELs is associated with only one region.
3. **Anticipated Separation** - the notion that controllers can issue clearances and instructions to aircraft in anticipation that legal separation between aircraft will exist when required, even though legal separation does not currently exist.

A runway is not safe to enter at a runway intersection if a target's hot zone overlaps the REL activation region at the intersection and the intersection is not subject to anticipated separation. The algorithms illuminate RELs if a hot zone overlaps an associated REL activation region; the lights are off otherwise. An exception may be made due to the application of anticipated separation. Figure B-1 illustrates the basic concepts used to control the RELs.

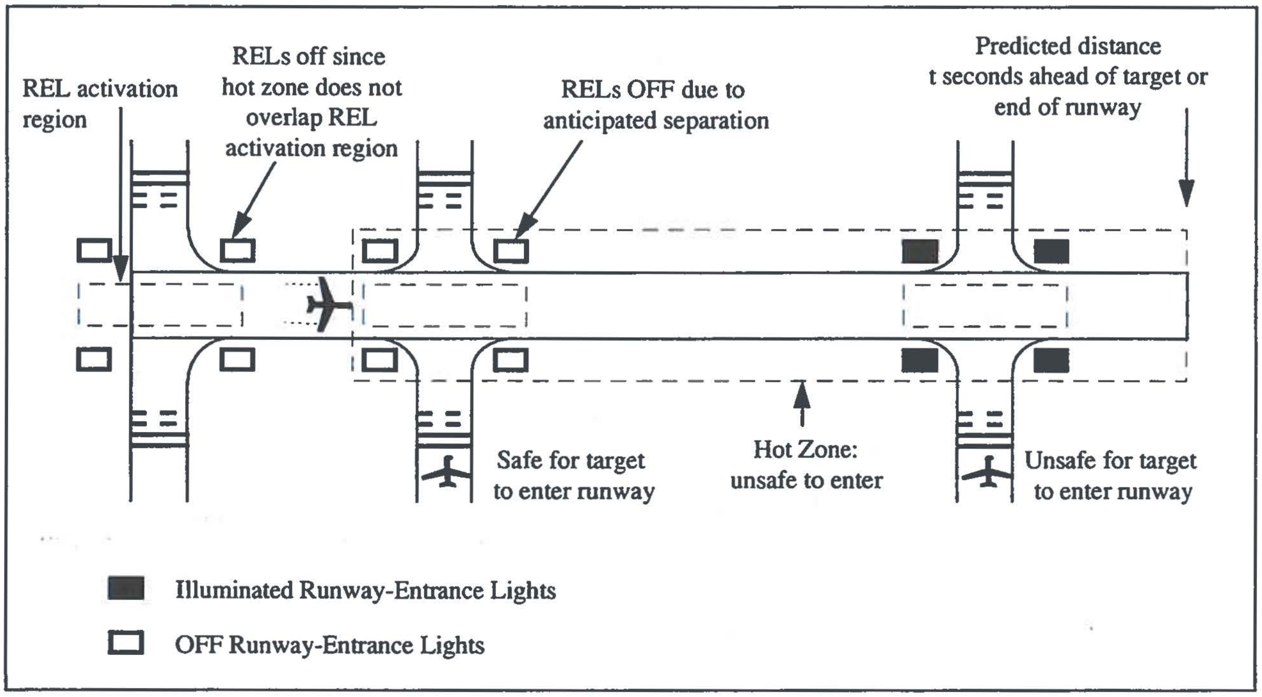


FIGURE B-1. REL CAPABILITIES

There are two types of hot zones, each with a different type of length:

1. t-second zones, whose length is the distance corresponding to *t* seconds ahead of the target, where *t* is a function of the target state
2. whole runway zones, whose length is the whole runway ahead of a target.

The type of hot zone will be dependent on the target's movement state, as computed by the existing AMASS logic (see Section 4-4):

a. Targets in the arrival state (ARR) will have a t-second hot zone

b. Targets in the departure state (DEP) or in the departure abort state (DBT) will have whole runway hot zones

c. Targets in the landing state (LDG) will have a whole runway hot zone while their speed is greater than or equal to an adaptable parameter (55 kts), and will have a t-second hot zone otherwise

d. Targets in the taxi state (TAX) or the stop state (STP) will have a hot zone length of zero since their target speeds are so low that it is safe for other targets to cross the runway ahead of them.

Each REL activation region will be associated with a group of RELs. REL groups will be determined based on lights that are deployed about a runway intersection, with a REL group consisting of the lights used to control runway access at an intersection. The REL groups for Logan Airport will be defined as shown in Figure B-2. Each group will be assigned a unique numeric identifier as depicted in the figure. The REL control logic will illuminate a group of RELs if a target's hot zone overlaps the REL activation region associated with the REL group, except when anticipated separation applies.

There are two ways to determine when a hot zone overlaps an REL activation region, depending on the type of hot zone. If the target has a whole runway zone, then the target's hot zone will overlap all REL activation regions ahead of it. If the target has a t-second zone, then the target's hot zone will overlap all REL activation regions ahead of it up to the t-second predicted position of the target.

Special logic is applied for RELs at runway-runway intersections to avoid distracting high-speed traffic and for RELs along the Bravo taxiway, which are affected by traffic on two runways: 9 and 4L.

The capabilities in the following paragraphs will be invoked at the completion of an ASDE radar sweep (i.e., approximately once per second) for all AMASS targets that meet the following conditions:

a. The target has not been tagged as a multipath target by the AMASS Target Management function

b. The target is associated with a valid AMASS segment. (Note: In AMASS, the airport runways and taxiways have been segmented into polygons and each polygon has been assigned a unique ID.)

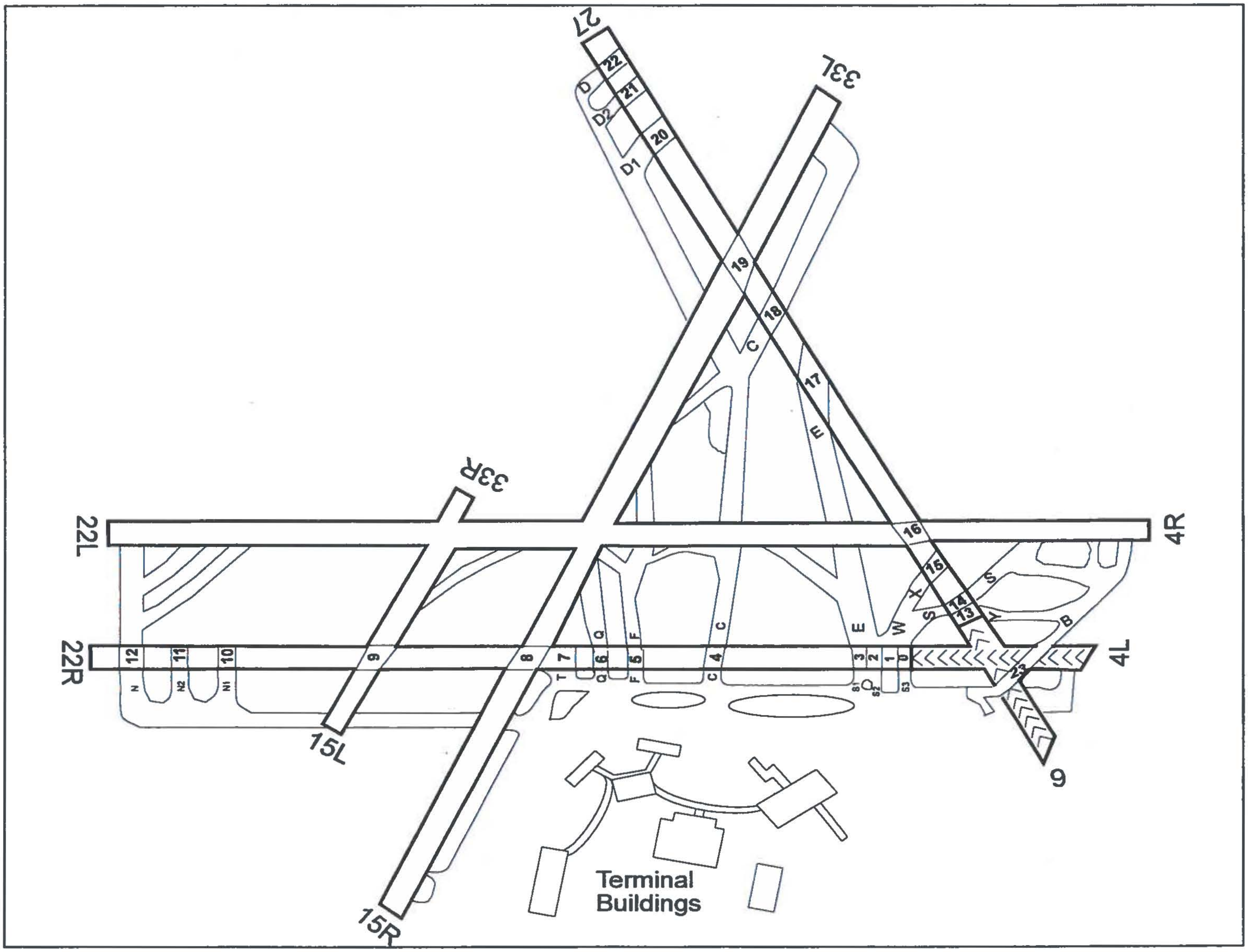


FIGURE B-2. REL LIGHT GROUPS

B.1.1 Arrival Targets

Figure B-3 illustrates the REL processing for an arrival target.

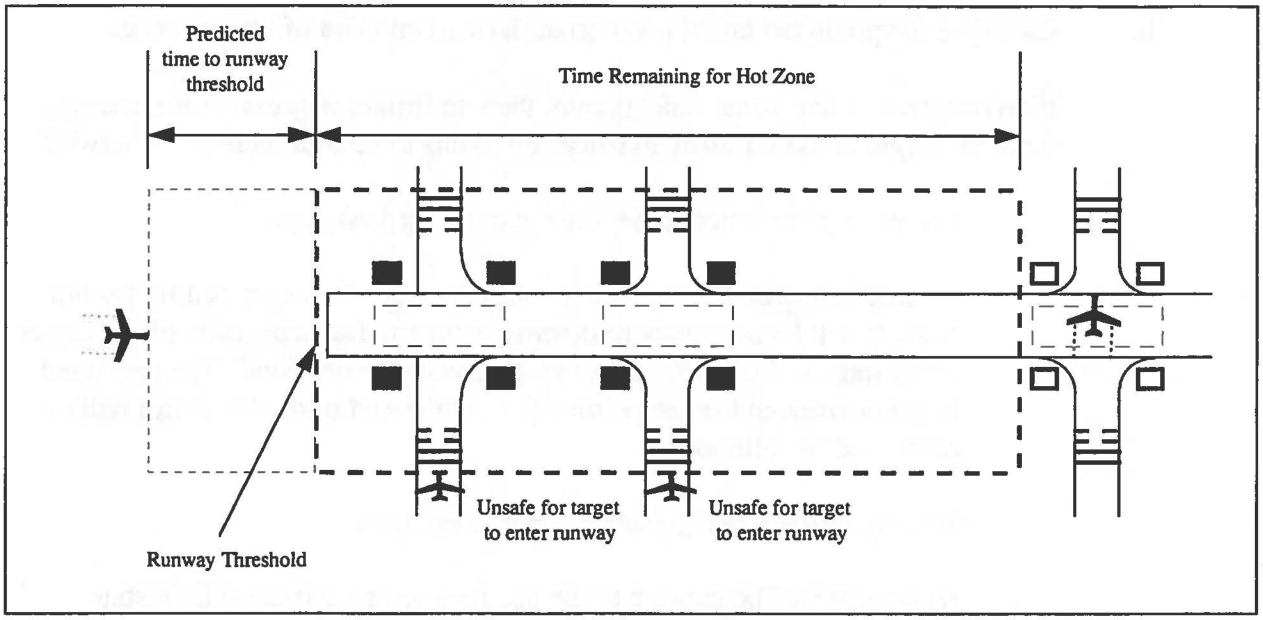


FIGURE B-3. ARRIVAL TARGET HOT ZONE

For each target in the arrival state and within an adaptable distance from the runway threshold (arrival_threshold_param), the following REL processing will be performed:

a. Calculate the predicted time for the target to reach the runway threshold:

arrival_time = distance_to_runway / target_velocity

where,

$$\text{distance\_to\_runway} = ((\text{tgt\_x\_pos} - \text{rwy\_thresh\_x\_pos})^2 + (\text{tgt\_y\_pos} - \text{rwy\_thresh\_y\_pos})^2)^{0.5}$$

tgt_x_pos = AMASS calculated target x position

tgt_y_pos = AMASS calculated target y position

rwy_thresh_x_pos = AMASS preset x position of the runway threshold

rwy_thresh_y_pos = AMASS preset y position of the runway threshold

(Note: The runway threshold to use will be obtained based on the AMASS determined approach runway for the target.)

target_velocity = AMASS computed_velocity

b. Calculate the predicted target position at the start and end of the hot zone.

If arrival_time ≥ hot_zone_time_param, then no further processing is necessary since the target is too far away to cause any lights to be illuminated. Otherwise,

hot_zone_time = hot_zone_time_param - arrival_time

To determine the REL activation regions that are overlapped by the hot zone, it will be necessary to determine the predicted position of the target at the start of the hot zone and at the end of the hot zone. The predicted target position at hot_zone_time (i.e., at the end of the hot zone) will be calculated as follows:

dist_on_rwy = target_velocity * hot_zone_time

Hysteresis will be applied to the hot zone to prevent rapid light state changes due to surveillance and tracking errors.

```
delta_dist = (dist_on_rwy from previous radar sweep) -
(dist_on_rwy from current radar sweep)

If (delta_dist > 0) ∧ (delta_dist / target_velocity <
hyst_time_param) then

    set (dist_on_rwy from current radar sweep) to (dist_on_rwy
    from previous radar sweep)
```

x_pos_pred_hz_end = rwy_thresh_x_pos + dist_on_rwy * x_sur_dir_vector

y_pos_pred_hz_end = rwy_thresh_y_pos + dist_on_rwy * y_sur_dir_vector

where,

> (x_sur_dir_vector, y_sur_dir_vector) is a unit vector along the direction of the approach runway.

If the point (x_pos_pred_hz_end, y_pos_pred_hz_end) is beyond the end of the runway surface then (x_pos_pred_hz_end, y_pos_pred_hz_end) will be set to the end point of the runway.

The predicted position of the target at the start of the hot zone will take into account the anticipated separation region. The anticipated separation region ensures that RELs are off prior to the time that a controller would issue runway crossing instructions to an aircraft. RELs in the anticipated separation region will be off even though the RELs are located in a hot zone.

If arrival_time < anticipated_sep_param then an anticipated separation region exists and the predicted position of the target at the start of the hot zone will be calculated as follows:

dist_on_rwy = target_velocity * (anticipated_sep_param - arrival_time)

Hysteresis will be applied to the anticipated separation region to prevent rapid light state changes due to surveillance and tracking errors.

```
delta_dist = (dist_on_rwy from previous radar sweep) - (dist_on_rwy from current radar sweep)

If (delta_dist > 0) ∧ (delta_dist / target_velocity < hyst_time_param) then

    set (dist_on_rwy from current radar sweep) to (dist_on_rwy from previous radar sweep)
```

x_pos_pred_hz_start = rwy_thresh_x_pos + dist_on_rwy * x_sur_dir_vector

y_pos_pred_hz_start = rwy_thresh_y_pos + dist_on_rwy * y_sur_dir_vector

where,

(x_sur_dir_vector, y_sur_dir_vector) is a unit vector along the direction of the approach runway.

Otherwise (anticipated separation does not apply),

x_pos_pred_hz_start = rwy_thresh_x_pos
y_pos_pred_hz_start = rwy_thresh_y_pos

c. Find the REL activation regions that overlap with the hot zone (compensated for anticipated separation) and set associated REL groups to the illuminate state.

For each REL activation region that overlaps the line segment from (x_pos_pred_hz_start, y_pos_pred_hz_start) to (x_pos_pred_hz_end, y_pos_pred_hz_end), the associated REL light group in the Light_Table will be set to the illuminate state.

B.1.2 Landing Targets

For targets in the landing state, the REL processing will divide targets into two cases:

(1) Once a target enters the landing state, a whole runway hot zone will be used until the target is "under control" (i.e., its speed has dropped below landing_rollout_speed_param).

(2) When the target is under control it will be considered to be in a landing rollout and a t-second hot zone will be used.

Figures B-4 and B-5 illustrate the REL processing for a landing target.

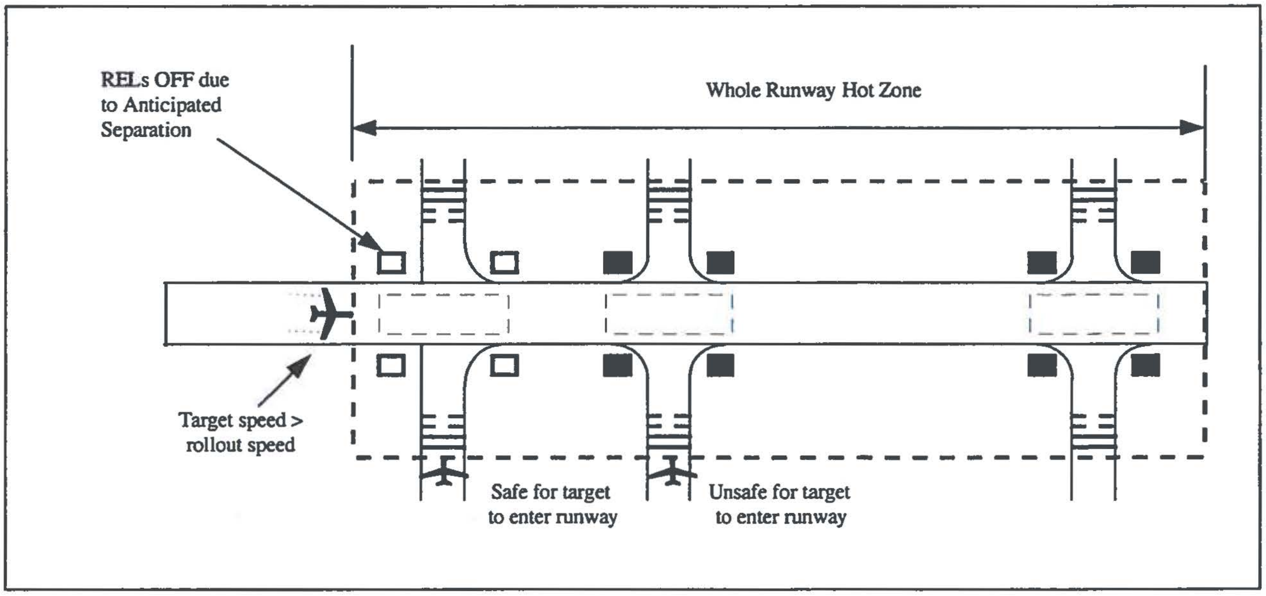


FIGURE B-4. LANDING HOT ZONE (WHOLE RUNWAY)

For each target in the landing state, the following REL processing will be performed:

a. Calculate the predicted target position at the start and end of the hot zone.

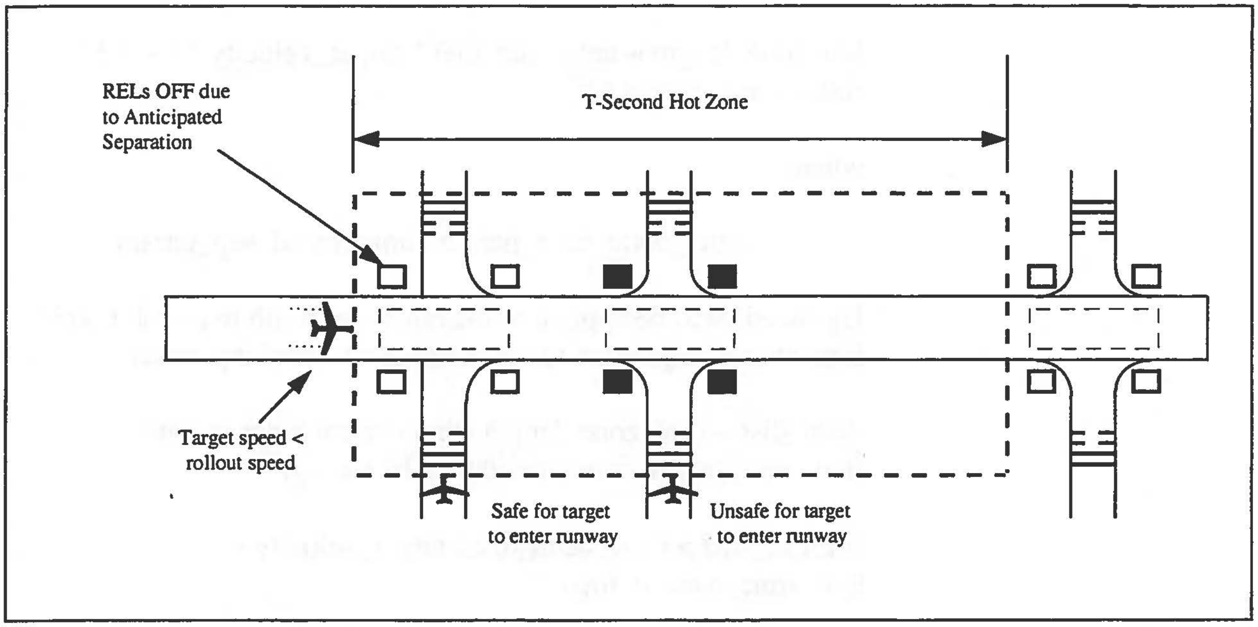


FIGURE B-5. LANDING HOT ZONE (T-SECOND)

The predicted position of the target at the start of the hot zone must take into account the anticipated separation region. The anticipated separation region ensures that RELs are off prior to the time that a controller would issue runway crossing instructions to an aircraft. RELs in the anticipated separation region will be off even though the RELs are located in a hot zone.

$$\text{antic\_sep\_dist} = \text{target\_velocity} * t + 0.5 * \text{tgt\_acc} * t^2$$

$$\text{x\_pos\_pred\_hz\_start} = \text{tgt\_x\_pos} + \text{antic\_sep\_dist} * \text{x\_sur\_dir\_vector}$$

$$\text{y\_pos\_pred\_hz\_start} = \text{tgt\_y\_pos} + \text{antic\_sep\_dist} * \text{y\_sur\_dir\_vector}$$

where,

```
t = anticipated_sep_param
if target is in landing state then
        tgt_acc = ldg_acc_param
else (target is in landing rollout)
        tgt_acc = rollout_acc_param
```

The predicted position of the target at the end of the hot zone will depend on the speed of the landing target. For slow speed landing targets (i.e., targets in a landing rollout) a t-second hot zone will be used. Otherwise, a whole runway hot zone will be used.

If target_velocity < landing_rollout_speed_param, then hot_zone_length = antic_sep_dist * target_velocity * t + 0.5 * rollout_acc_param * t^2

where,

t = hot_zone_time_param - anticipated_sep_param

Hysteresis will be applied to the hot zone length to prevent rapid light state changes due to surveillance and tracking errors.

delta_dist = (hot_zone_length from current radar sweep) - (hot_zone_length from previous radar sweep)

If (delta_dist > 0) $\wedge$ (delta_dist / target_velocity < hyst_time_param), then

set hot_zone_length to (hot_zone_length from previous radar sweep)

x_pos_pred_hz_end = tgt_x_pos + hot_zone_length * x_sur_dir_vector

y_pos_pred_hz_end = tgt_y_pos + hot_zone_length * y_sur_dir_vector

If the point (x_pos_pred_hz_end, y_pos_pred_hz_end) is beyond the end of the runway surface then (x_pos_pred_hz_end, y_pos_pred_hz_end) will be set to the end point of the runway.

Otherwise (target_velocity ≥ landing_rollout_speed_param)

x_pos_pred_hz_end = rwy_end_x_pos
y_pos_pred_hz_end = rwy_end_y_pos.

b. Find the REL activation regions that overlap with the hot zone (compensated for anticipated separation) and set associated REL groups to the illuminate state.

For each REL activation region that overlaps the line segment from (x_pos_pred_hz_start, y_pos_pred_hz_start) to (x_pos_pred_hz_end, y_pos_pred_hz_end), the associated REL light group in the Light_Table will be set to the illuminate state.

B.1.3 Departure Targets and Departure Abort Targets

Figure B-6 illustrates the REL processing for a departure target.

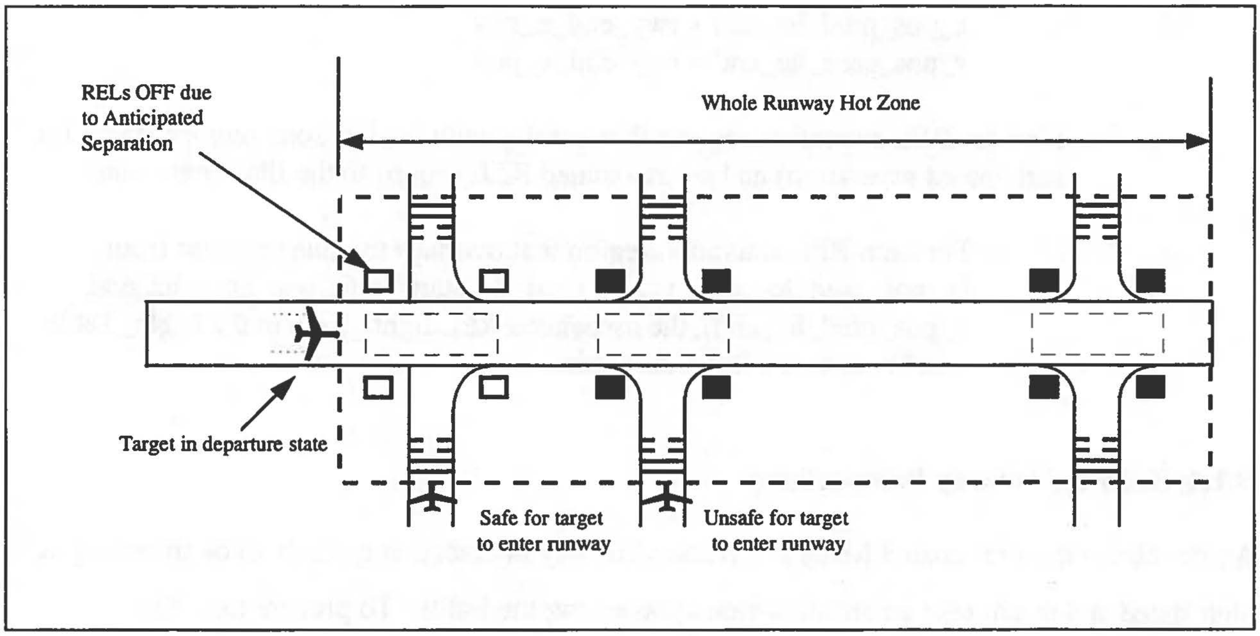


FIGURE B-6. DEPARTURE HOT ZONE

For each target in the departure state or the departure abort state, the following REL processing will be performed:

a. Calculate the predicted target position at the start and end of the hot zone.

The predicted position of the target at the start of the hot zone must take into account the anticipated separation region. The anticipated separation region ensures that RELs are off prior to the time that a controller would issue runway crossing instructions to an aircraft. RELs in the anticipated separation region will be off even though the RELs are located in a hot zone.

$$\text{antic\_sep\_dist} = \text{target\_velocity} * t + 0.5 * \text{tgt\_acc} * t^2$$

$$\text{x\_pos\_pred\_hz\_start} = \text{tgt\_x\_pos} + \text{antic\_sep\_dist} * \text{x\_sur\_dir\_vector}$$

$$\text{y\_pos\_pred\_hz\_start} = \text{tgt\_y\_pos} + \text{antic\_sep\_dist} * \text{y\_sur\_dir\_vector}$$

where,

```
t = anticipated_sep_param
if target is in departure state then
        tgt_acc = dep_acc_param
else (target is in departure abort state)
        tgt_acc = dbt_acc_param
```

The predicted position of the target at the end of the hot zone will be set to the end of the runway (whole runway hot zone).

x_pos_pred_hz_end = rwy_end_x_pos
y_pos_pred_hz_end = rwy_end_y_pos.

b. Find the REL activation regions that overlap with the hot zone (compensated for anticipated separation) and set associated REL groups to the illuminate state.

For each REL activation region that overlaps the line segment from (x_pos_pred_hz_start, y_pos_pred_hz_start) to (x_pos_pred_hz_end, y_pos_pred_hz_end), the associated REL light group in the Light_Table will be set to the illuminate state.

B.1.4 Runway/Runway Intersections

A pilot observing illuminated RELs at a runway/runway intersection is likely to be travelling at high speed and might take an unsafe action upon seeing the lights. To prevent this, REL processing will use the following logic rules:

a. REL groups will be deactivated at runway/runway intersections except for those cases when a runway is consistently being used only as a taxiway in the current airport configuration.

b. If a high speed target (i.e., a target in the ARR, LDG, DEP, or DBT state) is approaching illuminated RELs at a runway/runway intersection, the RELs will be turned off.

B.1.5 Bravo Taxiway

Boston's Logan Airport has long, crossing stopways at the approach ends of runways 4L and 9. The Bravo taxiway passes through the stopway area associated with Runway 9 and through the stopway area associated with runway 4L. RELs are located at the Bravo intersection with the Runway 9 stopway area and with the Runway 4L stopway area. Figure B-7 illustrates the deployment of RELs for the Bravo taxiway. These RELs are unlike any other at Logan Airport in that their state is affected by traffic on two runways: 9 and 4L. For this reason, special logic is required to operate the RELs associated with the Bravo taxiway. The following special logic rules will be used for the Bravo taxiway:

a. Two REL activation regions will be used to control the RELs associated with the Bravo taxiway. One REL activation region will be associated with traffic on Runway 9/27 and one REL activation region will be associated with traffic on Runway 4L/22R.

b. Hot zone processing for traffic on Runway 4L/22R will include the Bravo taxiway REL activation region for the Runway 4L stopway.

c. Hot zone processing for traffic on Runway 9/27 will include the Bravo taxiway REL activation region for the Runway 9 stopway.

d. REL lights for Group 23 (see Figure B-2) will be controlled by the hot zone processing for Runway 4L/22R and for Runway 9/27. If the hot zone processing for either Runway 4L/22R or Runway 9/27 indicate that Group 23 should be illuminated, then Group 23 will be placed in the illuminate state. Otherwise, REL Group 23 will be in the off state.

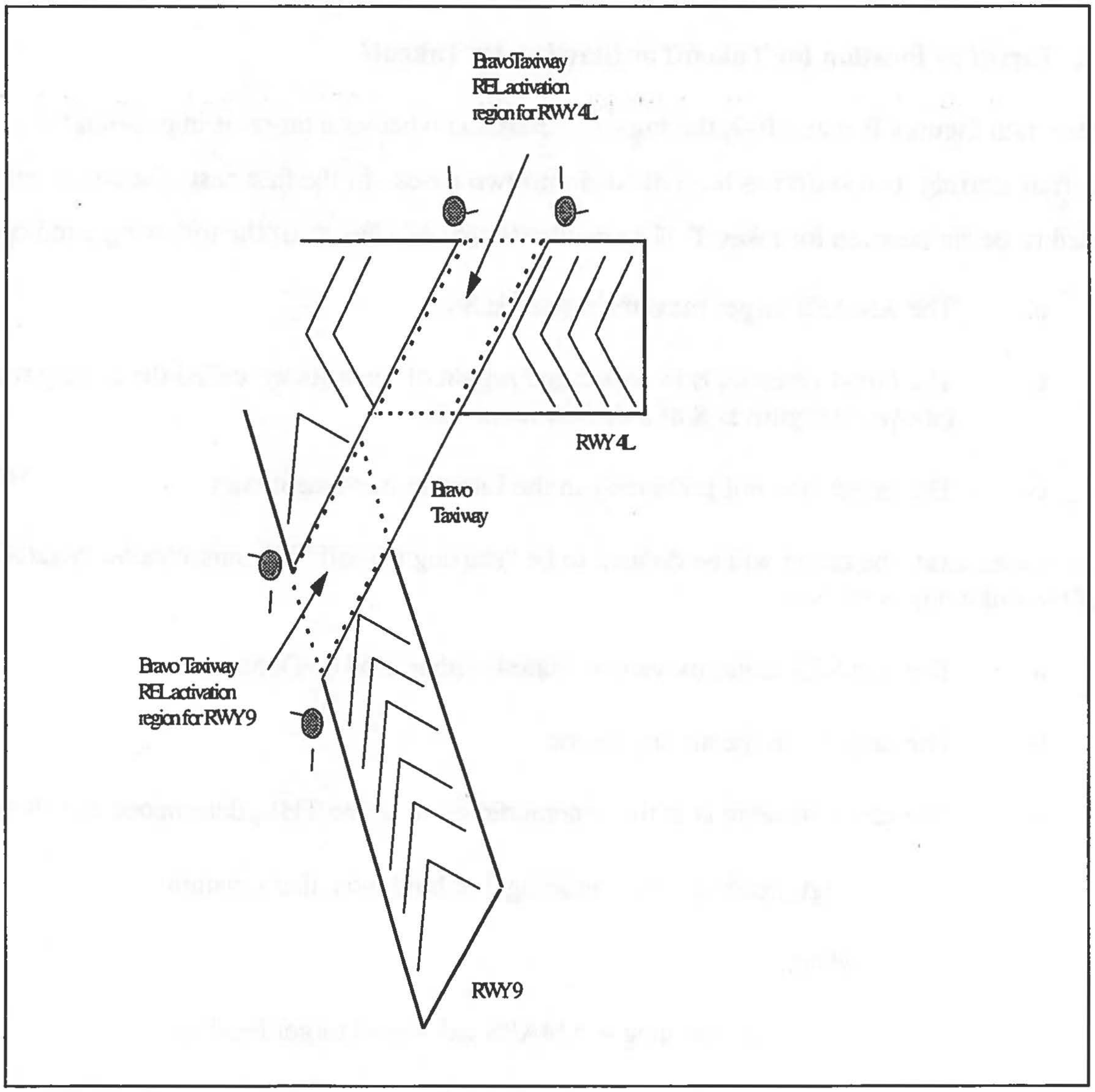


FIGURE B-7. RELS FOR BRAVO TAXIWAY

B.2 Takeoff-Hold Light Capabilities

The LM function will provide capabilities for illuminating takeoff-hold lights next to runways. The requirements for the processing to provide these capabilities are grouped into the following areas:

a. Target in Position for Takeoff or Starting Its Takeoff;

b. Targets on the Same Runway; and

c. Targets on Intersecting Runways.

B.2.1 Target in Position for Takeoff or Starting Its Takeoff

As shown in Figures B-8 and B-9, the logic to determine whether a target is in position for takeoff or starting its takeoff has been divided into two cases. In the first case, the target will be defined to be "in position for takeoff" if it simultaneously satisfies all of the following conditions:

a. The AMASS target movement state is Stop

b. The target centroid is in a specified region of the runway, called the arming region (shown in Figure B-8 as a dashed rectangle)

c. The target was not previously in the Landing movement state

In the second case, the target will be defined to be “starting takeoff” if it simultaneously satisfies all of the following conditions:

a. The AMASS target movement state is either Taxi or Departure

b. The target is in the arming region

c. The target heading is in the general direction of the THL, determined as follows:

$$| \text{tgt\_heading} - \text{rwy\_heading} | < \text{hold\_pos\_theta\_param}$$

where,

tgt_heading = AMASS calculated target heading

rwy_heading = heading of the runway containing the target

hold_pos_theta_param = angle adaptation parameter used to determine if the target is in position.

Hysteresis will be applied to the heading window to prevent rapid light state changes due to surveillance and tracking errors. Once the target is determined to be in the heading window (as described above), the rule for leaving this condition will be as follows:

| tgt_heading - rwy_heading | ≥ hold_pos_theta_param + hold_pos_theta_hyst_param

where,

hold_pos_theta_hyst_param = hysteresis margin for clearing the heading window.

d. The tgt velocity is less than an adaptable parameter:

tgt_velocity < arming_vel_threshold_param

where,

tgt_velocity = AMASS computed_velocity

arming_vel_threshold_param = adaptable speed threshold for determining that a target is in position for takeoff.

e. The target was not previously in Landing movement state.

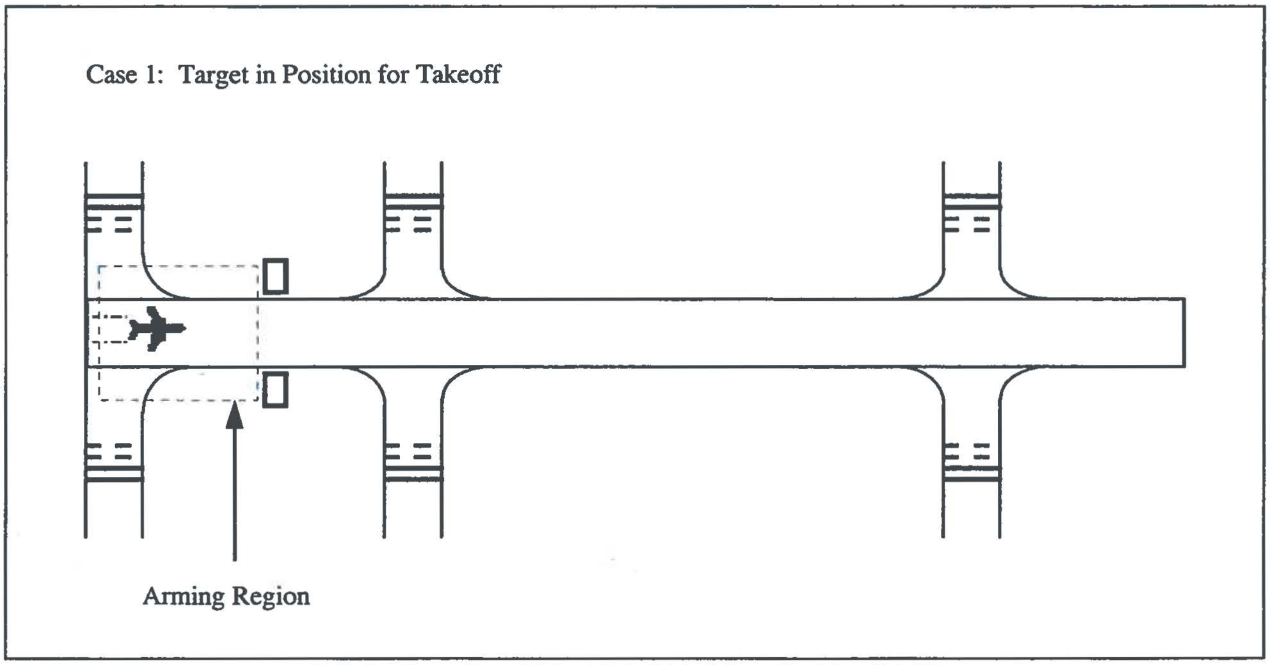

Case 1: Target in Position for Takeoff

FIGURE B-8. THL ARMING REGION CASE 1

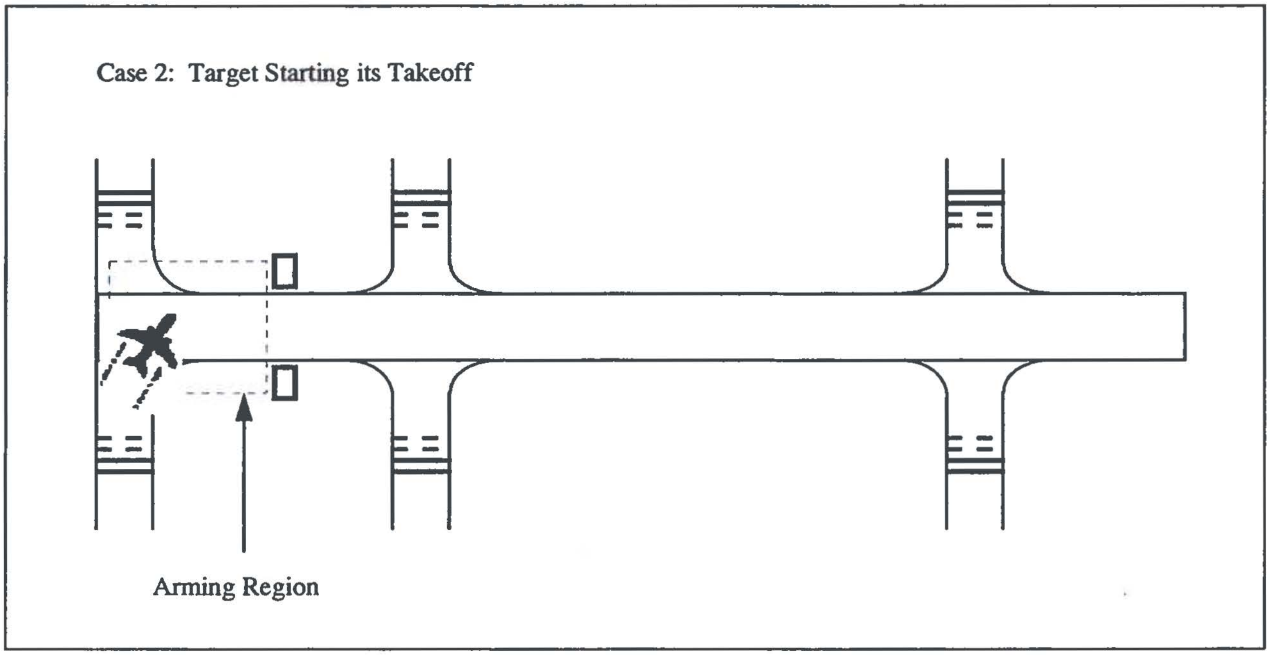

Case 2: Target Starting its Takeoff

FIGURE B-9. THL ARMING REGION CASE 2

APPENDIX B

LIGHT MANAGER LOGIC

The Light Manager function provides capabilities for automatically controlling the runway status lights. Two types of runway status lights are implemented, runway entrance lights (RELs) and takeoff hold light (THLs), with separate logic used for each type. Runway status lights may be in one of two states: ON, in which the lights are red, indicating that it is unsafe to enter the runway or unsafe to begin takeoff, or OFF.

The runway status lights function automatically in response to real-time surveillance and are designed to avoid interfering with controller clearances or impeding the normal flow of traffic. An overview of the REL and THL logic is provided in section 4.2.

B.1 Runway Entrance Light Capabilities

Runway entrance lights are placed at runway/taxiway and runway/runway intersections and when illuminated indicate that a runway is unsafe to enter. The algorithms for controlling the RELs are based on three fundamental concepts:

1. **Target Hot Zones** - an area ahead of a high-speed target that should be free of other targets. The length of the hot zone corresponds to a distance t seconds ahead of the target, where t is an adaptable parameter that is a function of target state.
2. **REL Activation Region** - an area on the runway at an intersection associated with a group of RELs. A condition applying to the region affects all RELs associated with the region. A region may control more than one set of RELs, but a set of RELs is associated with only one region.
3. **Anticipated Separation** - the notion that controllers can issue clearances and instructions to aircraft in anticipation that legal separation between aircraft will exist when required, even though legal separation does not currently exist.

A runway is not safe to enter at a runway intersection if a target's hot zone overlaps the REL activation region at the intersection and the intersection is not subject to anticipated separation. The algorithms illuminate RELs if a hot zone overlaps an associated REL activation region; the lights are off otherwise. An exception may be made due to the application of anticipated separation. Figure B-1 illustrates the basic concepts used to control the RELs.

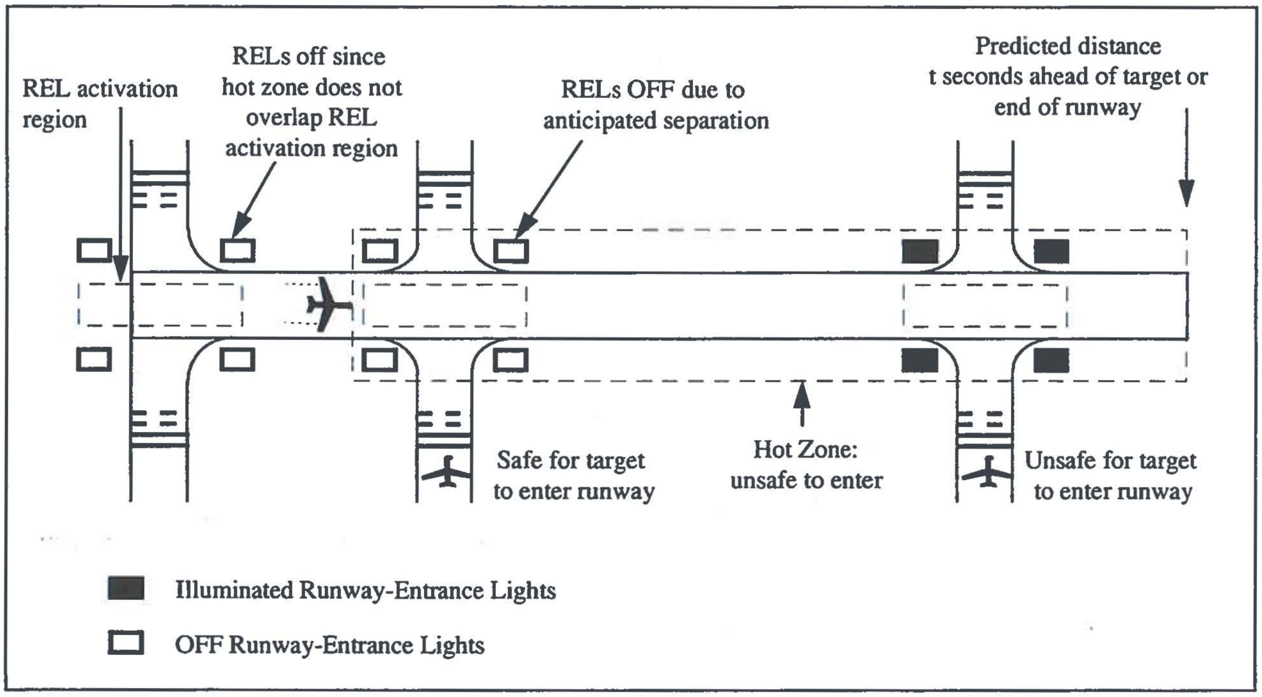


FIGURE B-1. REL CAPABILITIES

There are two types of hot zones, each with a different type of length:

1. t-second zones, whose length is the distance corresponding to *t* seconds ahead of the target, where *t* is a function of the target state
2. whole runway zones, whose length is the whole runway ahead of a target.

The type of hot zone will be dependent on the target's movement state, as computed by the existing AMASS logic (see Section 4-4):

a. Targets in the arrival state (ARR) will have a t-second hot zone

b. Targets in the departure state (DEP) or in the departure abort state (DBT) will have whole runway hot zones

c. Targets in the landing state (LDG) will have a whole runway hot zone while their speed is greater than or equal to an adaptable parameter (55 kts), and will have a t-second hot zone otherwise

d. Targets in the taxi state (TAX) or the stop state (STP) will have a hot zone length of zero since their target speeds are so low that it is safe for other targets to cross the runway ahead of them.

Each REL activation region will be associated with a group of RELs. REL groups will be determined based on lights that are deployed about a runway intersection, with a REL group consisting of the lights used to control runway access at an intersection. The REL groups for Logan Airport will be defined as shown in Figure B-2. Each group will be assigned a unique numeric identifier as depicted in the figure. The REL control logic will illuminate a group of RELs if a target's hot zone overlaps the REL activation region associated with the REL group, except when anticipated separation applies.

There are two ways to determine when a hot zone overlaps an REL activation region, depending on the type of hot zone. If the target has a whole runway zone, then the target's hot zone will overlap all REL activation regions ahead of it. If the target has a t-second zone, then the target's hot zone will overlap all REL activation regions ahead of it up to the t-second predicted position of the target.

Special logic is applied for RELs at runway-runway intersections to avoid distracting high-speed traffic and for RELs along the Bravo taxiway, which are affected by traffic on two runways: 9 and 4L.

The capabilities in the following paragraphs will be invoked at the completion of an ASDE radar sweep (i.e., approximately once per second) for all AMASS targets that meet the following conditions:

a. The target has not been tagged as a multipath target by the AMASS Target Management function

b. The target is associated with a valid AMASS segment. (Note: In AMASS, the airport runways and taxiways have been segmented into polygons and each polygon has been assigned a unique ID.)

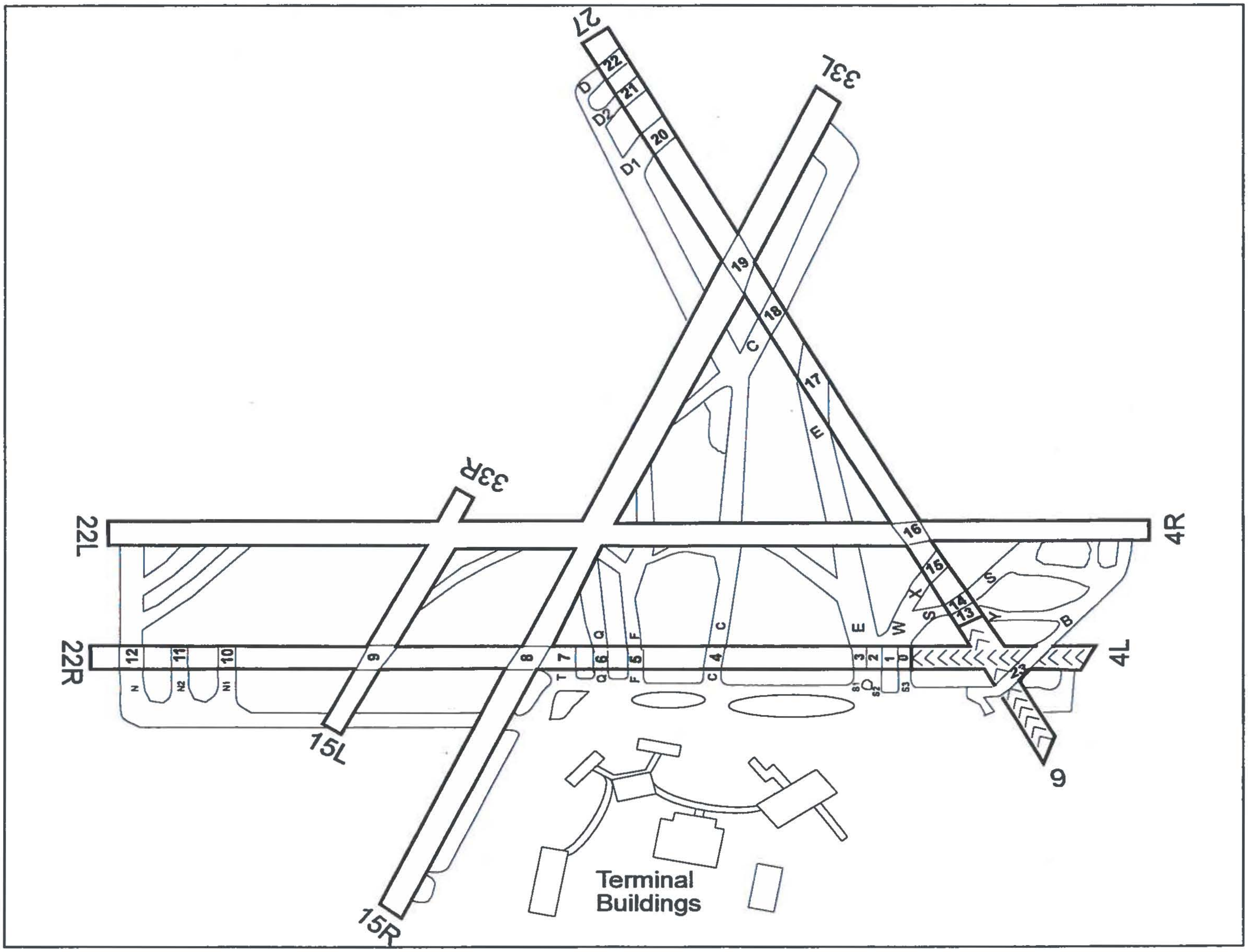


FIGURE B-2. REL LIGHT GROUPS

B.1.1 Arrival Targets

Figure B-3 illustrates the REL processing for an arrival target.

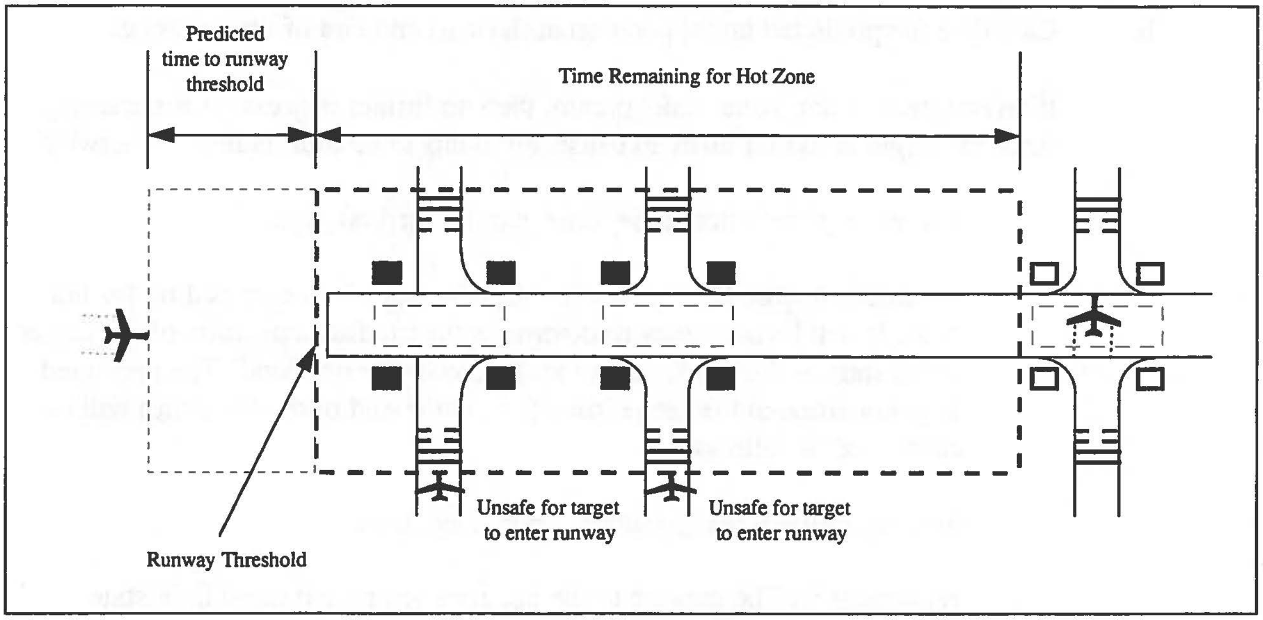


FIGURE B-3. ARRIVAL TARGET HOT ZONE

For each target in the arrival state and within an adaptable distance from the runway threshold (arrival_threshold_param), the following REL processing will be performed:

a. Calculate the predicted time for the target to reach the runway threshold:

arrival_time = distance_to_runway / target_velocity

where,

$$distance\_to\_runway = ((tgt\_x\_pos - rwy\_thresh\_x\_pos)^2 + (tgt\_y\_pos - rwy\_thresh\_y\_pos)^2)^{0.5}$$

tgt_x_pos = AMASS calculated target x position

tgt_y_pos = AMASS calculated target y position

rwy_thresh_x_pos = AMASS preset x position of the runway threshold

rwy_thresh_y_pos = AMASS preset y position of the runway threshold

(Note: The runway threshold to use will be obtained based on the AMASS determined approach runway for the target.)

target_velocity = AMASS computed_velocity

b. Calculate the predicted target position at the start and end of the hot zone.

If arrival_time ≥ hot_zone_time_param, then no further processing is necessary since the target is too far away to cause any lights to be illuminated. Otherwise,

hot_zone_time = hot_zone_time_param - arrival_time

To determine the REL activation regions that are overlapped by the hot zone, it will be necessary to determine the predicted position of the target at the start of the hot zone and at the end of the hot zone. The predicted target position at hot_zone_time (i.e., at the end of the hot zone) will be calculated as follows:

dist_on_rwy = target_velocity * hot_zone_time

Hysteresis will be applied to the hot zone to prevent rapid light state changes due to surveillance and tracking errors.

delta_dist = (dist_on_rwy from previous radar sweep) - (dist_on_rwy from current radar sweep)

If (delta_dist > 0) ∧ (delta_dist / target_velocity < hyst_time_param) then

set (dist_on_rwy from current radar sweep) to (dist_on_rwy from previous radar sweep)

x_pos_pred_hz_end = rwy_thresh_x_pos + dist_on_rwy * x_sur_dir_vector

y_pos_pred_hz_end = rwy_thresh_y_pos + dist_on_rwy * y_sur_dir_vector

where,

(x_sur_dir_vector, y_sur_dir_vector) is a unit vector along the direction of the approach runway.

If the point (x_pos_pred_hz_end, y_pos_pred_hz_end) is beyond the end of the runway surface then (x_pos_pred_hz_end, y_pos_pred_hz_end) will be set to the end point of the runway.

The predicted position of the target at the start of the hot zone will take into account the anticipated separation region. The anticipated separation region ensures that RELs are off prior to the time that a controller would issue runway crossing instructions to an aircraft. RELs in the anticipated separation region will be off even though the RELs are located in a hot zone.

If arrival_time < anticipated_sep_param then an anticipated separation region exists and the predicted position of the target at the start of the hot zone will be calculated as follows:

```
dist_on_rwy = target_velocity * (anticipated_sep_param - arrival_time)
```

Hysteresis will be applied to the anticipated separation region to prevent rapid light state changes due to surveillance and tracking errors.

```
    delta_dist = (dist_on_rwy from previous radar sweep) - (dist_on_rwy from current radar sweep)

    If (delta_dist > 0) ∧ (delta_dist / target_velocity < hyst_time_param) then

        set (dist_on_rwy from current radar sweep) to (dist_on_rwy from previous radar sweep)

x_pos_pred_hz_start = rwy_thresh_x_pos + dist_on_rwy * x_sur_dir_vector

y_pos_pred_hz_start = rwy_thresh_y_pos + dist_on_rwy * y_sur_dir_vector
```

where,

(x_sur_dir_vector, y_sur_dir_vector) is a unit vector along the direction of the approach runway.

Otherwise (anticipated separation does not apply),

```
x_pos_pred_hz_start = rwy_thresh_x_pos
y_pos_pred_hz_start = rwy_thresh_y_pos
```

c. Find the REL activation regions that overlap with the hot zone (compensated for anticipated separation) and set associated REL groups to the illuminate state.

For each REL activation region that overlaps the line segment from (x_pos_pred_hz_start, y_pos_pred_hz_start) to (x_pos_pred_hz_end, y_pos_pred_hz_end), the associated REL light group in the Light_Table will be set to the illuminate state.

B.1.2 Landing Targets

For targets in the landing state, the REL processing will divide targets into two cases:

(1) Once a target enters the landing state, a whole runway hot zone will be used until the target is "under control" (i.e., its speed has dropped below landing_rollout_speed_param).

(2) When the target is under control it will be considered to be in a landing rollout and a t-second hot zone will be used.

Figures B-4 and B-5 illustrate the REL processing for a landing target.

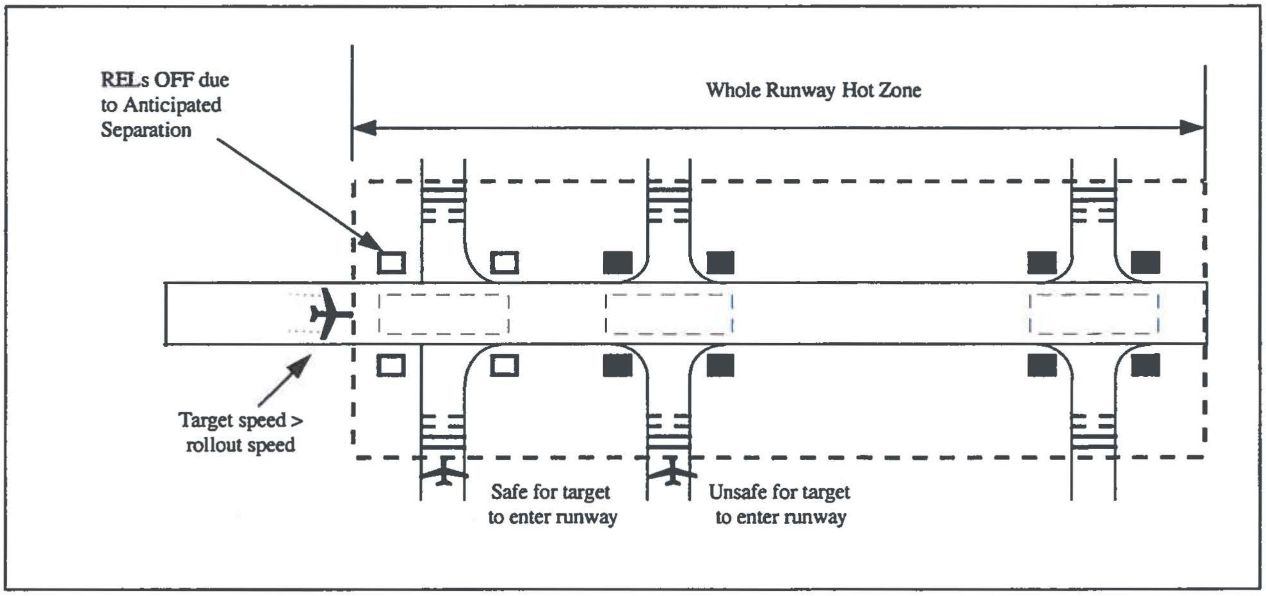


FIGURE B-4. LANDING HOT ZONE (WHOLE RUNWAY)

For each target in the landing state, the following REL processing will be performed:

a. Calculate the predicted target position at the start and end of the hot zone.

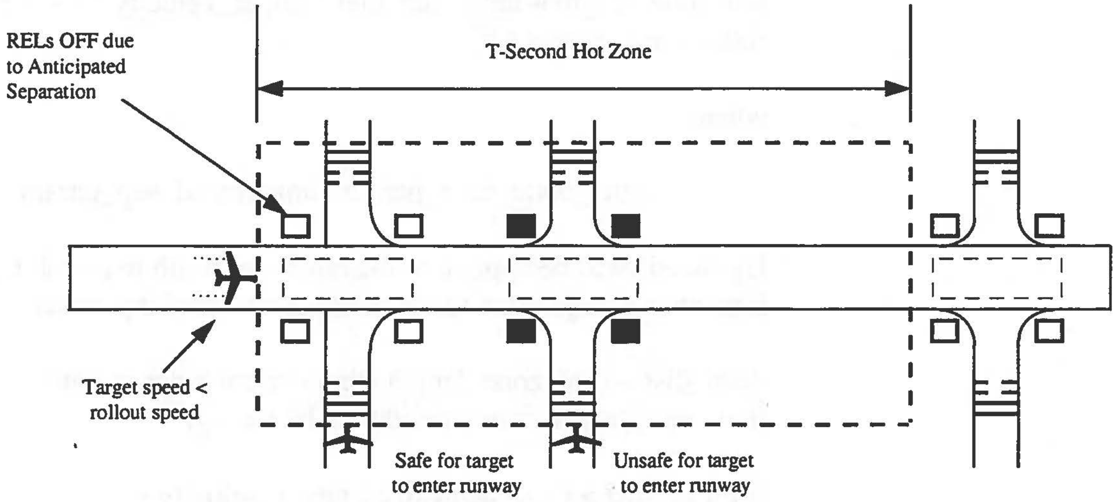


FIGURE B-5. LANDING HOT ZONE (T-SECOND)

The predicted position of the target at the start of the hot zone must take into account the anticipated separation region. The anticipated separation region ensures that RELs are off prior to the time that a controller would issue runway crossing instructions to an aircraft. RELs in the anticipated separation region will be off even though the RELs are located in a hot zone.

$$antic\_sep\_dist = target\_velocity * t + 0.5 * tgt\_acc * t^2$$

$$x\_pos\_pred\_hz\_start = tgt\_x\_pos + antic\_sep\_dist * x\_sur\_dir\_vector$$

$$y\_pos\_pred\_hz\_start = tgt\_y\_pos + antic\_sep\_dist * y\_sur\_dir\_vector$$

where,

```
    t = anticipated_sep_param
    if target is in landing state then
        tgt_acc = ldg_acc_param
    else (target is in landing rollout)
        tgt_acc = rollout_acc_param
```

The predicted position of the target at the end of the hot zone will depend on the speed of the landing target. For slow speed landing targets (i.e., targets in a landing rollout) a t-second hot zone will be used. Otherwise, a whole runway hot zone will be used.

If target_velocity < landing_rollout_speed_param, then hot_zone_length = antic_sep_dist * target_velocity * t + 0.5 * rollout_acc_param * t^2

where,

t = hot_zone_time_param - anticipated_sep_param

Hysteresis will be applied to the hot zone length to prevent rapid light state changes due to surveillance and tracking errors.

delta_dist = (hot_zone_length from current radar sweep) - (hot_zone_length from previous radar sweep)

If (delta_dist > 0) ∧ (delta_dist / target_velocity < hyst_time_param), then

set hot_zone_length to (hot_zone_length from previous radar sweep)

x_pos_pred_hz_end = tgt_x_pos + hot_zone_length * x_sur_dir_vector

y_pos_pred_hz_end = tgt_y_pos + hot_zone_length * y_sur_dir_vector

If the point (x_pos_pred_hz_end, y_pos_pred_hz_end) is beyond the end of the runway surface then (x_pos_pred_hz_end, y_pos_pred_hz_end) will be set to the end point of the runway.

Otherwise (target_velocity ≥ landing_rollout_speed_param)

x_pos_pred_hz_end = rwy_end_x_pos
y_pos_pred_hz_end = rwy_end_y_pos.

b. Find the REL activation regions that overlap with the hot zone (compensated for anticipated separation) and set associated REL groups to the illuminate state.

For each REL activation region that overlaps the line segment from (x_pos_pred_hz_start, y_pos_pred_hz_start) to (x_pos_pred_hz_end, y_pos_pred_hz_end), the associated REL light group in the Light_Table will be set to the illuminate state.

B.1.3 Departure Targets and Departure Abort Targets

Figure B-6 illustrates the REL processing for a departure target.

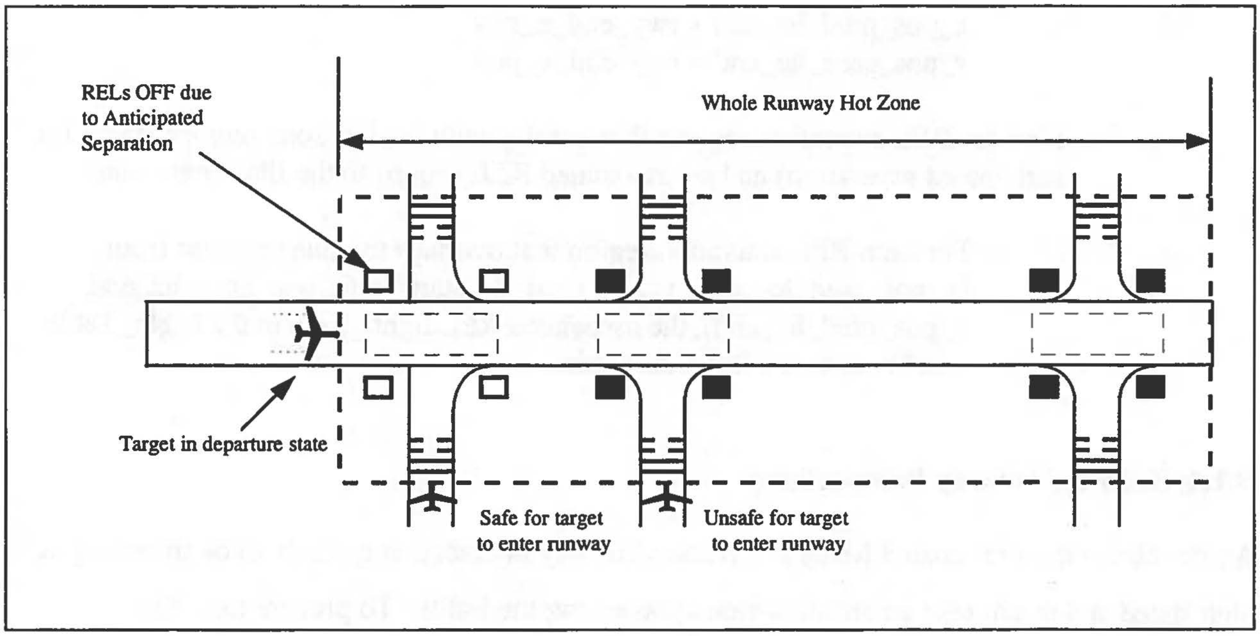


FIGURE B-6. DEPARTURE HOT ZONE

For each target in the departure state or the departure abort state, the following REL processing will be performed:

a. Calculate the predicted target position at the start and end of the hot zone.

The predicted position of the target at the start of the hot zone must take into account the anticipated separation region. The anticipated separation region ensures that RELs are off prior to the time that a controller would issue runway crossing instructions to an aircraft. RELs in the anticipated separation region will be off even though the RELs are located in a hot zone.

$$\text{antic\_sep\_dist} = \text{target\_velocity} * t + 0.5 * \text{tgt\_acc} * t^2$$

$$\text{x\_pos\_pred\_hz\_start} = \text{tgt\_x\_pos} + \text{antic\_sep\_dist} * \text{x\_sur\_dir\_vector}$$

$$\text{y\_pos\_pred\_hz\_start} = \text{tgt\_y\_pos} + \text{antic\_sep\_dist} * \text{y\_sur\_dir\_vector}$$

where,

```
t = anticipated_sep_param
if target is in departure state then
        tgt_acc = dep_acc_param
else (target is in departure abort state)
        tgt_acc = dbt_acc_param
```

The predicted position of the target at the end of the hot zone will be set to the end of the runway (whole runway hot zone).

x_pos_pred_hz_end = rwy_end_x_pos
y_pos_pred_hz_end = rwy_end_y_pos.

b. Find the REL activation regions that overlap with the hot zone (compensated for anticipated separation) and set associated REL groups to the illuminate state.

For each REL activation region that overlaps the line segment from (x_pos_pred_hz_start, y_pos_pred_hz_start) to (x_pos_pred_hz_end, y_pos_pred_hz_end), the associated REL light group in the Light_Table will be set to the illuminate state.

B.1.4 Runway/Runway Intersections

A pilot observing illuminated RELs at a runway/runway intersection is likely to be travelling at high speed and might take an unsafe action upon seeing the lights. To prevent this, REL processing will use the following logic rules:

a. REL groups will be deactivated at runway/runway intersections except for those cases when a runway is consistently being used only as a taxiway in the current airport configuration.

b. If a high speed target (i.e., a target in the ARR, LDG, DEP, or DBT state) is approaching illuminated RELs at a runway/runway intersection, the RELs will be turned off.

B.1.5 Bravo Taxiway

Boston's Logan Airport has long, crossing stopways at the approach ends of runways 4L and 9. The Bravo taxiway passes through the stopway area associated with Runway 9 and through the stopway area associated with runway 4L. RELs are located at the Bravo intersection with the Runway 9 stopway area and with the Runway 4L stopway area. Figure B-7 illustrates the deployment of RELs for the Bravo taxiway. These RELs are unlike any other at Logan Airport in that their state is affected by traffic on two runways: 9 and 4L. For this reason, special logic is required to operate the RELs associated with the Bravo taxiway. The following special logic rules will be used for the Bravo taxiway:

a. Two REL activation regions will be used to control the RELs associated with the Bravo taxiway. One REL activation region will be associated with traffic on Runway 9/27 and one REL activation region will be associated with traffic on Runway 4L/22R.

b. Hot zone processing for traffic on Runway 4L/22R will include the Bravo taxiway REL activation region for the Runway 4L stopway.

c. Hot zone processing for traffic on Runway 9/27 will include the Bravo taxiway REL activation region for the Runway 9 stopway.

d. REL lights for Group 23 (see Figure B-2) will be controlled by the hot zone processing for Runway 4L/22R and for Runway 9/27. If the hot zone processing for either Runway 4L/22R or Runway 9/27 indicate that Group 23 should be illuminated, then Group 23 will be placed in the illuminate state. Otherwise, REL Group 23 will be in the off state.

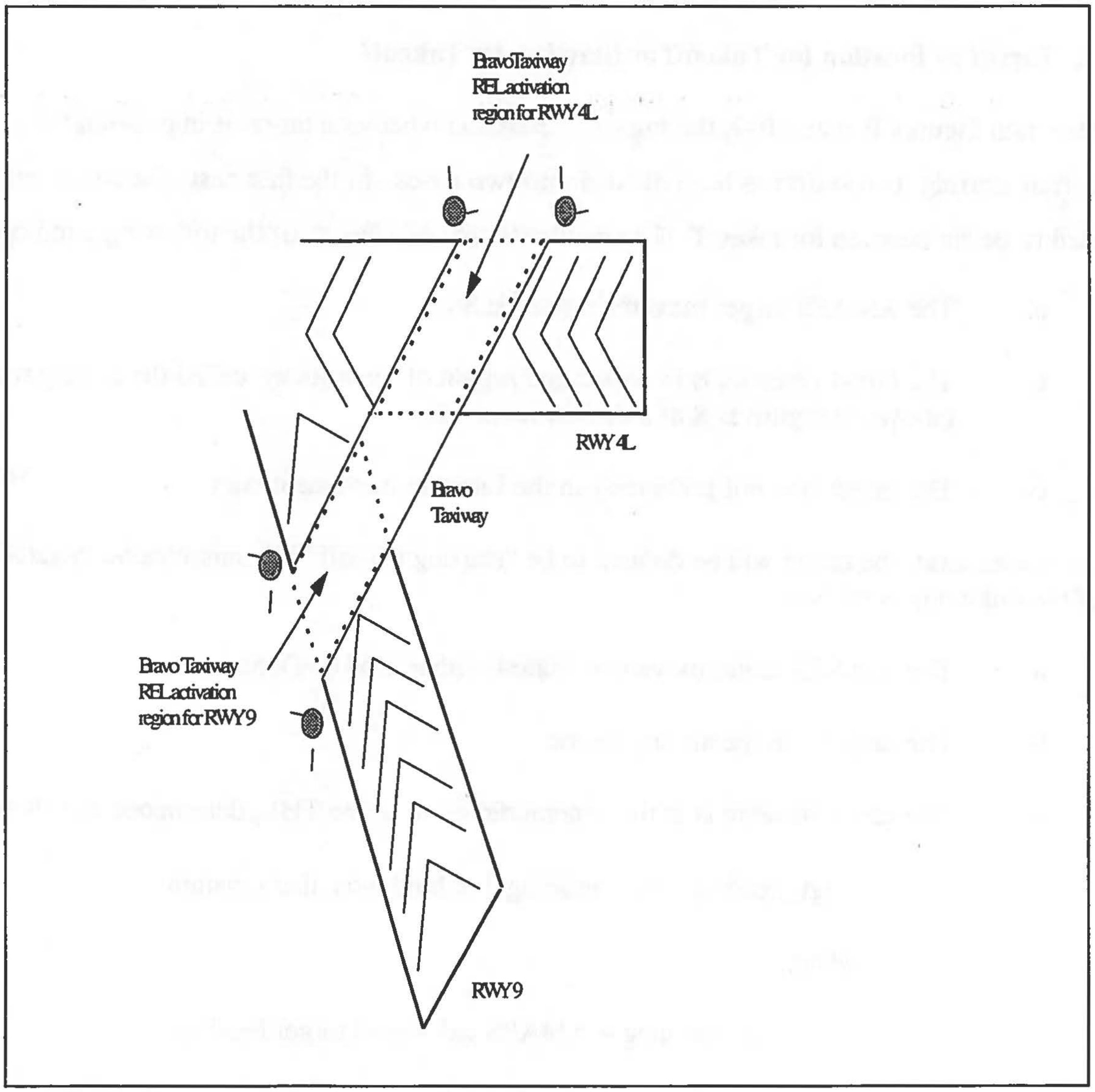


FIGURE B-7. RELS FOR BRAVO TAXIWAY

B.2 Takeoff-Hold Light Capabilities

The LM function will provide capabilities for illuminating takeoff-hold lights next to runways. The requirements for the processing to provide these capabilities are grouped into the following areas:

a. Target in Position for Takeoff or Starting Its Takeoff;

b. Targets on the Same Runway; and

c. Targets on Intersecting Runways.

B.2.1 Target in Position for Takeoff or Starting Its Takeoff

As shown in Figures B-8 and B-9, the logic to determine whether a target is in position for takeoff or starting its takeoff has been divided into two cases. In the first case, the target will be defined to be "in position for takeoff" if it simultaneously satisfies all of the following conditions:

a. The AMASS target movement state is Stop

b. The target centroid is in a specified region of the runway, called the arming region (shown in Figure B-8 as a dashed rectangle)

c. The target was not previously in the Landing movement state

In the second case, the target will be defined to be "starting takeoff" if it simultaneously satisfies all of the following conditions:

a. The AMASS target movement state is either Taxi or Departure

b. The target is in the arming region

c. The target heading is in the general direction of the THL, determined as follows:

$$| \text{tgt\_heading} - \text{rwy\_heading} | < \text{hold\_pos\_theta\_param}$$

where,

tgt_heading = AMASS calculated target heading

rwy_heading = heading of the runway containing the target

hold_pos_theta_param = angle adaptation parameter used to determine if the target is in position.

Hysteresis will be applied to the heading window to prevent rapid light state changes due to surveillance and tracking errors. Once the target is determined to be in the heading window (as described above), the rule for leaving this condition will be as follows:

$|\text{tgt\_heading} - \text{rwy\_heading}| \geq \text{hold\_pos\_theta\_param} + \text{hold\_pos\_theta\_hyst\_param}$

where,

hold_pos_theta_hyst_param = hysteresis margin for clearing the heading window.

d. The tgt velocity is less than an adaptable parameter:

$\text{tgt\_velocity} < \text{arming\_vel\_threshold\_param}$

where,

tgt_velocity = AMASS computed_velocity

arming_vel_threshold_param = adaptable speed threshold for determining that a target is in position for takeoff.

e. The target was not previously in Landing movement state.

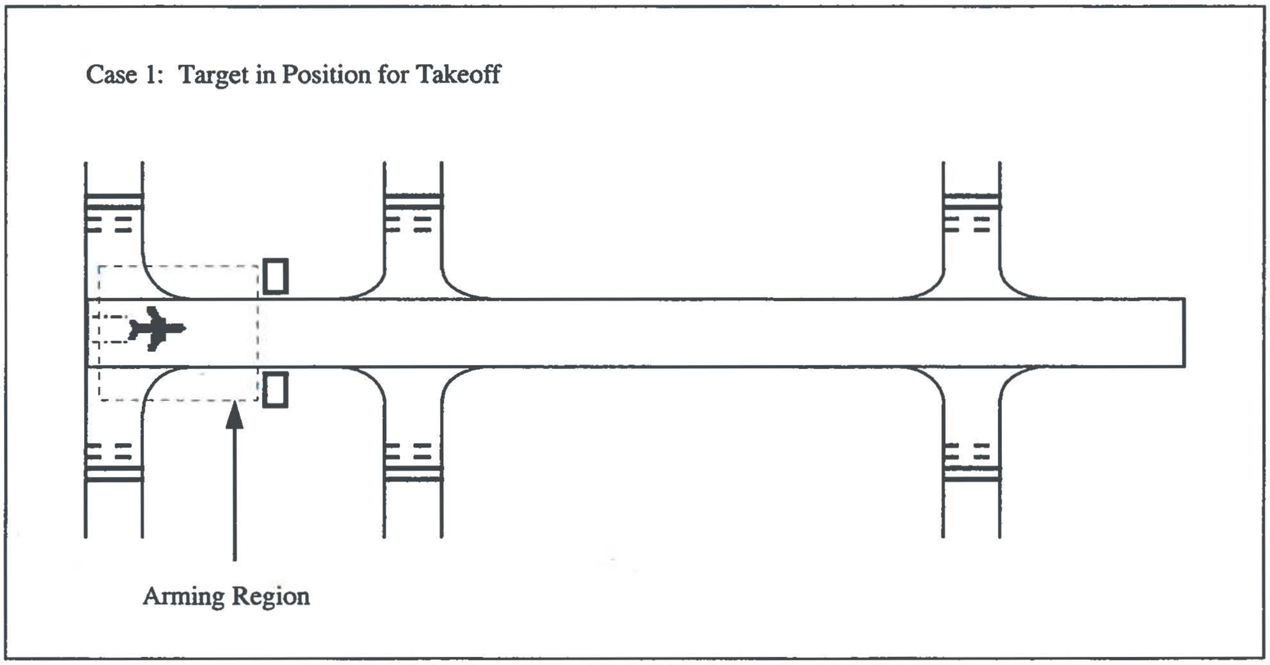


FIGURE B-8. THL ARMING REGION CASE 1

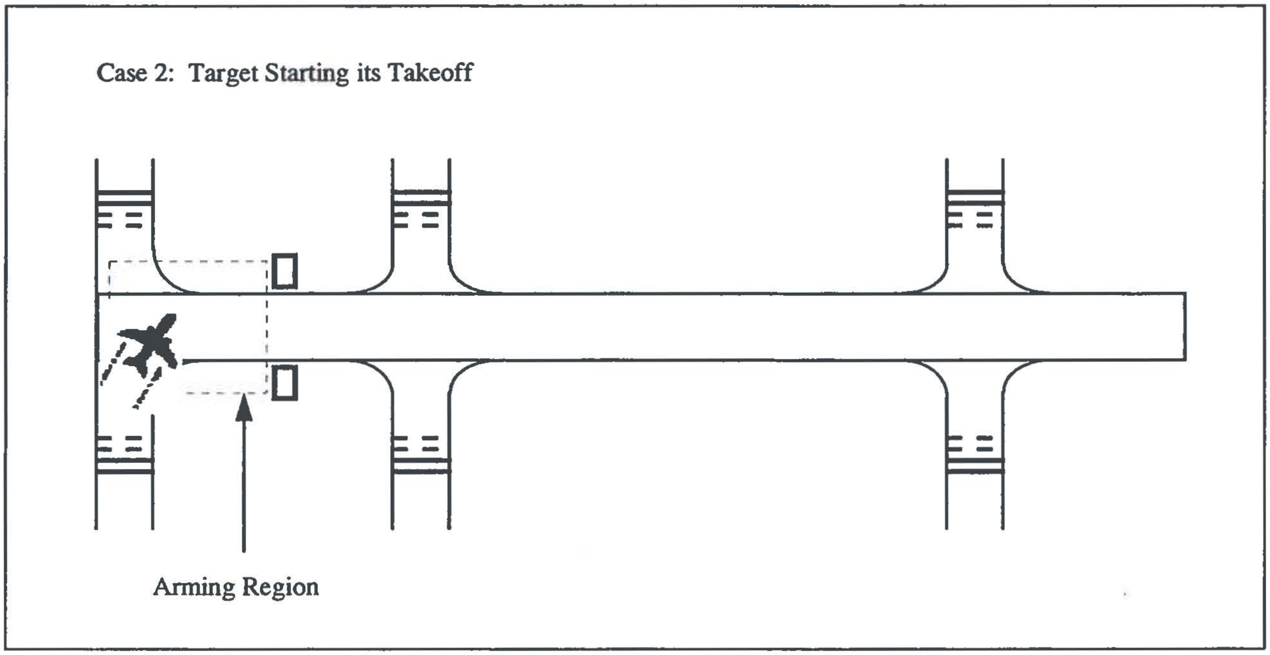


FIGURE B-9. THL ARMING REGION CASE 2

For each takeoff hold position, there will be two groups of takeoff hold lights with an arming region defined for each group of lights. The two sets of lights are provided to improve light visibility for pilots. As shown in Figure B-10, the first set of takeoff hold lights is located approximately 200 feet in front of the takeoff hold position and the second set of lights is located approximately 400 feet farther down the runway from the first set of lights. The THL groups for Logan Airport will be defined as shown in Figure B-11. Each group will be assigned a unique numeric identifier and will have an associated arming region as depicted in the figure.

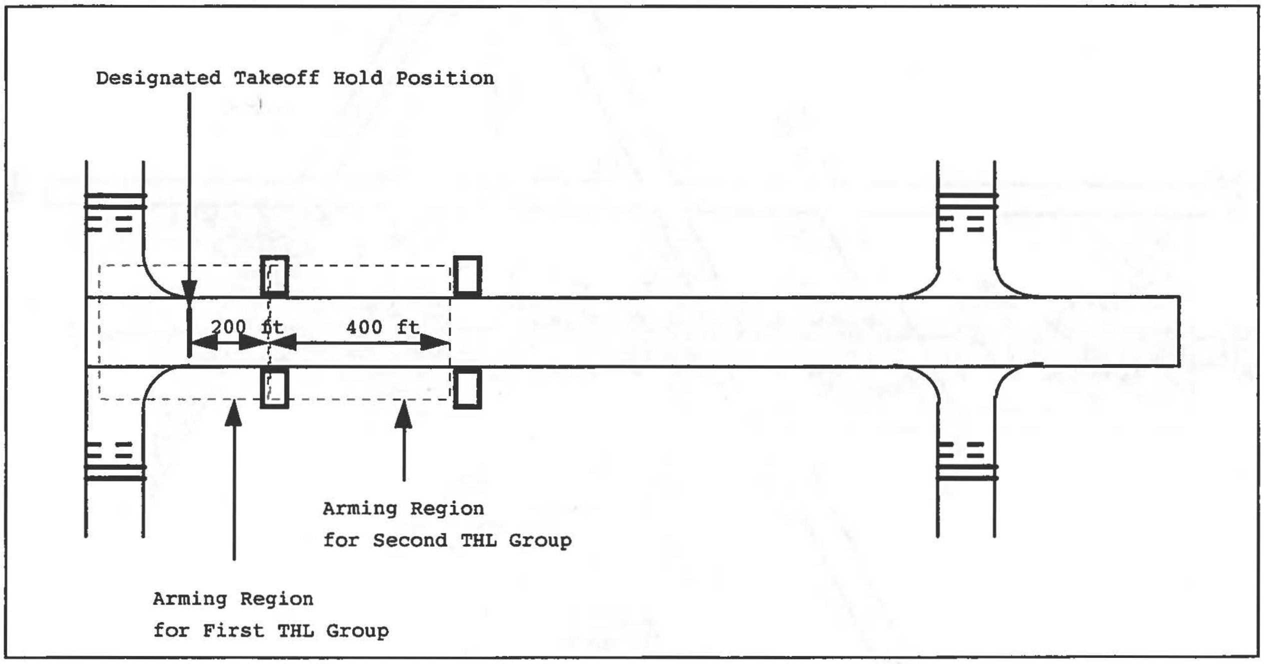


FIGURE B-10. THL GROUPS ASSOCIATED WITH A TAKEOFF HOLD POSITION

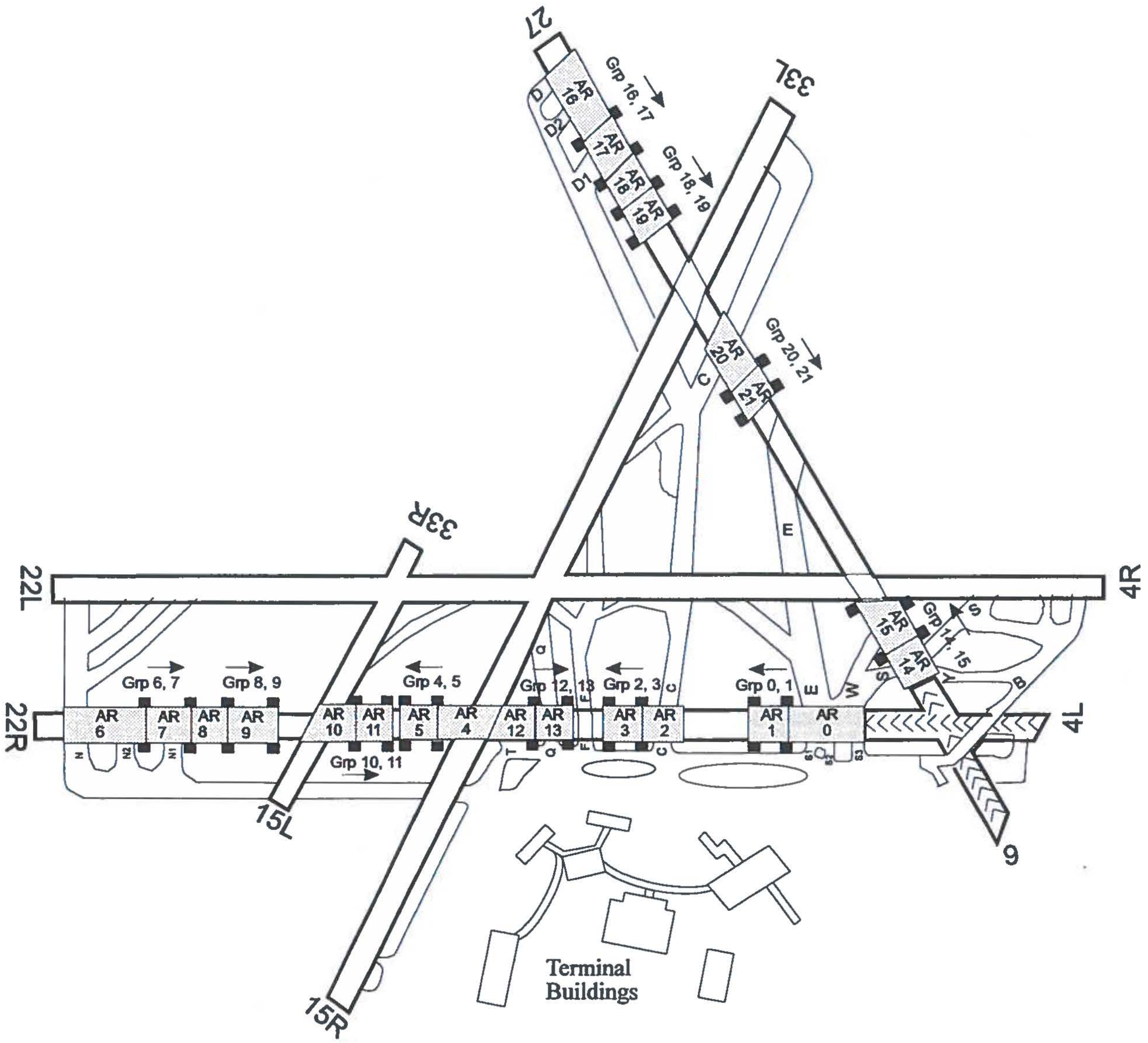


FIGURE B-11. THL ARMING REGIONS AND ASSOCIATED GROUPS

B.2.2 Targets on the Same Runway

THLs are illuminated if the runway is unsafe for takeoff. This condition can be divided into two cases depending on whether there is another target on the same runway as the departure or there is a target on an intersecting runway. This section will describe targets on the same runway, and the next section will describe targets on crossing runways.

Takeoff hold lights at a given location are illuminated if two conditions are satisfied: 1) a target is in takeoff position or starting its takeoff, and 2) the runway is not safe for takeoff because a target is in the THL activation region or about to enter the THL activation region on a crossing runway. The first condition implies that a target must be in the arming region in a position to see the THL. The second condition depends on whether there is another target that could conflict with the departure.

The THL logic rule states that the runway is unsafe for takeoff if there is a target inside the THL activation region, an area that is ahead of the lights as well as on either side of the runway. This is illustrated in Figure B-12, and shows that the THLs are illuminated, because one target is in position for takeoff and another target is in the THL activation region. The width of the activation region is an adaptable parameter (activation_width_param) and will be set so that the activation region extends to the taxi hold lines.

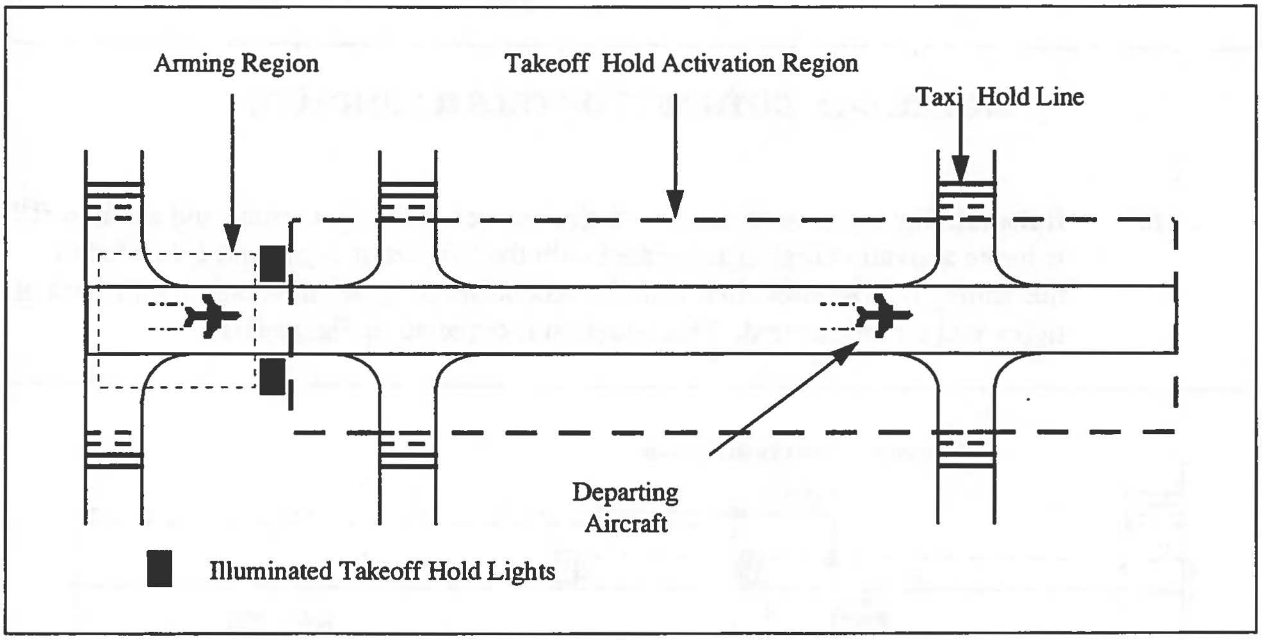


FIGURE B-12. TARGET IN THL ACTIVATION REGION

The length of the activation region will extend from the far end of the associated arming region to the end of the runway. For Runway 4L and Runway 9, the activation region will be extended to include the Bravo taxiway.

Control of the two sets of takeoff hold lights will be provided as follows:

a. If the arming region associated with the first set of lights is armed and an aircraft is in the activation region associated with the first set of lights and *is not* located in the arming region associated with the second set of lights, then both sets of lights will be illuminated. This situation is depicted in Figure B-13.

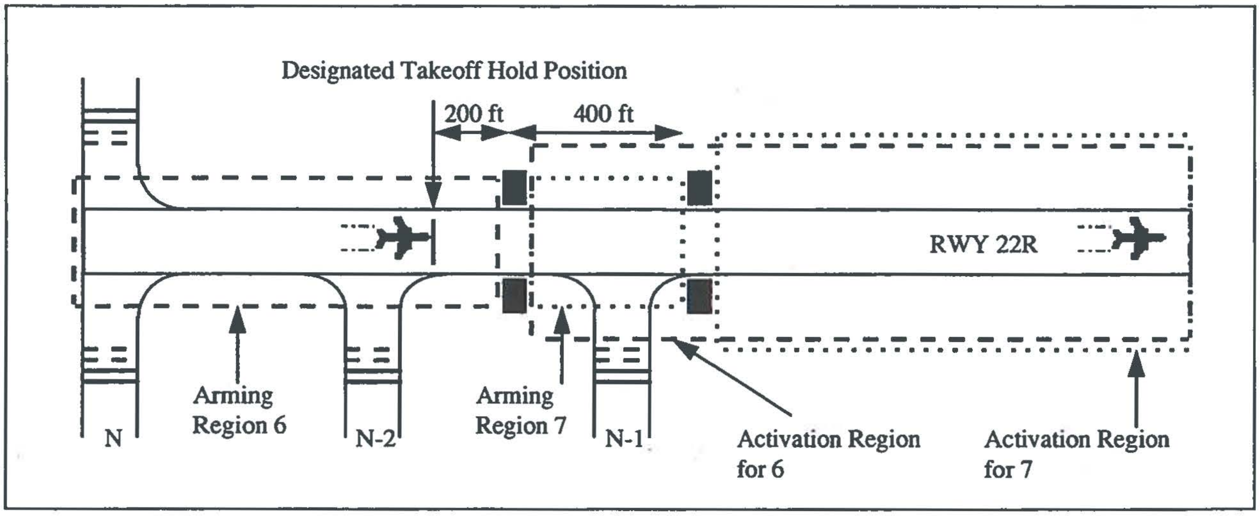


FIGURE B-13. BOTH SETS OF THLS ILLUMINATE

b. If the arming region associated with the first set of lights is armed and an aircraft is in the activation region associated with the first set of lights and *is* located in the arming region associated with the second set of lights, then only the first set of lights will be illuminated. This situation is depicted in Figure B-14.

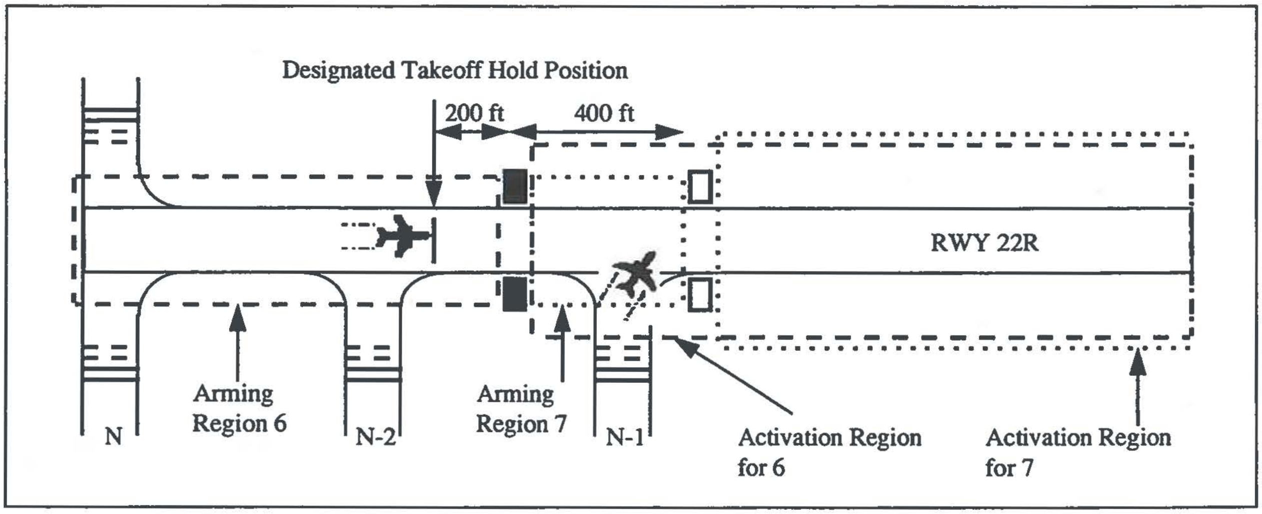


FIGURE B-14. ONLY FIRST SET OF THLS ILLUMINATE

c. If the arming region associated with the second set of lights is armed and an aircraft is in the activation region associated with the second set of lights, then only the second set of lights will be illuminated. This situation is depicted in Figure B-15.

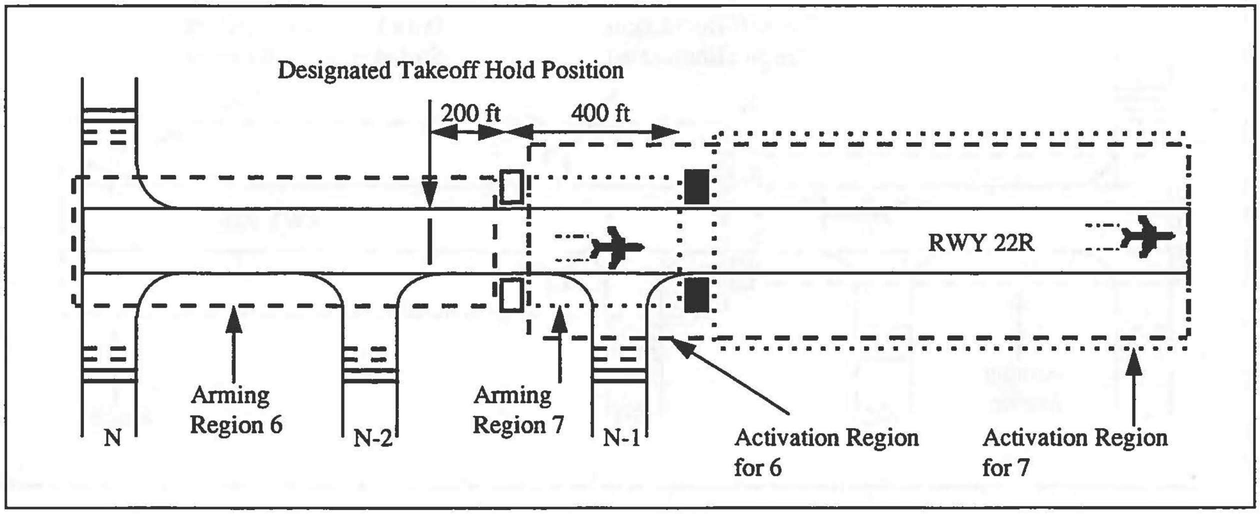


FIGURE B-15. ONLY SECOND SET OF THLS ILLUMINATE

An exception to this logic rule states that the runway is safe for takeoff if the target in the THL activation region will exit "soon". The THL logic covers two important exception scenarios. The first scenario involves a prior departure far down the runway that is airborne, as depicted in Figure B-16. When this occurs the runway is safe for takeoff even though the ASDE track, which does not include altitude, appears to be in the THL activation region. This is based on controller procedures that state it is legal to have an aircraft take off on a runway when a previous departure is still over the runway as long as certain conditions are met. A target in an activation region will be defined as a prior departure that is airborne if all of the following conditions are simultaneously satisfied:

a. The AMASS target movement state is Departure

b. The target's distance from the front of the associated arming region is > dep_thl_dist_param

c. The target's speed is > dep_thl_spd_param.

A target that has been defined as a prior departure that is airborne will not be considered to be in an activation region.

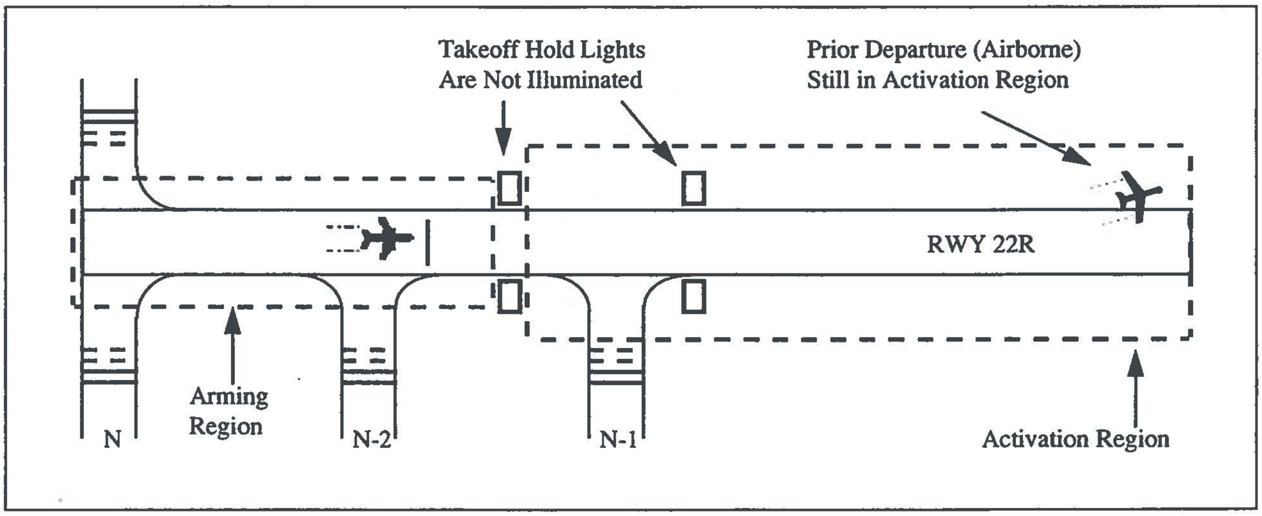


FIGURE B-16. THL EXCEPTION CASE FOR PRIOR DEPARTURE

The second exception involves a crossing aircraft that is predicted to exit the THL activation region with safe separation as depicted in Figure B-17. The following anticipated separation algorithm is used to decide that a crossing aircraft is safely separated from an aircraft in a takeoff-hold position:

a. the crossing aircraft must be in the Taxi state,

b. the heading of the crossing aircraft must meet the runway crossing angle criteria,

c. the deceleration model must indicate that the crossing aircraft can exit the THL activation region before it reaches zero velocity,

d. the deceleration model for the crossing aircraft must indicate that the aircraft can exit the activation region (within a safe margin) before the aircraft in the take-off hold position can reach the crossing aircraft applying the take-off acceleration model.

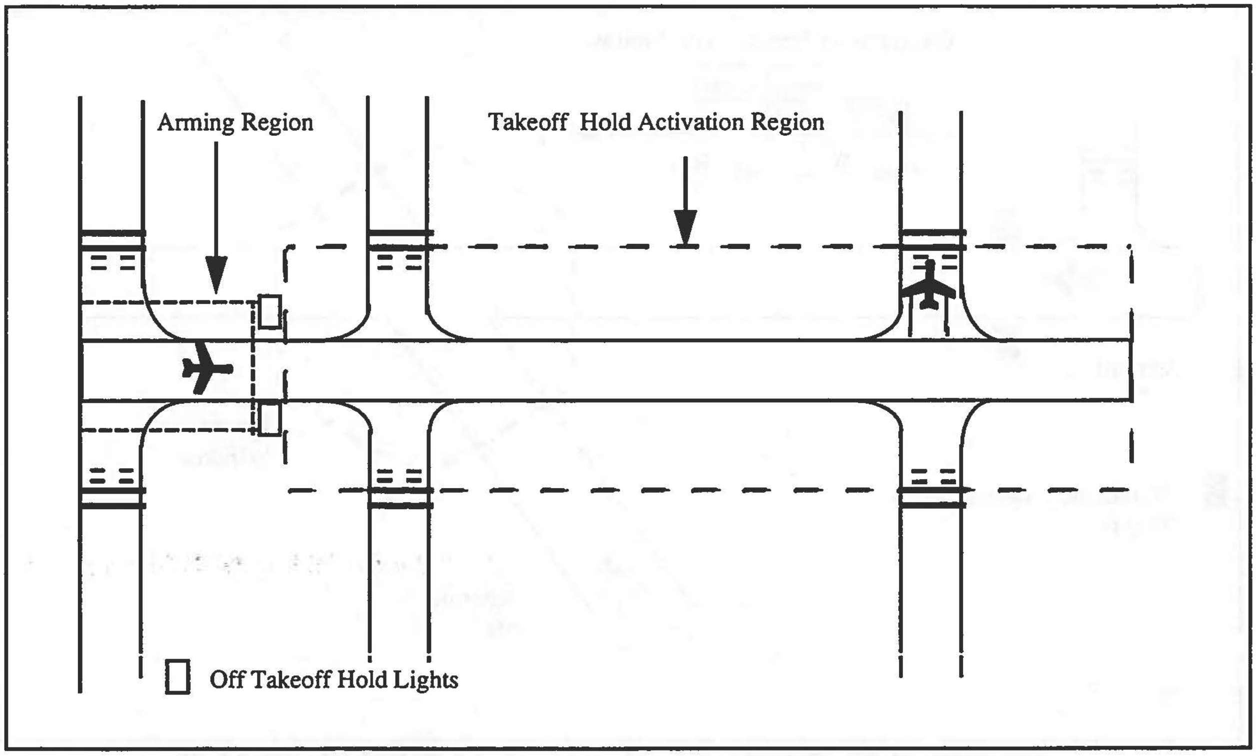


FIGURE B-17. THL EXCEPTION CASE FOR PREDICTED EXIT FROM THE ACTIVATION REGION

B.2.3 Targets on Intersecting Runways

A runway can also be unsafe for takeoff when there is a potential conflict with a high speed target on an intersecting runway. The logic for this is illustrated in Figure B-18. The concept of an intersection window is introduced in this case. An intersection window exists where runways intersect. The runway is unsafe for takeoff if target A, which is in position for takeoff or starting takeoff, and target B, which is in any state except Stopped and Taxi, could be in the intersection window simultaneously if A started takeoff. This logic rule again uses the concept of anticipated separation. Rather than wait for B to cross the intersection before turning off the THLs, the THL control logic turns off the lights in anticipation that B will be through the intersection before A could be in conflict with B if A moved into the Departure state.

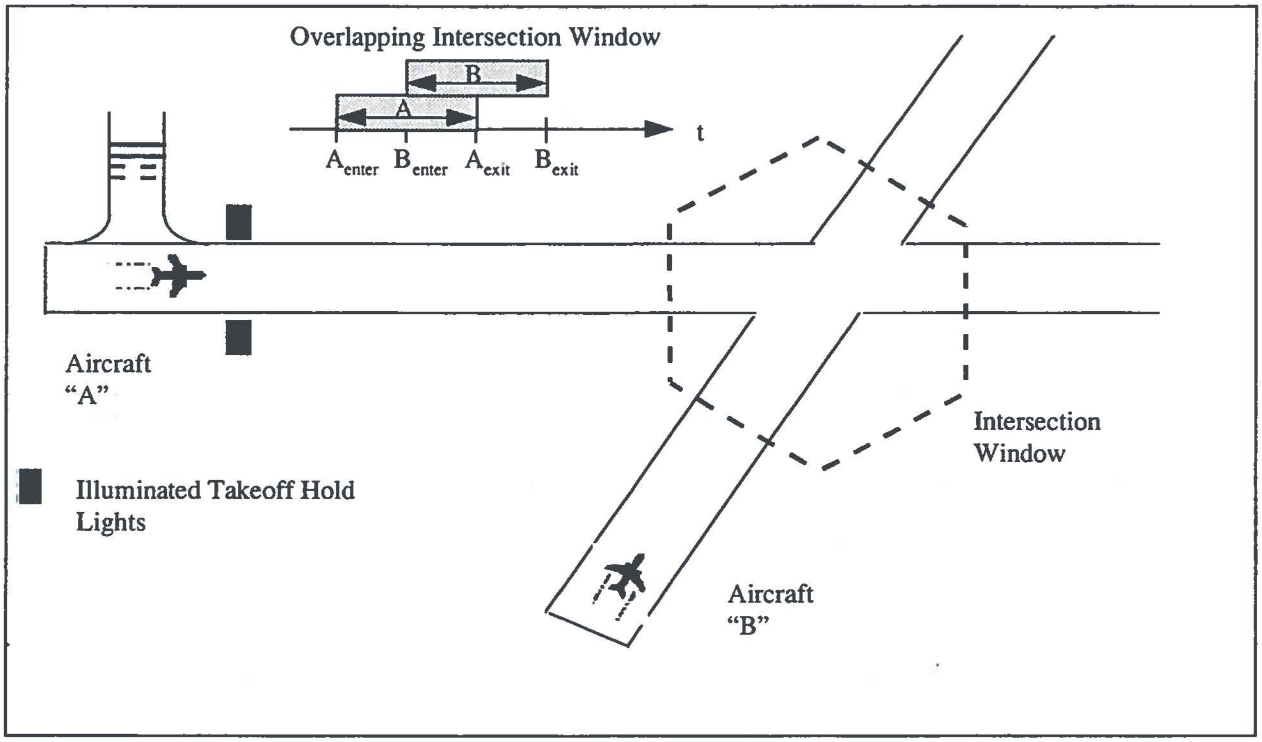


FIGURE B-18. TARGETS ON INTERSECTING RUNWAYS

According to the rule described in the previous section, as B crosses A's runway the THLs would illuminate while B is in the THL activation region along A's runway. To prevent this from happening, the THL control logic will keep track of whether B is on an intersecting runway or along the same runway as A. If B is on an intersecting runway, the THLs for A will not illuminate.

The THL control logic computes the time interval A could be in the intersection window and the time interval B could be in the intersection window. The logic then becomes: the runway is unsafe for takeoff if the time intervals of A and B overlap with a safety margin time added to the time intervals. The THL control logic uses acceleration and deceleration models of target motion to compute the time intervals. For B, the earliest time to enter the window is calculated using its acceleration model, and the latest time to exit the intersection window is calculated using the deceleration model. Table B-1 describes the acceleration and deceleration models based on target states. Target A is usually stopped or moving slowly, so the deceleration path is likely to end before the intersection window. Consequently, both its earliest time to enter the window and the latest time to exit the window are calculated using the acceleration model for departures. For each runway/runway intersection down the runway from the departure, all targets will be identified for conflict.

TABLE B-1. ACCELERATION/DECELERATION MODELS

Target State	Acceleration Model	Deceleration Model
Departure	accelerate at accel_nom_dep_param to a maximum departure velocity, v_max_dep_param	decelerate at decel_nom_dep_param
Landing	continue at current velocity	decel_nom_ldg_param
Landing Rollout	continue at current velocity	decel_nom_ldg_param
Arrival	continue at current velocity	continue at current velocity
Departure Abort	continue at current velocity	decelerate at decel_nom_dbt_param

The earliest time to enter the intersection window for target's A and B (see Figure B-18) will be calculated as follows:

a. For target A (in position for takeoff or starting takeoff), assume the target is at rest and use the target position and the departure acceleration (see Table B-1) to determine the distance A would travel up to a maximum departure velocity:

$$\text{dep\_max\_dist\_param} = (\text{v\_max\_dep\_param})^2 / (2 * \text{accel\_nom\_depart\_param})$$

Let A_dist_to_enter be the distance to the intersection window from the front of the target. If A_dist_to_enter ≤ dep_max_dist_param, then

$$\text{t\_min\_enter\_A} = (2 * \text{A\_dist\_to\_enter} / \text{accel\_nom\_depart\_param})^{0.5}$$

Else,

$$\text{t\_min\_enter\_A} = (\text{v\_max\_dep\_param} / \text{accel\_nom\_depart\_param}) + (\text{A\_dist\_to\_enter} - \text{dep\_max\_dist\_param}) / \text{v\_max\_dep\_param}.$$

b. For target B (on intersecting runway and in any state except STOP or TAXI), use the target speed, position, and acceleration (from Table B-1) to calculate the minimum time to enter the window:

If AMASS movement state = DEP, then

$$\text{dep\_max\_dist} = (\text{v\_max\_dep\_param})^2 / (2 * \text{accel\_nom\_depart\_param})$$

Let B_dist_to_enter be the distance to the intersection window from the front of the target. If B_dist_to_enter ≤ dep_max_dist, then

$$\text{t\_min\_enter\_B} = (2 * \text{B\_dist\_to\_enter} / \text{accel\_nom\_depart\_param})^{0.5}$$

Else,

$$\text{t\_min\_enter\_B} = (\text{v\_max\_dep\_param} / \text{accel\_nom\_depart\_param}) + (\text{B\_dist\_to\_enter} - \text{dep\_max\_dist}) / \text{v\_max\_dep\_param}.$$

If AMASS movement state = DBT or LDG or LRO or ARR, then

$$\text{t\_min\_enter\_B} = \text{B\_dist\_to\_enter} / \text{target\_velocity}$$

where,

$$\text{target\_velocity} = \text{AMASS computed\_velocity}.$$

The latest time to exit the intersection window for target's A and B (see Figure B-18) will be calculated as follows:

a. For target A (in position for takeoff or starting takeoff), assume the target is at rest and use the target position and the departure acceleration (see Table B-1) to determine the distance A would travel up to a maximum departure velocity:

$$\text{dep\_max\_dist\_param} = (\text{v\_max\_dep\_param})^2 / (2 * \text{accel\_nom\_depart\_param})$$

Let A_dist_to_exit be the distance to the back edge of the intersection window from the rear of the target. If A_dist_to_exit ≤ dep_max_dist_param, then

$$\text{t\_max\_exit\_A} = (2 * \text{A\_dist\_to\_exit} / \text{accel\_nom\_depart\_param})^{0.5}$$

Else,

$$\text{t\_max\_exit\_A} = (\text{v\_max\_dep\_param} / \text{accel\_nom\_depart\_param}) + (\text{A\_dist\_to\_exit} - \text{dep\_max\_dist\_param}) / \text{v\_max\_dep\_param}.$$

b. For target B (on intersecting runway and in any state except STOP or TAXI), use the target speed, position, and acceleration (from Table B-1) to calculate the maximum time to exit the window:

Based on AMASS movement state, set tgt_decel to the appropriate deceleration value from Table B-1. Let B_dist_to_exit be the distance to the back edge of the intersection window from the rear of the target.

If tgt_decel = 0, then

t_max_exit_B = B_dist_to_exit / target_velocity

where,

target_velocity = AMASS computed_velocity.

Else,

Calculate the maximum time to reach zero velocity:

B_time_to_zero_vel = - target_velocity / tgt_decel

Calculate the distance B must travel to reach zero velocity:

B_dist_to_zero_vel = 0.5 * target_velocity * B_time_to_zero_vel

If B_dist_to_zero_vel > B_dist_to_exit, then

$\text{t\_max\_exit\_B} = -(\text{target\_velocity} / \text{tgt\_decel}) - (2 * (\text{B\_dist\_to\_exit} - \text{B\_dist\_to\_zero\_vel}) / \text{tgt\_decel})^{0.5}$

Else

t_max_exit_B = B_time_to_zero_vel.

Check to see if there is any overlap in the time A is in the intersection window and the time B is in the intersection window.

If (t_min_enter_A - t_max_exit_B ≤ safety_margin_clear_param) AND (t_min_enter_B - t_max_exit_A) ≤ safety_margin_clear_param) then B will be declared to be in A's activation region.

Hysteresis will be applied to the intersection window algorithm to prevent rapid light state changes due to surveillance and tracking errors. If B was previously in A's activation region, the following check will be performed to see if there is any overlap in the time A is in the intersection window and the time B is in the intersection window.

If (t_min_enter_A - t_max_exit_B ≤ safety_margin_clear_hys_param) AND (t_min_enter_B - t_max_exit_A) ≤ safety_margin_clear_hys_param) then B will be declared to be in A's activation region.

B.3 Capabilities Controlling Both RELs and THLs

Special REL and THL algorithms were introduced to overcome the lack of altitude information for departing aircraft in the current AMASS system. An aircraft is considered to have "lifted off" after reaching a certain altitude (about 200 feet). However, the ASDE-3 radar continues to track the departing aircraft to about 300 feet if the aircraft stays above the runway region. When an aircraft reaches the "lift off" altitude, the air traffic controller is allowed to give runway crossing clearances to aircraft at the far end of the runway being used by the departing aircraft. This could create interference with the REL logic that illuminates all runway RELs covered by the departure hot-zone. This also could create interference with THL logic since the next aircraft in the departure queue is allowed to takeoff as soon as the departing aircraft has lifted off. To compensate for the lack of altitude data, the following algorithm is used to estimate when an aircraft has lifted off:

a. aircraft are categorized into three sizes depending on the estimated target extent of the aircraft: large (200-300 feet), medium (100-199 feet), and small (less than 100 feet)

b. for each aircraft category there is a minimum distance that an aircraft must travel on the runway (in the departure state) before the aircraft is a candidate for "lift off"

c. when an aircraft reaches the minimum departure distance, the acceleration profile of the departing aircraft is tracked for the "ground effect," a phenomena whereby the aircraft's acceleration becomes negative for a short duration of time due to forces applied as the aircraft is lifting off from the runway surface

d. an aircraft is declared to be "lifted off" when the acceleration profile goes negative

e. also, an aircraft is declared to be lifted off when the maximum departure distance is reached (adaptable for each aircraft category).

APPENDIX C

TEST DATA PROCESSING

C.1 INTRODUCTION

The data processing method is depicted in Figure C-1. It was split into four main sub-processes:

- Data Collection
- Data Reduction
- Performance Analysis
- Interpretation

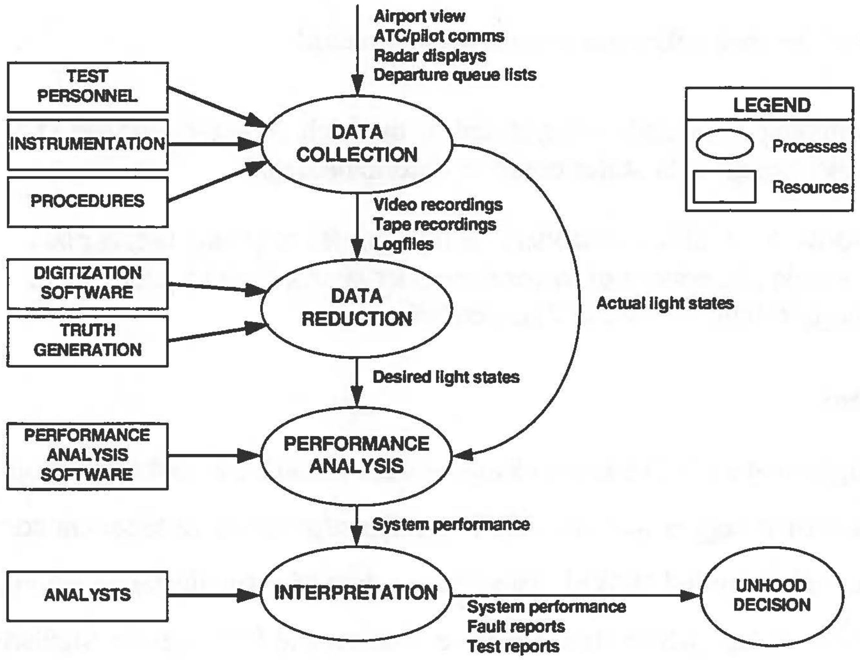


FIGURE C-1. DATA PROCESSING APPROACH - OVERVIEW

C.2 INPUTS

There were five main inputs:

1. The view from the RWSL Test Center on the 16th floor of Logan Tower overlooking the airfield. Visibility of the approach end of 22R up to the intersection of 22R with 15L/33R is restricted due to the shape of the tower and the location of the Test Center.
2. Radio communications between tower and pilots/vehicle operators.
3. Radar displays (ARTS and ASDE-3).
4. Departure queue lists.
5. Time.

C.2 DATA COLLECTION

C.2.1 Objective

The primary objective of the data collection process was to record:

- light switching commands being issued by the Light Manager and the LCC, from which actual light states could be determined, and
- the Shadow Air Traffic Controllers' commentaries of events taking place on the airfield and echoes of tower controller instructions to pilots, from which desired light states could be determined.

C.2.2 Method

Commands to switch lights issued by the Light Manager were recorded in LM logfiles on the AMASS PC. These were time tagged with the ASDE-3 radar scan count. Subsequent correlation of the radar scan count with recorded "RWSL Time" was achieved manually by reviewing videotapes of the AMASS screen, which shows both scan count and RWSL time. Similarly, commands issued by the LCC were recorded in logfiles on the LCC PC.

The primary sources of information for the SATCs were the radio communications between the tower and pilots and the view of the airfield. SATCs wore headsets through which radio communications between the tower and pilots/vehicle operators were audible. Each SATC was assigned a single Local Controller i.e., each SATC monitored only those events pertaining to a single RWSL-instrumented runway e.g., in a 4/9 configuration, SATC A monitored runway 4L, SATC B monitored runway 9 - see Table C-1 below for monitoring responsibilities.

TABLE C-1. MONITORING RESPONSIBILITIES

RUNWAY CONFIG	SATC A RESPONSIBILITIES	SATC B RESPONSIBILITIES
4/9	Crossings/operations on 4L	Crossings/operations on 9 including 4R crossings
27/22	Crossings/operations on 22R	Crossings/operations on 27 including 22L crossings (including land and hold short)
33/27	Crossings/operations on 27 including 33L crossings	
15/9	Crossings/operations on 9 including 15R crossings	

SATCs viewed the airfield in the same way as the tower controllers. An important aspect of this was that, under IFR conditions, the SATCs used the ASDE-3 radar display. The significant benefit in adopting this approach was that SATC commentaries captured the way in which the tower controllers were controlling the airport under all visibility conditions. The view of the airfield from the Test Center window was supplemented by a real-time display from the video camera.

SATCs' commentaries of events were governed by strict procedures (see Appendix D). These procedures were formulated in conjunction with the Truth Generation logic and were completely commensurate with the entire data processing approach.

As part of their commentaries, SATCs were required to associate with each event an aircraft or vehicle tag. The ARTS display provided tag information for arriving aircraft while the departure queue provided some of the departing aircraft tags. Tags for other departing aircraft were obtained either by inference from tower/pilot communications or from departure queue lists or from real-time tag entries on the AMASS display.

C.2.3 Instrumentation

Instrumentation was necessary to capture the data required for RWSL performance evaluation. The instrumentation requirements established early in the program prior to hooded testing were required to:

- Capture the SATCs' interpretation of the operations and critical events in real-time
- Monitor and record the off-air voice traffic between the tower controllers and the pilots
- Time tag all audio, video and digital recordings with an accuracy of ±0.5 seconds
- Employ non-invasive interfaces to the RWSL System so as not to compromise normal operation
- Develop data analysis workstations that utilize the available time synchronization

The following instrumentation design objectives supported the above requirements:

- Collect the data necessary to enable the identification of the "truth" for quantitative performance evaluation
- Configure the instrumentation in a manner that will maximize the efficiency of the SATCs and Analysts
- Strive to enable "complete" data entry in real time
- Provide for efficient and unambiguous post-time data reduction and analysis: record all operationally-critical data and guarantee time synchronization with all computer files

The instrumentation is illustrated in a block diagram format in Figure C-2. The RWSL equipment is identified with shaded boxes and the lines between boxes indicate data flow and control interfaces. Central to the instrumentation suite was the RWSL Time Generator (RTG) which produced the IRIG-B timing signal that is recorded on all analog tapes. This was a stand-alone i286 computer that received AMASS clock time and date over the RS-232 twisted-pair once per sec at a rate of 9600 Baud. The received time had a resolution of 0.01 sec and was used to reset a stable clock (0.0005% stability) in the RTG with an accuracy of 0.05 seconds if the difference between the AMASS time and the RTG time exceeded 0.3 seconds. Because the AMASS time was derived from the same model stable clock, the relative drift between the clocks following synchronization was small and resets did not generally occur during a test period. The AMASS clock time was recorded in the AMASS log files and displayed on the AMASS display.

An IRIG-B encoder card installed in the RTG also had a stable clock which was reset to the RTG clock if the difference between the two clocks exceeds 0.3 second. IRIG-B is an industry encoding scheme and utilizes a 1 kHz audio carrier that is modulated to encode the time. The resolution of the IRIG-B encoded time is 1 ms and time is synchronized with an accuracy of 0.05 second. This audio signal was recorded on one of the available audio tracks of the cassette recorders and the VCRs.

The Analysis Workstation (or SATC Computer) contained a time decoder card that was used to synchronize the data files. Playback accuracy was unaffected by tape speed variations as large as 2:1 and momentary tape dropouts were interpolated by the decoder card. Timing accuracy was verified through end-to-end testing. The maximum timing error relative to the AMASS reference time was 0.5 second with an observed RMS error on the order of 0.2 seconds.

Two VCRs were used to capture the AMASS display which was transformed into an NTSC video format by a scan converter. Video tape was convenient for the analysts since it can be easily paused and rewound as necessary. The IRIG time code on the audio track ensured time synchronization. The second audio track of the stereo VCRs was used to record the voice of the SATC, one on each VCR. Other video equipment included a camcorder that was used to record field operations and a video feed from the Tower Cab displayed the flight strips which were used to tag the flight numbers on the AMASS display.

Two four-channel audio cassette recorders were used to record the off-air dialog from three radio channels along with the SATC and the IRIG-B time code. One cassette was assigned to each SATC and provided about one-hour of record time per tape cassette. Offsetting the time of tape replacement between the two machines, which could be accomplished in less than five seconds, guaranteed that no data is lost.

Each SATC used a standard FAA headset which was interfaced to the audio equipment through a custom interface. Recording integrity was guaranteed because the SATC only received off-air information in the earpiece if the cassette recorder was in the record mode.

A custom VCR controller interface enabled remote control of the two VCRs by the Test Director. A Test Director Console enabled the TD to monitor all audio channels on a non-interfering basis for real-time quality control. Audio could be directed to earphones or to two loudspeakers. In order to insure the availability and integrity of the instrumentation, there was no need to make any cable changes. All operations were supported by switches and detailed check lists to make sure the switches are in the correct position. The instrumentation was in operation throughout the hooded testing and did not experience any failures other than a broken headphone cable. Recorded data was verified to be reliable and complete.

Not shown in Figure C-2 is a direct telephone line to the Tower Cab. This powered-phone did not go through the regular telephone network and enabled the Tower Supervisor to quickly contact the RWSL Test Director.

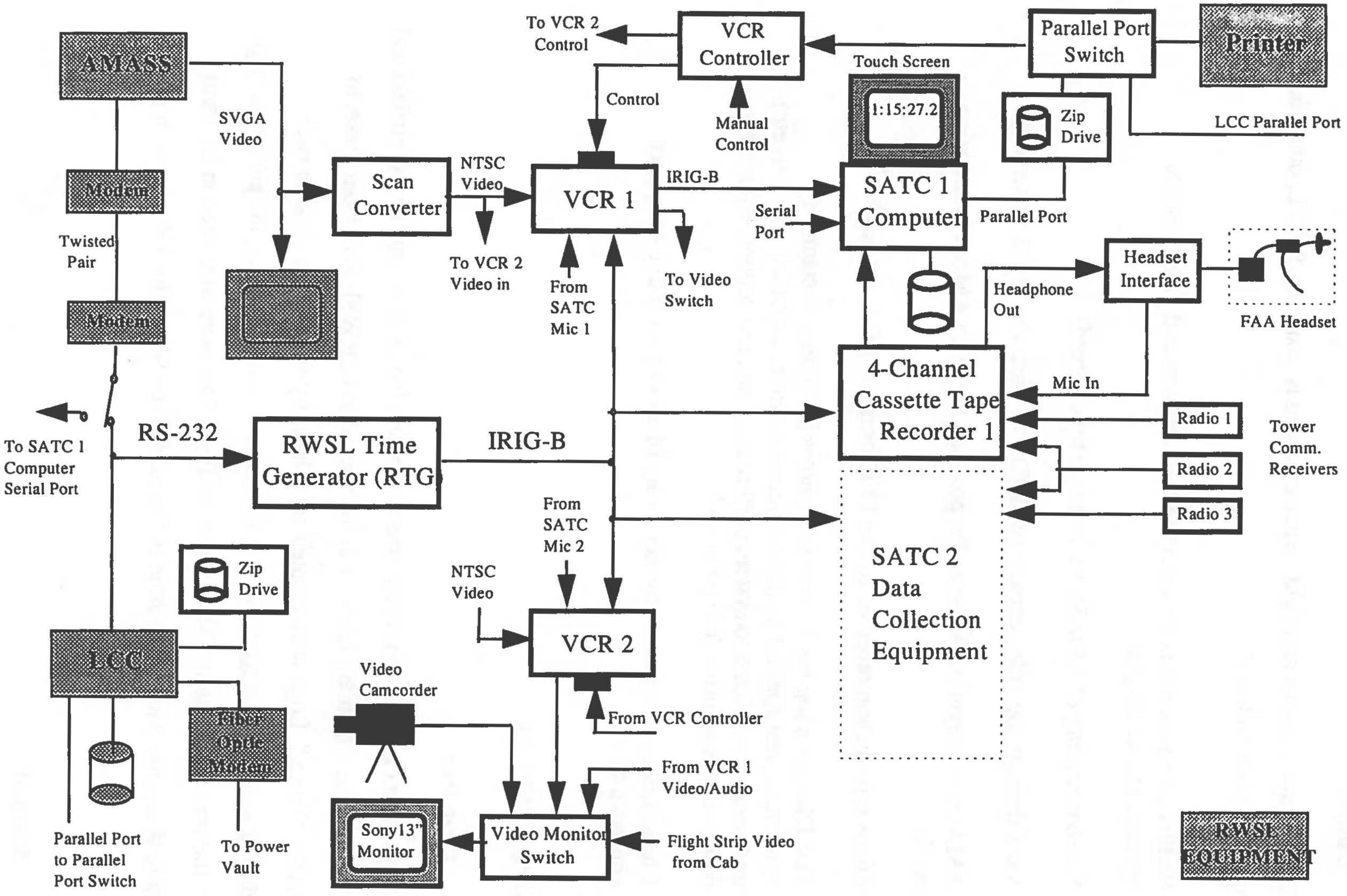


FIGURE C-2 RWSL INSTRUMENTATION SUITE

C.2.4 Outputs

In addition to SATC commentaries and light switch commands issued by RWSL, other data recorded during test periods included:

- Radio communications between tower controllers and pilots/vehicle operators (time tagged).
- Video recording of AMASS PC display (time tagged).
- View through the video camera (with RWSL Time displayed on screen).
- AMASS PC target track inputs for post-test replay in AMASS simulation mode.
- Status information received by the LCC from the LC in the vault.
- Test Director's log book, containing notes pertaining to status of equipment, test conditions (runway configuration, visibility, weather, etc), and anomalies related to system performance and test support equipment that took place during the test period.
- Checklists used to ensure correct set-up of all system and test support equipment.

C.3 DATA REDUCTION

C.3.1 Objective

The objective of the Data Reduction process was to create a log of all events on the airfield and in the immediate airspace which are relevant to the operation of RWSL and, from these, to generate the SATC "Truth." Logs were created on a flight-by-flight basis. Within each individual flight log was a time tagged list of commands to, and actions by, the particular flight that may affect the state of the lights. The completed flight logs were then used in the truth generation step to determine the correct state of the lights throughout the test period on a light-by-light basis.

C.3.2 Method

The analyst had three data sources that could be used to create the necessary flight logs:

- Video Camera Recorded Video Tape
- 4-Track Recorded Audio Cassette
- VCR Recorded Video Tape

The video camera data was video of the airfield that was recorded during the test. In general, the camera was pointed at a busy portion of the airfield and remained stationary throughout the test period.

The 4-track record audio cassettes contained the following:

- All Three Tower Controller Frequencies (East, West, Ground)
- Shadow ATC Audio for both Shadow Controllers
- IRIG Time Code

All relevant audio was recorded via the 4-track recorders. The IRIG time code is an audio signal from which a running time can be interpreted by a time codereader board in a PC. This was an important piece of data that was necessary to synchronize audio events with RWSL light events in post-processing.

The VCR recorded video contained the following:

- Video of the AMASS Screen
- SATC Audio
- IRIG Time Code

The VCR recorded video tapes were the primary source of data used in the digitization process. The reason that the VCR tapes were used instead of the AMASS display and the audio tapes is that they provided rewind, fast forward, and pause capabilities and they contained all of the information necessary to digitize the SATC commentaries on a single medium. The SATC audio contained echoes of all relevant instructions issued by the tower, as well as additional information concerning the state of traffic on the airfield. The audio cassettes therefore were not used as primary data sources in the digitization process. The audio cassettes were archived and were available for use for verification of the timing of critical tower instructions, if this was considered necessary (e.g., if a late call is recorded by the SATCs). The field of view of the video camera was also too limited to be used as a primary data source; this data was archived and available for subsequent review of critical events within its field of view.

The outputs from the Data Reduction process were a set of data files containing “desired” light states, as determined from ATC instructions and SATC commentaries.

C.4 PERFORMANCE ANALYSIS

The last step in the data analysis process was the comparison of the SATC “Truth” generated in the previous steps with the RWSL light states. The results of the comparison were then analyzed to highlight any differences between the two light state sources and to label the differences as discrepancies, false alarms, and missed detections. Finally, the errors found were categorized according to the reason for their occurring.

C.5 DATA PROCESSING METHOD VALIDATION

C.5.1 Objectives

A heavy reliance was placed on the data processing method which was adopted. The process was automated to the maximum extent possible. Consequently, validation was needed that the approach and, in particular, the automation software, worked as required.

The objectives of the method validation effort were to:

- determine the effectiveness of the adopted approach
- determine the accuracy and consistency of the results
- determine to what extent the method can be relied upon
- identify limitations of the method

C.5.2 Approach

The approach taken to validate the data processing method was to manually process test data and check manually derived results against automatically derived results. In addition, results from the process were compared against results derived from the RWSL Light Manager Analysis Tool. This is a tool that was developed to verify the operation of the Light Manager logic as an independent software unit. It differs from the hooded test data processing approach in that it makes extensive use of internal data (in particular, AMASS target tracks) to determine inconsistencies in the logic.

Accuracy of Truth

The key issue in determining whether the process was working correctly lay in the accuracy of the "Truth" generated by the data collection process. The critical aspects of the analysis process were therefore:

- the accuracy of determining when the light turning on or off became visible to the pilot, and
- accuracy of event time tagging.

The uncertainty in when the light became visible to the pilot depends on many factors, including:

- ambient lighting conditions,
- human factors (e.g. pilot workload), and
- variation in when the light actually turns on and off.

The main sources of error in time tagging events were:

- variations in SATC commentaries relative to the occurrence of actual events
- delays introduced in the digitization process
- synchronization of recording media

Variation in Light Observance

Ambient lighting conditions and human factors associated with the pilot's observance of the light are difficult to establish until the lights are exposed to them in a live situation. The determination of the effect of these factors was the primary objective of the unhooded assessment. For the hooded assessment and the data processing method being analyzed, it was assumed that: (a) lights would be observable to pilots when they reach 50% of full luminance, and (b) pilots would see the light switching as soon as it is observable.

The variation in when the light actually turned on and off was measured during end-to-end system testing. Lamp response was determined by measuring the time from when a command was issued by the LCC to the time at which the lamp turned on or off. These times were found to be 1.4 seconds for the lamp to reach 50% luminance at CCR intensity level 3 and 0.6 seconds for the lamp to turn off, independent of intensity level. There was in addition a variance of about ±0.5 seconds for both on and off commands.

It was assumed that the fixed component of the delay was a function of intensity level but that the variation in response was independent of the intensity level. The <u>fixed</u> components were incorporated into the data processing software. The <u>variation</u> in response was added into the timing uncertainty budget for the data processing method.

Variation of SATC Commentary

Variation in SATC commentary were minimized in several ways. Firstly, established and strict procedures for describing events were developed prior to the hooded test program and were thoroughly reviewed and learned by the SATCs. These procedures were developed in unison with the data processing software in a combined effort by system engineers, software engineers, and SATCs.

Secondly, SATCs were monitored consistently throughout Phase 1 of the hooded test and were kept appraised of their performance. Modifications were made to the procedures where necessary.

Thirdly, the data processing method was explained to the SATCs to help them understand the relevance and importance of their performance.

Finally, SATCs were highly experienced air traffic controllers with many years of experience at Logan tower and had a strong understanding of how RWSL is intended to operate.

Accuracy of Event Timing

The accuracy with which timing of critical events was logged depends on several factors:

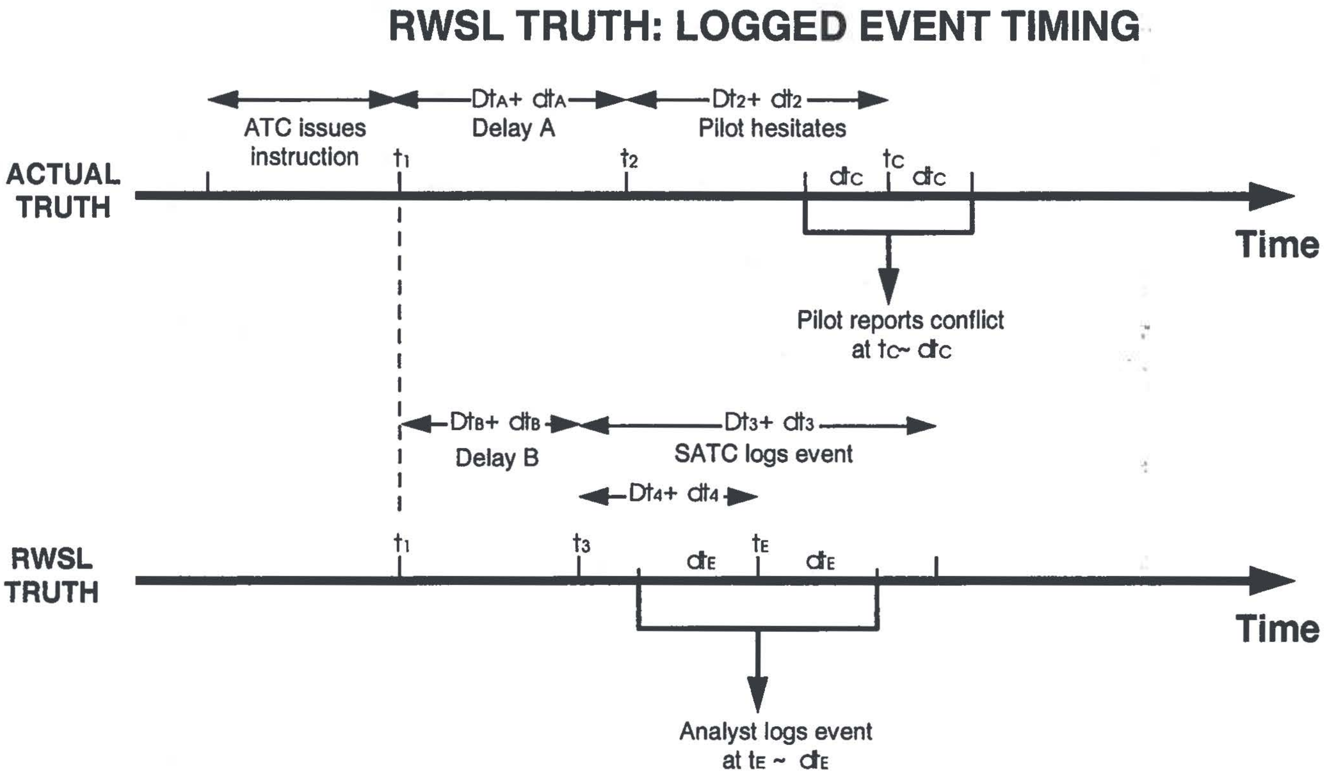
- The time taken for the SATC to respond to the controller's instruction.
- The time taken for the SATC to record the event verbally.
- The time taken for the analyst to record the event digitally as he listens to a playback of the SATC's commentary.

Figure C-3 shows the various activities involved with digitizing an event. Also shown in the figure is a timeline which depicts the sequence of actions that would be taken by a pilot if presented with a conflict between the controller's instruction and the state of the lights.

The time taken for a pilot to pick up the microphone depends on what event is being logged. If the pilot is at an intersection and is cleared to cross, it is unlikely that the pilot will be holding the microphone. However, a pilot waiting for clearance to take off, will probably have the microphone in hand.

The time taken for the pilot to report the discrepancy again depends on the situation. A pilot waiting for clearance to take off, will be more focused on the THLs and will report the conflict almost immediately. There may, however, be some hesitation, especially if the pilot is unfamiliar with the lights.

Based on data recorded during hooded testing, the average time for a pilot to respond to clearance instructions from the tower (i.e. $\Delta t_A + \Delta t_2$) is 1.73 seconds with a variance of 2.83 seconds^2 (i.e. $\sigma_A{}^2 + \sigma_2{}^2 = 2.83$).



$Dt_A + dt_A$ = Time for pilot to pick up microphone
$Dt_2 + dt_2$ = Time between picking up microphone and reporting conflict
$Dt_B + dt_B$ = Time for SATC to respond
$Dt_3 + dt_3$ = Time for SATC to record event
$Dt_4 + dt_4$ = Time for analyst to record event

NOTE: Dts are biases, dts are random

FIGURE C-3. RWSL TRUTH: LOGGED EVENT TIMING

The time taken for the SATC to respond to ATC's clearance depends on traffic volume. In light traffic, the SATC is anticipating the clearance and can log the event just as the ATC finishes giving the clearance. In heavy and/or complex traffic, the SATC might react more slowly. The measured average SATC delay, Δt_B, is 1.30 second with a variance, σ_B^2, of 1.31 seconds^2.

The time at which the analyst logs the event in the RWSL truth file depends again, to some extent, on traffic volume and complexity. If the analyst is anticipating the clearance, the event can be recorded almost at the instant that the SATC started the annotation on the tape. In all cases, the event is never logged later than the completion of the SATC annotation. Given that the duration of the SATC annotation, Δt_3, lasts for about 3 seconds, the average value of Δt_4 is taken to be 1.5 seconds with a maximum deviation of 1.5 seconds (assumed uniformly distributed $\Rightarrow$ σ_4^2=0.75 seconds^2).

The time at which a conflict would be reported by pilot is given by

$$t_C = t_1 + \Delta t_A + \delta t_A + \Delta t_2 + \delta t_2$$

The time at which an event is logged in the event file is given by

$$t_E = t_1 + \Delta t_B + \delta t_B + \Delta t_4 + \delta t_4$$

or, assuming $\Delta t_4 = \frac{\Delta t_3}{2} + \delta t_3$, the discrepancy between the time of the pilot's report and the logged event is

$$t_D = t_E - t_C = \Delta t_B - \Delta t_A + \frac{\Delta t_3}{2} - \Delta t_2 + \delta t_A - \delta t_B + \delta t_4 - \delta t_2$$

The mean value of discrepancy time is $\mu_D = \Delta t_B - \Delta t_A + \frac{\Delta t_3}{2} - \Delta t_2$

with a variance of $\sigma_D^2 = \sigma_A^2 + \sigma_B^2 + \sigma_3^2 + \sigma_4^2 + \sigma_2^2$

The mean discrepancy time, μ_D, is therefore 1.1 seconds with a deviation, σ_D, of 2.6 seconds.

Overall Timing Accuracy

Based on this analysis, it is assumed that a discrepancy will occur if the light stays on for more than 3 seconds after the controller issues the clearance. The residual bias of 1.1 seconds due to delays in logging events was been incorporated into the data processing software.

C.5.3 Effectiveness of Data Processing

By adopting the tower controller as "absolute truth," the process naturally captures the human variation associated with movement of traffic. This includes variations in the way tower controllers operate the airport and the observability of lights by pilots.

The analysis process proved to be highly effective in capturing errors. The process also captured almost all missed detections and false alarms which last for more than 3 seconds observed by analysts. Flicker detection software was also added to capture some of the errors which last for less than 3 seconds.

The process also captured several errors that may not have been captured otherwise:

- THL arming region problems on runway 27
- Split THL problem on runway 9
- Arming region on runway 9
- Early departure

Results generated by the data processing method were also compared against outputs generated by the LM Analysis Tool. This tool is highly efficient in capturing missed detections which are not readily captured by the automatic processing software (e.g., MDs due to track drops during take-off roll). From tests checked against the LM tool, the processing method captured all RWSL Tool "Significant Events."[1].

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[1] LM Tool Significant Events are operational anomalies, including situations in which aircraft cross through a light which is on.

C.5.4 Limitations of the Method

Late SATC Calls

The data collection and analysis process relied heavily on inputs from the SATCs. During busy test periods, it is possible that an SATC gave late or inaccurate information. It should be noted that it is not always due to a mistake by the SATC. The SATCs were required to process many events simultaneously, and in many cases had to prioritize events, which in turn, delayed the commentary for other events. Regardless of the cause of a late call, procedures were implemented for the handling of such events in the data processing method.

Velocity Related Events

Generally speaking, all of the events captured by the data collection and analysis process were either related to time (e.g., the time at which a clearance is given) or location (e.g., what taxiway the plane is passing on its takeoff roll). However, there is a group of events in the RWSL algorithms for determining light states that are dependent upon aircraft velocity:

a) Hot Zones
    i) Arrival
    ii) Rollout
b) State Transitions
    i) Arrival to Rollout
    ii) Rollout to Taxiing
    iii) Taxiing to Departure
c) THL Enabling from crossing runway targets

Although performance of the system during these events were checked by the performance analysis software, the results were categorized as questionable. Flags were raised against possible anomalies which occurred during such events to provide the analyst with an indication that an anomaly *might* have occurred.

APPENDIX D

HOODED TEST PROCEDURES FOR SHADOW ATCS

This section contains the procedures used by the Shadow Air Traffic Controllers during hooded testing.

D.1 PRELIMINARIES

1. As soon as the cassette tape recorders are switched on for the test and prior to entering any aircraft information, state the date and time as displayed on the AMASS PC display and the test identifier as stated by the Test Director.
2. Prior to entering aircraft information, make a visual inspection of the runways (if possible) and state where vehicles are parked and any special operations in progress. State if runways are not visible.
3. Make a brief statement of airport operating conditions (runway configuration, weather, visibility).

In the procedures which follow, it is not imperative to make statements using the exact wording as stated. However, the intent of the statements that you make should be unambiguous and easily reconcilable to their counterparts below.

D.2 DEPARTURES

D.2.1 Aircraft Entering The Active Airfield Surface

When an aircraft or vehicle leaves TWY Kilo for departure (or other purpose), state:

(a) the aircraft's tag

(b) the type of aircraft (heavy, large, small jet, turboprop, etc)

(c) that it is taxiing out for departure

e.g "American 123 heavy is taxiing out"

Timing of this event is not critical since its purpose is simply to initiate an aircraft log. It must, however, be entered on the tape before any other information pertaining to this aircraft is entered i.e., this information can be entered before the aircraft leaves TWY K.

D.2.2 Getting An Aircraft Across A Runway With Hold Short

(1) When an aircraft (or vehicle) is instructed to hold short of a runway (including an implied hold short by ground control), wait until you consider that the pilot of the aircraft can see the RELs at the appropriate TWY/RWY intersection. Then state:

(a) the aircraft's tag

(b) that it is holding short

(c) the runway which it is approaching

(d) the taxiway which it is on

e.g., "American 123 hold short of 4 left on Sierra"

(2) As soon as the aircraft is cleared to cross the runway after it has been holding at the runway entrance hold lines, state:

(a) the aircraft's tag

(b) that it is about to cross a runway

(c) the runway which it is about to cross

(d) the taxiway which it is on

e.g., "American 123 is crossing 4 left on Sierra"

It is important to mimic the tower controller's instructions in this situation as soon as possible after they are issued, and not as you interpret the situation.

(3) When the aircraft reaches the runway entrance hold lines on the opposite side of the runway (i.e., is in a safe position) after crossing that runway, state:

(a) the aircraft's tag

(b) that it has crossed a runway

(c) the runway which it crossed

(d) the taxiway which it is on

e.g., "American 123 has crossed 4 left on Sierra"

D.2.3 Getting An Aircraft Across A Runway Without Hold Short

(1) When an aircraft (or vehicle) is cleared to cross a runway before it arrives at the runway entrance hold lines, wait until: (a) you consider that the pilot of the aircraft can see the RELs at the appropriate TWY/RWY intersection and is in a position to act on the state of the lights or (b) if you consider that the pilot can already see the RELs and is in a position to act on the state of the lights when the instruction is issued, wait until the instruction is issued. Then state:

(a) the aircraft's tag

(b) that it is clear to cross

(c) the runway which it will cross

(d) the taxiway which it is on

e.g., "American 123 is clear to cross 4 left on Sierra"

(2) When the aircraft reaches the runway entrance hold lines, state:

(a) the aircraft's tag

(b) that it is about to cross a runway

(c) the runway which it is about to cross

(d) the taxiway which it is on

e.g., "American 123 is crossing 4 left on Sierra"

(3) When the aircraft reaches the runway entrance hold lines on the opposite side of the runway and you consider it to be in a safe position after crossing that runway, state:

(a) the aircraft's tag

(b) that it has crossed a runway

(c) the runway which it crossed

(d) the taxiway which it is on

e.g., "American 123 has crossed 4 left on Sierra"

D.2.4 Take-Off After Holding Short And With Take-Off Hold

(1) When an aircraft is instructed to hold short of its departure runway, wait until you consider that the pilot of the aircraft can see the RELs at the appropriate TWY/RWY intersection. Then state:

(a) the aircraft's tag

(b) that it is holding short

(c) the runway which it is approaching

(d) the taxiway which it is on

e.g., "American 123 hold short of 4 left on Sierra"

(2) As soon as the aircraft is cleared to taxi into position and hold on its departure runway after it has been holding at the runway entrance hold lines, state:

(a) the aircraft's tag

(b) that it is about to enter its departure runway

(c) the departure runway

(d) the taxiway which it is on

e.g., "American 123 taxi into position on 4 left from Sierra"

If the aircraft subsequently taxis away from the taxiway from which it entered for departure at another position on the runway, state the same information again but with the closest taxiway behind its departure position.

It is important to mimic the tower controller's instructions in this situation as soon as possible after they are issued, and not as you interpret the situation.

(3) When you consider that the pilot of the aircraft can see the THLs, state:

(a) the aircraft's tag

(b) that it is in position for take-off

(c) the departure runway

e.g., "American 123 is in position on 4 left"

(4) As soon as the aircraft is given clearance to take-off, state:

(a) the aircraft's tag

(b) that it has been cleared for take-off

(c) the departure runway

e.g., "American 123 is clear to take off on 4 left"

It is important to mimic the tower controller's instructions in this situation as soon as possible after they are issued, and not as you interpret the situation.

(5) At the point when you consider that it is safe to cross other aircraft ahead of the aircraft which is taking off, state:

(a) the aircraft's tag

(b) that it has taken off

(c) the departure runway

e.g., "American 123 has departed from 4 left"

D.2.5 Take-Off After Holding Short And Without Take-Off Hold

(1) When an aircraft is instructed to hold short of its departure runway, wait until you consider that the pilot of the aircraft can see the RELs at the appropriate TWY/RWY intersection. Then state:

(a) the aircraft's tag

(b) that it is holding short

(c) the runway which it is approaching

(d) the taxiway which it is on

e.g., "American 123 hold short of 4 left on Sierra"

(2) As soon as the aircraft is cleared to enter the departure runway and take off after it has been holding at the runway entrance hold lines, state:

(a) the aircraft's tag

(b) that it is about to enter its departure runway

(c) the departure runway

(d) the taxiway which it is on

e.g., "American 123 is clear for take off on 4 left from Sierra"

If the aircraft subsequently taxis away from the taxiway from which it entered for departure at another position on the runway, state the same information again but with the closest taxiway behind its departure position.

It is important to mimic the tower controller's instructions in this situation as soon as possible after they are issued, and not as you interpret the situation.

(3) When you consider that the pilot of the aircraft can see the THLs, state:

(a) the aircraft's tag

(b) that it is taking off

(c) the departure runway

e.g., "American 123 is taking off on 4 left"

(4) At the point when you consider that it is safe to cross other aircraft ahead of the aircraft which is taking off, state:

(a) the aircraft's tag

(b) that it has taken off

(c) the departure runway

e.g., "American 123 has departed from 4 left"

D.2.6 Take-Off Without Holding Short And With Take-Off Hold

(1) When an aircraft is cleared to taxi into position for take-off before it arrives at the runway entrance hold lines, wait until: (a) you consider that the pilot of the aircraft can see the RELs at the appropriate TWY/RWY intersection and is in a position to act on the state of the lights or (b) if you consider that the pilot can already see the RELs and is in a position to act on the state of the lights when the instruction is issued, wait until the instruction is issued. Then state:

(a) the aircraft's tag

(b) that it is clear to taxi into position

(c) the departure runway

(d) the taxiway which it is on

e.g., "American 123 taxi into position on 4 left from Sierra"

If the aircraft subsequently taxis away from the taxiway from which it entered for departure at another position on the runway, state the same information again, but with the closest taxiway behind its departure position.

(2) When you consider that the pilot of the aircraft can see the THLs, state:

(a) the aircraft's tag

(b) that it is in position for take-off

(c) the departure runway

e.g., "American 123 is in position on 4 left"

(3) As soon as the aircraft is given clearance to take-off, state:

(a) the aircraft's tag

(b) that it has been cleared for take-off

(c) the departure runway

e.g., "American 123 is clear to take off on 4 left"

It is important to mimic the tower controller's instructions in this situation as soon as possible after they are issued, and not as you interpret the situation.

(4) At the point when you consider that it is safe to cross other aircraft ahead of the aircraft which is taking off, state:

(a) the aircraft's tag

(b) that it has taken off

(c) the departure runway

e.g., "American 123 has departed from 4 left"

D.2.7 Take-Off Without Holding Short And Without Take-Off Hold

(1) When an aircraft is cleared for takeoff before it arrives at the departure runway entrance hold lines, wait until: (a) you consider that the pilot of the aircraft can see the RELs at the appropriate TWY/RWY intersection and is in a position to act on the state of the lights or (b) if you consider that the pilot can already see the RELs and is in a position to act on the state of the lights when the instruction is issued, wait until the instruction is issued. Then state:

(a) the aircraft's tag

(b) that it is clear to take off

(c) the departure runway

(d) the taxiway which it is on

e.g., "American 123 clear to take off on 4 left from Sierra"

If the aircraft subsequently taxis away from the taxiway from which it entered for departure at another position on the runway, state the same information again but with the closest taxiway behind its departure position.

(2) When you consider that the pilot of the aircraft can see the THLs, state:

(a) the aircraft's tag

(b) that it is taking off

(c) the departure runway

e.g., "American 123 is taking off on 4 left"

(3) At the point when you consider that it is safe to cross other aircraft ahead of the aircraft which is taking off, state:

(a) the aircraft's tag

(b) that it has taken off

(c) the departure runway

e.g., "American 123 has departed from 4 left"

D.2.8 Effect Of Aircraft Operating On Crossing Runways

When an aircraft is landing or departing on a crossing runway, state, at the point when you consider it unsafe to allow aircraft on your runway to start their take-off:

(a) the tag of the aircraft on your runway

(b) that it should hold it's take-off

(c) the reason for the hold

e.g., "American 123 is holding take-off on 27 because of arrival on 33 left"

D.3 ARRIVALS

D.3.1 Aircraft on Final Approach

When an aircraft is cleared to land, state:

(a) the aircraft's tag

(b) the type of aircraft

(c) that it is arriving

(d) its arrival runway

e.g "American 123 is arriving on 4 left"

Timing of this event is not critical since its purpose is simply to initiate an aircraft log. It must, however, be entered on the tape before any other information pertaining to this aircraft is entered.

D.3.2 Aircraft Landing

(1) When you consider that it would be unsafe to cross any aircraft over the arrival runway ahead of the landing aircraft (i.e. at the boundary), state:

(a) the arriving aircraft's tag

(b) that it is landing

(c) its arrival runway

e.g "American 123 is landing on 4 left"

(2) When you consider that the aircraft is under control after landing, state:

(a) the aircraft's tag

(b) that it is rolling out

e.g "American 123 is rolling out"

(3) When you consider that the aircraft has completed its roll out and is taxiing on the arrival runway or if the aircraft exits the arrival runway, state:

(a) the aircraft's tag

(b) that it has landed

(c) the arrival runway

(d) the exit taxiway (if applicable)

e.g "American 123 has landed on 4 left and is exiting on Charlie"

D.3.4 Landing Abort

If an aircraft aborts its landing or is instructed to go around, state:

(a) the aircraft's tag

(b) that it is aborting its arrival

e.g "American 123 is aborting its landing"

D.3.5 Getting An Aircraft Across A Runway With Hold Short

Same procedure as for departing aircraft (see "DEPARTURES").

D.3.6 Getting An Aircraft Across A Runway Without Hold Short

Same procedure as for departing aircraft (see "DEPARTURES").

D.4 VEHICLES

D.4.1 Crossing Runways

For vehicles crossing runways, follow the same procedures as for aircraft.

Runway Inspections Or Other Use Of Runway By A Vehicle

(1) When a vehicle commences (or continues) a runway inspection, state:

(a) the vehicle's tag, if known. If not, create a dummy tag.

(b) that it is starting (or continuing) a runway inspection

(c) the runway being inspected

(d) where it is entering the runway

e.g., "Massport vehicle 42 is starting/continuing inspection of 4 left from Charlie".

(2) When the vehicle completes or temporarily suspends a runway inspection, state:

(a) the vehicle's tag

(b) that it has completed (or suspended) a runway inspection

(c) the runway being inspected

(d) where it is entering the runway

e.g., "Massport vehicle 42 has completed/suspended inspection of 4 left - exiting on Tango."

D.4.2 Parked Vehicles

(1) When vehicles park on runway edges, state:

(a) the vehicle's tag, if known. If not, create a dummy tag.

(b) that it is parking

(c) where it is parked

e.g., "Massport vehicle 42 is parking on east side of 4 left between Charlie and Foxtrot."

(2) When the vehicle moves away from its parked position, state:

(a) the vehicle’s tag

(b) that it is leaving its parked position

e.g., “Massport vehicle 42 is leaving east side of 4 left between Charlie and Foxtrot”.

D.4.3 Runway Closures

Vehicles operating on closed runways (e.g., snowplows) can be ignored. However, annotation should be mode on the tape that the runway has been closed.

D.5 OTHER GENERAL PROCEDURES

If an aircraft or vehicle exits your airport region of coverage and subsequently enters the other shadow ATC’s region of coverage, state this and then inform the other shadow ATC accordingly.

When there are multiple aircraft waiting in a queue to cross or enter a runway, ignore all aircraft in the queue except the first. All aircraft except the first should be considered not to be in a position to react to the lights until the first aircraft has started to cross. When this event takes place, the second aircraft should immediately be considered as being at the head of the queue.

D.6 PRIORITY OF DATA ENTRY

Occasions may arise when two or more events occur simultaneously. In these cases, the following precedence applies:

1. Cleared for take-off
2. Clear to cross
3. Taxi into position
4. Other events

In the event that you are late in making an annotation, state that this is the case.

APPENDIX E

LIGHT VISIBILITY TESTING AT LOGAN

E.1 OBJECTIVES

On June 18, 1996, a test of the RWSL Light Subsystem was conducted at Logan airport in order to assess human factors issues associated with the RWSL lights. The primary objectives of the test were to asses: (a) the suitability of the location of the lights relative not only to runways and taxiways but also to other airfield lights, (b) visibility of the lights at standard runway entrance hold positions and take-off hold positions on the runway, and (c) human factors relating to light intensity.

E.2 TEST SET-UP

The area of the airport set aside for the test included the portions of Delta taxiway and runway 27 Northeast of runway 33L. The status lights used for the testing were the RELs at D, D-2, and D-1, and the two sets of THLs at the approach end of runway 27. A bucket truck was used to elevate viewers to heights representative of a range of aircraft cockpits and vehicles, from 5 feet to 50 feet. Testing was conducted during the midnight shift from midnight to 4 am. Runway 27 was closed to all other traffic.

Viewers included two human factors specialists from TASC and an experienced pilot. Technical support was provided by Edwards and Kelcey on the airfield (bucket truck operation and light fixtures) and TASC in the control tower (to switch lights on and off). Coordination of the timing of the various light events was by open telephone connection between the participants on the field and the light operator in the control tower.

Weather for the duration of the test period remained at high overcast with greater than 10-mile visibility throughout.

E.3 TEST SCENARIOS

A number of pre-arranged scenarios were performed. These scenarios were developed to assess the interaction between the lights and a pilot in various sized aircraft planning a departure on runway 27 via any one of the three access points at D, D-2, and D-1.

E.3.1 Scenario 1

The first scenario was designed to gauge reaction from a pilot taxiing an aircraft East on Delta taxiway and passing abeam of D-1 and D-2 in anticipation of a full length runway 27 departure. During this taxi period, RELs at three access points to runway 27 (i.e., on D, D-2, and D-1) were cycling on and off to represent other aircraft activity on 27.

Pilot Reaction

During straight-ahead taxi operations, the pilot is focused directly ahead with occasional eye and head movements to the left and right. The cycling RELs caught the pilot's attention and served as a reminder to the pilot that there was an active runway to the right of the aircraft. When the RELs were on, they also helped define the access taxiways and, most importantly, the physical edge of the active runway.

From the pilot's perspective, in-pavement stop bars, the red runway entrance flashers at Atlanta, Hartsfield, and the Logan RELs are much more demonstrative than runway hold signs in defining and alerting crews to areas of the airport where extreme caution is to be exercised.

With light intensity set at level 3 (which is the expected level for clear night-time operation), the RELs enhanced situational awareness but did not distract and were not too bright. The pilot also considered that a higher intensity level[1] would be required in poor visibility conditions.

E.3.2 Scenario 2

The second scenario was designed to test visibility of the lights to the pilot of an aircraft cleared to hold short of runway 27 for a full length departure.

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[1] RWSL lights have five intensity levels, level 1 being the lowest.

Pilot Reaction

Again, the cycling RELs helped define the access point for a full length departure on the runway. The lights, when on, continued to remind the pilot of his proximity to an active runway and that he was approaching the runway entrance hold line. As he approached the hold line, the light intensity, at level 3, did not appear either too dim or too bright. In addition, the time for the light to turn fully on (1 to 2 seconds) and fully off (0.5 seconds) was tolerable to the pilot, especially when compared with the discomfort of having sequence flashers (or similar) in his field of view. He further noted that the delays in switching on/off lights would probably not conflict with ATC communications.

While at the runway entrance hold point, the pilot was also exposed to the five different light intensity levels. Level 1 was considered too dim, while level 5 was too bright and was accompanied by a large halo around the light. Level 3 was considered ideal for the prevailing visibility conditions.

E.3.3 Scenario 3

The third scenario involved the use of the bucket truck at the Delta taxiway hold line, simulating a hold short for a full length departure on runway 27 for a variety of cockpit heights.

Pilot Reaction

From the simulated height of a Cessna 172 to that of a Boeing 747, the illuminated RELs served as a poignant reminder of the pilot's proximity to an active runway in use. The placement, intensity, and angulation of the light fixture provided the viewer with the same degree of light awareness, regardless of cockpit height. The only exception was that at ground level, the view of the lights appeared slightly cluttered in comparison with the "bird's eye view" from loftier flight decks. The addition of light baffles to confine the light beamwidth from spilling down the runway had no appreciable effect on observable light intensity. Operation of the cycling RELs on the adjacent taxiway (D-2) did not cause any confusion or distraction to the pilot. Although they were partially visible, they were obscured by the clutter of other airport lights.

E.3.4 Scenario 4

In this scenario, the bucket truck was used to simulate an aircraft landing over the approach end of runway 27 at an altitude of 50' (stationary). The purpose of this test was to determine whether light from the RELs would be visible to a landing aircraft.

Pilot Reaction

The only evidence of light from the RELs was a red glow of approximately 2' radius around the most easterly fixture. There was no indication of light spillover from any of the other REL fixtures.

E.3.5 Scenario 5

In this scenario, visibility of the THLs was measured at the full length position on 27 for various cockpit heights and at the D-2 and D-1 positions for smaller aircraft cockpit heights only.

Pilot Reaction

THL intensity and light transition times were satisfactory when viewed from all of the various cockpit heights and at all take-off hold positions. Location of the lights was good for the THLs located on the right side of the runway for all cockpit heights. However, the THLs on the left appeared to be in close proximity to the red VASI bar when viewed from the cockpit of a Boeing 747 (see Figure E-1). At lower cockpit levels, the red VASI bar appeared in the background of both set of THLs on the left side of the runway, thereby reducing light presentation (see Figure E-2). At the D-1 and D-2 hold positions, the view of the left THLs improved considerably since the VASI bar was no longer in the background.

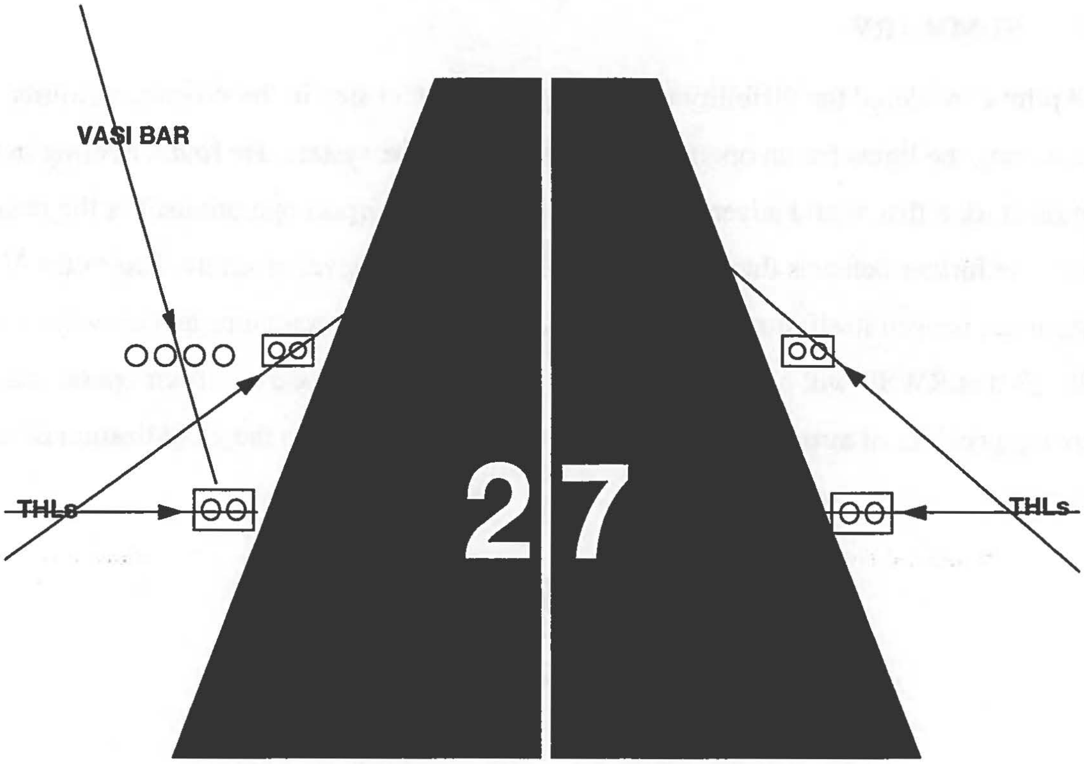

FIGURE E-1. VIEW OF THLS FROM BOEING 747

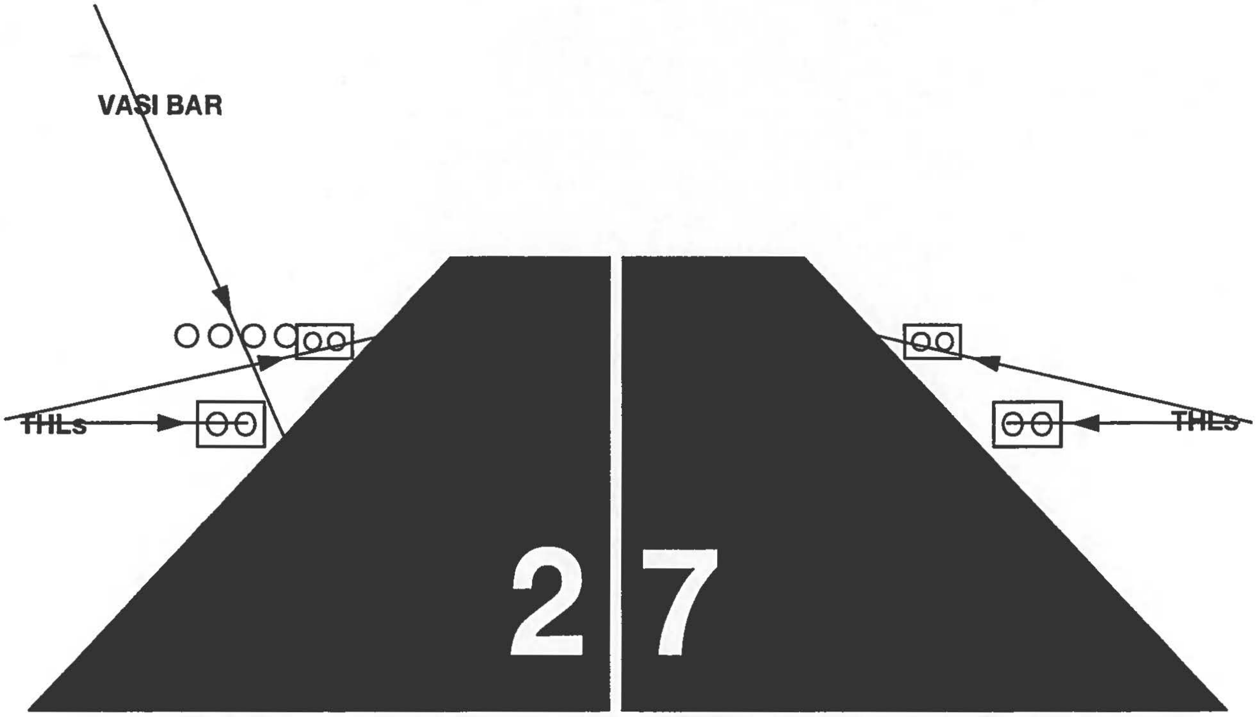

FIGURE E-2. VIEW OF THLS FROM SMALL AIRCRAFT

E.4 SUMMARY

The pilot considered the visibility tests to be an important step in the progress towards uncovering the lights for an operational assessment of the system. He found nothing in the demonstration that would adversely impact the safety of airport operations. For the reasons stated above, he further believes that the system will enhance the level of safety. Just as the VASI light system has proven itself in reducing incidences of threshold excursions and runway overruns, he believes that RWSL will be necessary given the expected increase in airport operations and the growing problem of airports which are unfamiliar to pilots due to the globalization of air transport.

APPENDIX F

LCC-LC COMMUNICATIONS PROTOCOL

F.1 INTRODUCTION

This appendix presents the data protocol used for communications between the Light Control Computer on the 16th floor in the tower and the Light Computer located in the Lighting Vault (refer to Appendix G for a detailed description of the SX Subsystem). This version of the communications protocol is used by the ADB SX Subsystem employed for hooded and dry run testing at Logan.

Data are passed between the LCC and the LC for control and status monitoring purposes. The information provided to the LC is a **Command Table** containing a list of controllable items with the desired state (ON, OFF) of each item. Controllable items include the CCRs in the lighting vault, the SXs, and other subsystem components, such as the UPS in the Lighting Vault. Information returned from the LC is embodied in a **Status Table** which contains status information about each of the controllable items.

The Command and Status Tables are the primary means of communication between the LCC and the LC; secondary links include the LC boot circuit, which is available to reset the LC, and the telephone modem remote access using ReachOut. All commands to change the state of any hardware, and all status reports, are presented as entries in the Command and Status Tables—0 DATA INTERFACE REQUIREMENTS. The fiber optic data link between the LCC and the LC operates at a rate of 19,200 bits/second in a full duplex mode, and the fiber modems employ a standard RS-232 interface with the LCC and LC.

F.2 COMMAND TABLE

Individual lights are assigned numbers within the range 001 through 245. Each number corresponds to a physical location of a light fixture (identified by a fixture identification code) on the airport runway system. A **Light Configuration File** is used by the LC to map the airport light number (implemented in the LCC) into the associated SX address (see Appendix G). The Configuration File contents are field-modifiable using keyboard entry, or is replaceable from a floppy disk. Light groups are assigned numbers in the range 001 through 255. Each group number corresponds to a physical grouping of lights on the airfield. The light configuration file also contains the capability to transform the group numbers used by the LCC into a new set of group numbers that are used by the LC and down-loaded into the SXs on the field.

The format of the Group Command Table is given in Table F-1. It consists of three segments. The first eight-byte segment contains a header and miscellaneous commands which control items other than SX groups. The second segment contains up to 123 SX/group commands. Each command in this segment is two bytes in length. The first byte of each command identifies the SX number or a group number to be commanded. It should be noted that although the communications protocol supports commanding of individual SXs, this capability is not implemented in the LCC and not used at Logan. Therefore, discussions herein are directed at the group command capability employed at Logan. The second byte of the command consists of command information pertaining to the group identified in the first byte (see Table F.5). The third segment contains an 16-bit table checksum.

The LC commands SXs to their desired state as dictated by group command bytes (see Table F-5). The LC broadcasts commands to the requested groups regardless of whether it has previously commanded the groups to the desired state. This is in support of the broadcast mode of operation used at Logan to ensure the highest system integrity. The LC executes consecutive Command Tables at a rate of one table per second.

F.3 Status Table

The LC collects status information for all of the controllable items under its domain with the exception of the CCRs, and transmits a complete Status Table to the LCC following each receipt of a Command Table. Table F-2 shows the format of the Status Table. Unlike the Command Table, the Light Status Table contains status information for individual SXs, as opposed to the status of SX groups.

The LC polls the SXs for status during time periods when the LC is not processing commands (i.e., status collection assumes the lowest priority of all LC activities). Each Status Table indicates if the status for each SX has been updated by the LC since the previous status table was transmitted to the

LCC. SXs are polled one at a time in a fixed round-robin sequence. Polling is resumed with the next SX in the sequence after all commands have been processed each command interval.

F.4 Time-outs

If a Command Table is not received by the LC in any five-second interval, the LC commands all SXs to the OFF state, sets the time-out fault status bit, and transmits the light status table to the LCC when the next Command Table is received from the LCC. Normal operation resumes following receipt of the next complete Command Table.

F.5 Initialization

LC initialization occurs following power restoration, or in response to a reset command received from the LCC, or following a reset of the LC. When the LC is re-booted, the CCRs are turned off (Level 0) and all SXs are commanded to the OFF state. The LC does not transmit any data to the LCC until it receives a Command Table, after which Status Tables are transmitted as described above (i.e. normal steady-state operation).

F.6 Checksum Failure

In order to provide a level of integrity in the communications interface between the LC and the LCC, a checksum is appended to each Command Table and Status Table. The checksum is a byte-wise exclusive-or of the first 8 +2N bytes in the Command Table and the first 9 +N bytes in the Status table where N is the number of group commands (nominally 15 or less) or the number of lights for with status is being reported (nominally the full complement of 170 lights activated on the airfield). In the event of a checksum failure in the received Command Table, the LC discards the table. The LC reports the checksum failure by setting the appropriate bits in the next Status Table transmitted to the LCC. The LC attempts to resynchronize with the next Command Table. A Status Table with a checksum error is discarded by the LCC and an error message is displayed.

TABLE F-1 COMMAND TABLE

ENTRY No.	ENTRY NAME	ENTRY VALUES (Note 1)	CONTENT
000	Table header	$8B_{16}$	Fixed table header identifying start of table.
001	Time stamp	0-255	LCC counter, modulo 256 (must advance monotonically).
002	Table length	0-123	Number of group command entries in this table (N).
003	Control #2	Boolean	Set output level for all CCRs. See Table F-3.
004	Control #3	AA_{16}	Reset LC command.
005	Control #4	Not used	
006	Control #5	Not used	
007	Control #6	Boolean	Miscellaneous command byte. See Table F-4
008	Group identity #1	001-255	Identity of first SX/group to be commanded
009	Group #1 command	Boolean	Command byte. See Table F.5
010	Group identity #2	001-255	Identity of second SX/group to be commanded
011	Group #2 command	Boolean	Command byte. See Table F-5
. . .	. . .	. . .	. . .
252	Group identity #123	001-255	Identity of 123rd SX/group to be commanded
253	Group #123 command	Boolean	Command byte. See Table F.5
254 255	16-bit checksum	$0\text{-}FFFF_{16}$	Table checksum

NOTES

1. In all cases, the bits in each byte are labeled 0 through 7, where bit position 0 is the least significant bit unless stated otherwise. Boolean functions are true if the bit state = 1.

TABLE F-2 STATUS TABLE

ENTRY No.	ENTRY NAME	ENTRY VALUES (Note 1)	CONTENT
000	Table header	$8B_{16}$	Fixed table header identifying start of table
001	Time stamp	0-255	LC counter, modulo 256 (must advance monotonically)
002	Table length	11-255	Number of light status entries in this table.
003	Status #2	Not used	
004	Status #3	Boolean	LC status. See Table F-6
005	Status #4	Boolean	UPS status. See Table F-7
006	Status #5	0-255	LCC counter from most recent valid Light/Group Control Table received from LCC
007	Status #6	Not used	
008	Status #7	Boolean	Summary alarm status. See Table F-8
009	Light #1	Boolean	Light status. See Table F-9
. . .	. . .	. . .	. . .
253	Light #245	Boolean	Light status. See Table F-9
254 255	16-bit checksum	$0\text{-}FFFF_{16}$	Table checksum

NOTES

1. In all cases, the bits in each byte are labeled 0 through 7, where bit position 0 is the least significant bit unless stated otherwise. Boolean functions are true if the bit state = 1.

TABLE F-3 CCR CONTROL COMMAND

This byte specifies in ASCII format the output current of the CCRs in the Lighting Vault. All CCRs are controlled simultaneously. There are six possible output states: OFF, and intensity levels 1 (lowest current) to 5 (highest current). The OFF output state is indicated by intensity level 0. Values of this byte and their associated meaning are as follows:

Value	Meaning
ASCII '0'	OFF.
ASCII '1'	Brightness level 1 (lowest current).
ASCII '2'	Brightness level 2.
ASCII '3'	Brightness level 3.
ASCII '4'	Brightness level 4.
ASCII '5'	Brightness level 5 (highest current).

Illogical settings: If a value which differs from any of the values given above is received, no action is taken.

TABLE F-4 MISCELLANEOUS COMMAND BYTE

Bits	Meaning
Bit 0	0 = Do not send Status Table 1 = Send Status Table
Bits 1-7	Not used.

TABLE F-5. GROUP COMMAND BYTE

Bits	Meaning
Bits 0,1	Not Used
Bits 2,3	Light/Group selector bits:
	00 = Not used
	01 = This is a group command
	10 = This is a SX command
	11 = Not used
Bits 4,5	SX/Group state command:
	00 = Ignore this command
	01 = SX/Group OFF - see note (a).
	10 = SX/Group ON - see note (a)
	11 = SX/Group OFF - see note (a)
Bit 6	Not used
Bit 7	SX/Group command priority:
	0 = High priority
	1 = Low priority
Notes: (a) If the command is for a group, all SXs in the specified group are commanded to the requested state. If the command is for an individual SX, only the individual SX is commanded to the requested state.	

TABLE F-6. LC STATUS BYTE

Bits	Meaning
Bit 0	1 = LC operating normally; bits 1-7 are all zeros.
	0 = LC operating abnormally; any of bits 1-7 are non-zero.
Bit 1	1 = Initialization complete, waiting for Group Control Table
Bit 2	1 = time-out. The LC has not received a Group Control Table during the last 5 seconds.
Bits 3-7	1-states indicate various LC faults
A summary status bit is set (= 1) in Status Table entry #008 if the OR'd value of bit positions 2-7 = 1. See Table F-8.	

TABLE F-7. UNINTERRUPTIBLE POWER SUPPLY (UPS) STATUS BYTE

Bit	Meaning
Bit 0	1 = UPS present and healthy
Bit 1	1 = UPS battery low.
Bit 2	1 = UPS has been operating continuously for at least 30 seconds.
Bit 3	1 = UPS faulty
Bits 4-7	Amount of time UPS has been operating continuously (LSB = 2 minutes).

A summary status bit is set (= 1) in Status Table entry #008 if the value of bit 3 = 1. See Table F.8

TABLE F-8. SUMMARY ALARM STATUS

Bit	Meaning
Bit 0	1 = CCR fault
Bit 1	1 = Checksum fault.
Bit 2	1 = LC fault; see Status Table entry #004.
Bit 3	1 = UPS fault; see Status Table entry #005.
Bit 4	1 = Communications fault; see Status Table entries #009-253.
Bit 5	1 = Reserved for modulator fault bit, if available; see Status Table entries #009-253.
Bit 6	1 = SX fault; see Status Table entries #009-253.
Bit 7	1 = Lamp failure; see Status Table entries #009-253.

TABLE F-9. LIGHT STATUS BYTE

The light(s) and associated SX(s) are identified by the table entry number.

Bits	Meaning
Bits 0,1	Last command sent to, received and successfully executed by SX
	00 = Light status not available (see note below)
	01 = Light is OFF
	10 = Light is ON
	11 = Light is FLASHING
Bit 2	1 = Lamp failure
Bit 3	1 = SX failure. Set if LC determines SX failure.
Bit 4	1 = Communications failure. The SX does not report status or will not respond to interrogation by the LC.
Bits 5-7	Not used

Bits 0 and 1 with a value of 00 indicates that status was not refreshed since last time sent in a Status Table. Setting bit 3 indicates failure of the SX to act as commanded, rather than a failure in status-gathering circuits. Since the fault requires replacement of the SX in either case, the issue is moot. Any fault causes the summary status bit to be set in Status Table entry #008; see Table F-8.

APPENDIX G

SMART TRANSFORMER SUBSYSTEM OPERATION

This appendix presents the equipment and operation of the Smart Transformer Subsystem.

G.1. EQUIPMENT OVERVIEW

A functional block diagram of the overall RWSL System is presented in Fig. G-1. All equipment located in the Lighting Vault, along with the cables and smart transformers on the Field, are considered part of the Smart Transformer Subsystem.

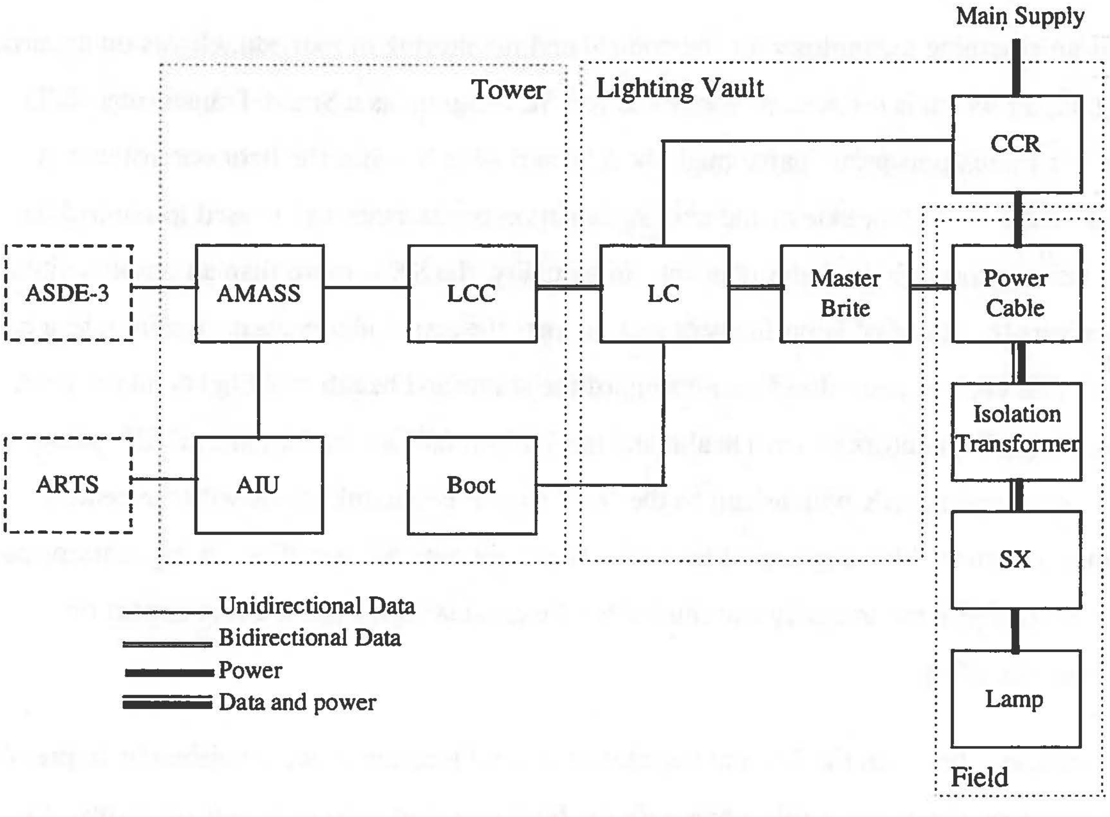

FIGURE G-1 FUNCTIONAL BLOCK DIAGRAM OF RWSL SYSTEM

Airport lighting systems employ series power circuits powered by Constant Current Regulators (CCRs) to ensure that all lights on the circuit will achieve the same illumination intensity, irrespective of resistance-induced cable losses. Each light fixture on the field, housing one or more lamps, is connected to the series power cable through an isolation transformer. If a lamp burns out on the secondary side of the transformer, the primary side of the transformer maintains circuit connectivity, unlike the old fashioned series Christmas tree lights where the entire circuit goes out when a single lamp fails. When current is supplied to the circuit by the CCR, this current flows though each of the lamps on the circuit and all lamps illuminate at the same intensity (assuming equal-wattage lamps). This is suitable for runway edge markers or center lines but it is necessary to control the illumination of individual lights, or specific groups of lights, in order to implement traffic control. One of the fundamental ground rules of the RWSL Program is to employ standard commercial off-the-shelf (COTS) equipment wherever possible. The decision was made early in the system design to employ standard field lighting equipment wherever possible and to augment this equipment as needed to enable control of the lights to implement the RWSL control logic.

There is an emerging technology for the control and monitoring of individual lights on an airfield lighting circuit which is referred to within the RWSL Program as a Smart Transformer (SX) System -- a more appropriate name might be a “smart switch” since the light control unit is installed on the secondary side of the existing isolation transformer and is used to control the current flowing through the lamp filament. In actuality, the SX is more than an on/off switch; it also monitors the status of lamp filament and reports the actual illumination condition to a central location. This enables centralized monitoring of the status and health of all lights on the field. Further, each SX monitors its own health and has built-in fail safe conditions: all SXs power up in the “off” state and the SX will default to the “off” state if communications with the central location is interrupted for a specified interval. These are critical capabilities in applications such as the RWSL where the integrity and reliability of individual lights has a direct impact on operations and safety.

Communications between the SX and the central control location is accomplished by impressing a control signal on the power cable along with the 60 Hz current used to power the lights. Because each SX has a unique (digital) address, the on/off state of the lights connected to each SX can be controlled and monitored from a central location. Each SX responds to its unique address and processes the associated command. This is essentially the same as two-way communications between two computers using modems over a cellular phone link, but the transmission medium for the SX signal is the underground power cable rather than over the air. Each series circuit has a modem (called the Master Brite by the system supplier: ADB-ALNACO, Inc.) that is connected to the power cable near the CCR in the field Lighting Vault. The series circuit modem provides the interface between the radio-frequency signal impressed on the power cable and the Light Computer (LC) which controls all of the SXs and gathers the status information from each SX. Additionally, the LC controls the current level of the CCRs which sets the desired illumination level of the lights on the field.

At Logan, the Lighting Vault is located at the south end of the airport near the General Aviation terminal at the end of runway 4L. This is the source of power for all field lighting circuits. RWSL is implemented with five separate series circuits; three circuits on runway 4L/22R and one to two circuits on runway 9/27, as illustrated in Fig. G-2. Note that Circuits 1 and 5 are one- to two-miles from the vault. This represents a rather long communications path for the control signals to and from the lighting vault. Each circuit has its own 15 kW CCR and a Master Brite which are controlled by the LC (see Figure G-3). Communications between the Master Brites and the LC is accomplished over five RS-422 circuits. The CCRs have five current levels (plus off) and are controlled, but not monitored, by the LC. (It is recommended that future systems include the capability to monitor the actual current level. Early problems with a loose control wire caused one CCR not to respond to LC commands. Although this problem was corrected and did not present any difficulty during system testing, it is prudent to monitor the actual current of each CCR -- an inherent capability of the CCR.)

Data communications between the vault and the 16th floor of the tower is accomplished over a pair of optical fibers with a fiber modem interfacing to one of the LC's RS-232 ports. On/off light commands for groups of lights are sent to the LC over the fiber link once per second and the status of all SXs gathered by the LC during the previous one-second interval are returned to the tower. A spare fiber is used to implement an LC boot capability. This boot capability enables remote booting of the LC from the tower by RWSL personnel in the event that the LC should "hang" thereby interrupting normal data communications over the fiber-pair. (This boot link is essential in the evaluation system because the available LC software is not mature and there are occasions associated with system start-up when it is desirable to reset the LC to a known initial state. This configuration is adequate for performance evaluation in a semi-automatic mode with human monitoring. However, an operational system will need to include additional LC control

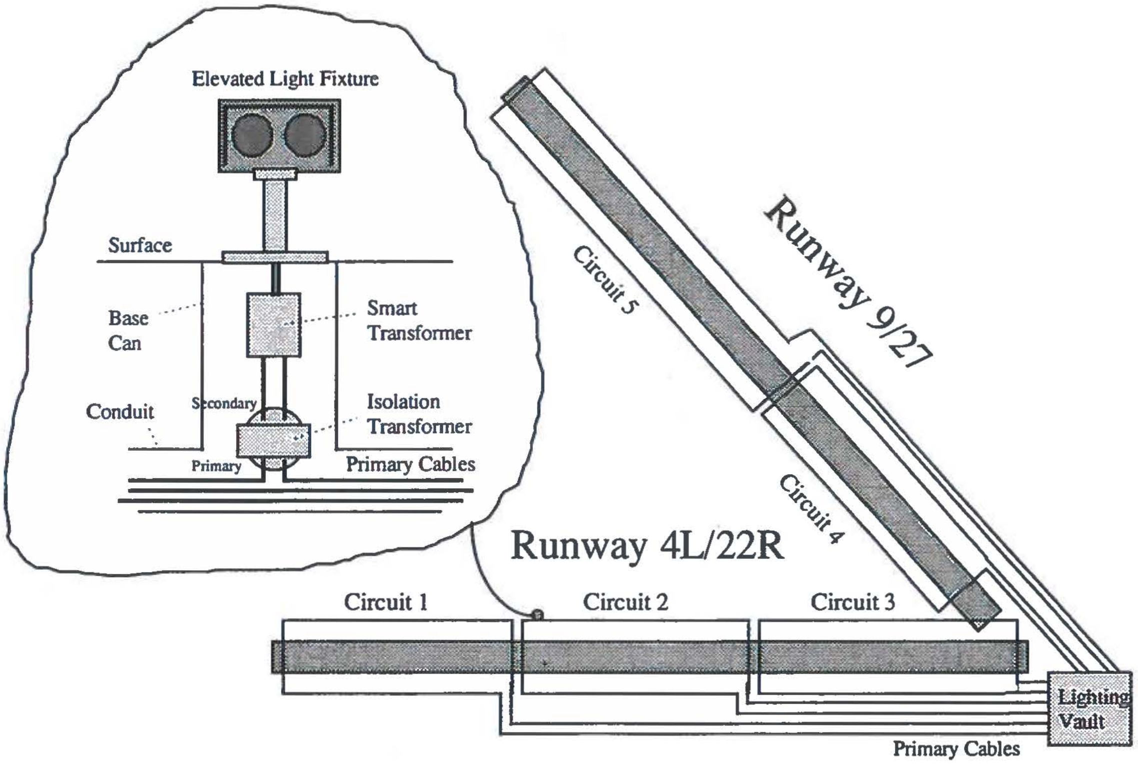

FIGURE G-2 RUNWAY CIRCUIT TOPOLOGY AT LOGAN INTERNATIONAL AIRPORT

logic/capability along with watchdog timers to enable fully automatic operation.) In addition to the fiber links into the LC, there is a telephone modem link which utilizes a COTS software package called ReachOut installed in the LC. This software enables remote access to the LC from the tower or other locations (such as from the ADB factory in Columbus, Ohio) to implement software and/or file changes and to facilitate system configuration activities. The LC is an i486-based microcomputer and is housed in a standard 19-inch enclosure. The enclosure is air conditioned because of the rather severe environment presented by the generator room where all of the RWSL equipment is housed in the Lighting Vault. A UPS supplies power to the enclosure and the five Master Brites. The Master Brites and pull switches (disconnects cables running to the field) for each circuit are mounted on a wooden partition located behind the five CCRs.

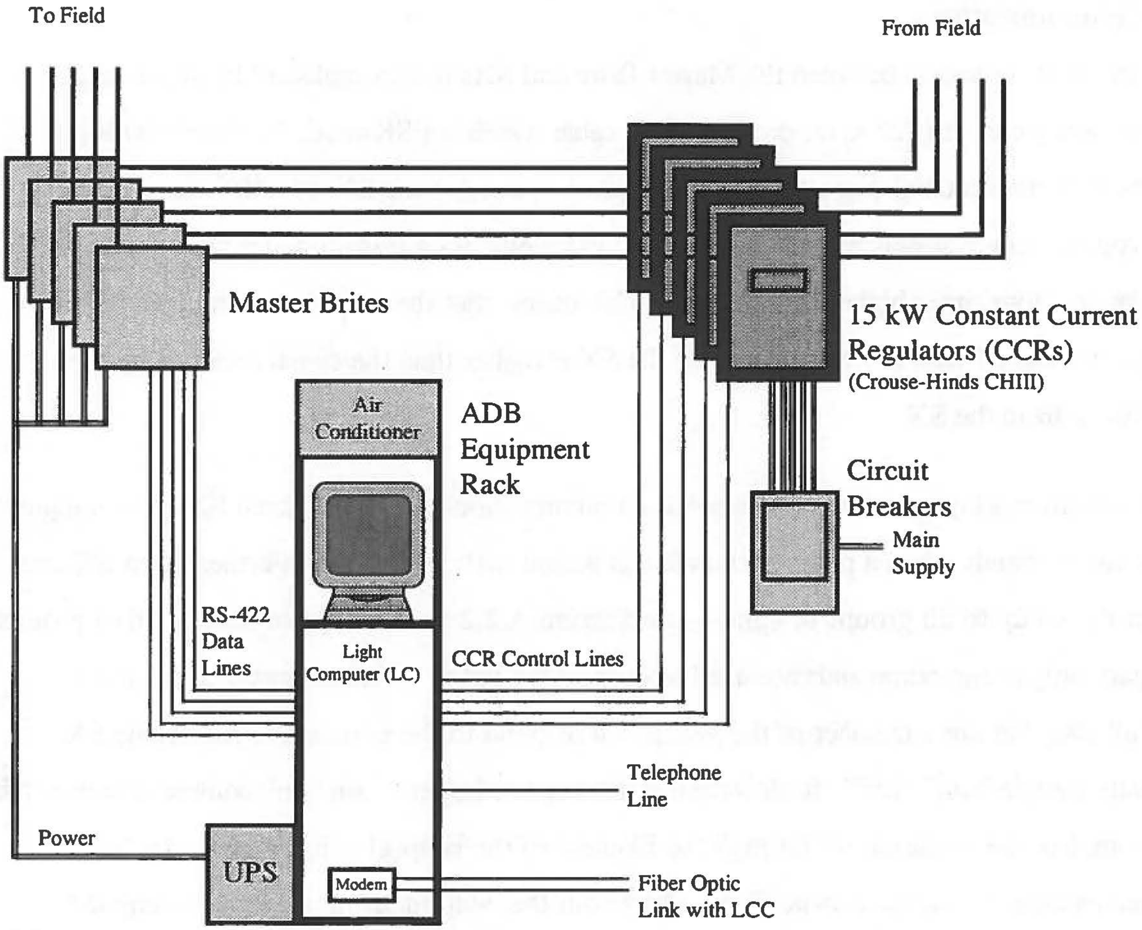

FIGURE G-3 LIGHTING VAULT EQUIPMENT AND INTERCONNECTIONS

G.2 SYSTEM OPERATION

To enable an understanding of the SX System operation, there are fundamental concepts that need to be understood:

1) Communications
2) Groups
3) Repeaters

Each of these concepts are addressed in the following sections, thereby providing a detailed description of SX Subsystem operation.

G.2.1 Communications

Two-way communication between the Master Brite and SXs is accomplished by impressing a radio frequency carrier (125 kHz) on the power cable which is FSK-modulated at 9600 baud. The Master Brite electronics are essentially the same as used in the SX with the exception of a higher voltage power supply in the Master Brite which enables a transmitted power which is approximately four times higher than the SX. This means that the expected communications reliability associated with commands sent to the SX is higher than the signal received by the Master Brite from the SX.

The subsystem employs a command-response communications protocol. Each SX has a unique address and responds when a polling command is issued with its address. Further, each SX can be a member of up to 20 groups of lights—see Section A.2.2 for a complete discussion of groups. At Logan, only group commands are used to control the lights. When a group command is issued, all SXs that are a member of the group will respond to the command. Allowable SX commands include “on,” “off,” “flash” (flash is not used at Logan). An “on” command causes the SX to complete the series circuit through the filament of the lamp(s) in its fixture. An “off” command essentially “closes a switch” that shorts out the lamp filament, thereby causing the current to bypass the filament and extinguish the lamp. Note that current still flows through the series circuit when the lamp is extinguished, unlike the old fashioned series Christmas tree lights. When the lamp is on, brightness is determined by the wattage of the lamp and the CCR current level (the CCR has five current levels plus off).

The LC parses group commands from the LCC and directs them to the appropriate Master Brite. Commands are issued simultaneously by each of the Master Brites on all five circuits but polling for status is interleaved. In other words, status cannot be simultaneously collected from multiple circuits. This is because there is substantial cross-talk between the circuits at Logan. It has been determined that in spite of excessive cross-talk between circuits, commands can be issued simultaneously on all five circuits.

SX commands and polling for status are sequential operations. Commands take priority and are issued once per second. After all of the commands have been issued by the LC, SXs are polled one at a time by the LC in a fixed round-robin sequence during the time remaining in the one-second command cycle. All status reports received by the LC during the polling interval are reported back to the LCC following reception of the next set of light commands from the LCC. Therefore, if polling and status reporting takes longer than the available time to encompass all of the SXs, the most recent status will not be available for all of the SXs in the next transmission to the LCC. This is the case at Logan where it takes approximately seven seconds to collect the status for all SXs in the absence of commands, and about 10 seconds (or more) in the presence of commands.

Like all communications systems, the SX Subsystem is susceptible to errors due to noise and interference. Noise and interference sources at Logan include: the CCRs which use rather noisy Silicon Controlled Rectifiers to control the conduction angle of the 60 Hz power to maintain a constant RMS current; cross-talk from adjacent cables in the raceway running from the lighting vault to the field; lightening strikes and other random sources of natural and man-made interference in the communications band. An observed problem is noise induced into the RWSL cables by other lighting circuits such as the runway edge lights.

Like any communications system, the signal-to-noise ratio (SNR) must be high enough to enable reliable detection of the signal. If the signal is not detected or if the data is corrupted, the SX is unable to respond to the command and the light will not respond. Also, if the Master Brite cannot detect and decode the SX status message, the status of that SX will not be received. Bit error checking is employed in the equipment so it is unlikely that a message will be erroneously interpreted. It is more likely that the message will be lost or rejected. During all of the testing at Logan, no erroneous responses to command have been noted but missed commands have been observed.

If status is requested from a SX by the LC and there is no response to the request, the LC re-issues the request two more times. If there is still no response, a communications error is declared by the LC and transmitted to the LCC in the tower. If after several polling cycles there is no response, the non-responding SX is declared dead, the LC stops polling that particular unit on a regular basis and only requests its status periodically. This logic was incorporated to reduce the time that the LC spends polling non-responding SXs since this greatly extends the interval required to collect a full round of status information from all of the SXs. This logic is acceptable for the assessment at Logan but needs to be restructured for a future operational system. Some type of smart polling was originally envisioned for Logan and should be reconsidered for any future system. The smart polling concept is to poll recently commanded SXs first followed by background polling of other SXs. This would minimize the delay between when the command is issued and the response is identified.

If an SX does not receive a command or a status request within any 10-second interval, logic in the SX switches its lamp into the off state. This ensures that all lights default to the "off" state in the event there is a failure in communications with the Master Brite. Further, if communications between the tower and the vault is interrupted for five seconds or more, the LC will issue "off" commands to all SXs. In addition to detecting communications problems, status monitoring also detects the actual state of the lamp and determines if the filament is burned out. The lamp does not have to be turned on for the SX to determine the filament integrity. Lamp status is sent to LC which passes it on to the tower for display on the LCC. Although the ADB SXs can also measure and communicate other parameters, both internal and external to the SX, this added capability is not exploited at Logan.

Because of the possibility that a command issued to an SX may be lost due to a communications error, a command broadcast mode of operation is employed. Ideally, if status monitoring could be accomplished rapidly, it would be desirable to sense the response of each SX to each command and re-issue the command if the SX state does not agree with the command. This closed-loop monitoring and control is not possible with the system at Logan due to the excessive time it takes to acquire status. Logic could have been developed for the LC which may have achieved the desired re-command capability but due to time and budget limitations the associated risk was considered excessive. Rather, the command broadcast approach provides a workable alternative where every SX on the field is commanded either "on" or "off" during every one-second command interval. If a command is missed during one command interval, one second later the same command is issued again. It is highly probable that the SX will respond to the second try of the command if it missed the command on the first try. If the SX responds correctly the first time, it simply ignores subsequent repeat commands. The goal is for all SXs to always respond by the third time the command is issued. This translates into a maximum added time delay of about two seconds between when the light should respond and the actual time of the response, which is considered acceptable in the overall response timing budget. The command reliability goals for the system are listed in Table G-1.

TABLE G-1. BROADCAST COMMAND RELIABILITY GOALS

Command Try	Response Probability
1	99%
2	99.9
3+	100

G.2.2 Groups

The time it takes for an SX to respond to a command (or the time to receive the SX status) depends on the communication data rate (or bandwidth). Data rate is a fundamental parameter that dictates overall system performance. The higher the realizable data rate, the faster that commands can be delivered to SXs and the faster that status is returned to the LC. Higher data rates also enable the interaction with more SXs in a given time interval. Response time is important because RWSL integrity may be reduced if the time delay in achieving the correct light state becomes excessive. The pilot may view a light state that is not in agreement with the desired light state specified by the Light Logic. Signal-to-noise ratio and system bandwidth are the fundamental parameters that define the performance (bit error rate) of all communications systems, including the SX Subsystem.

Commercially available SX Subsystems are not specifically designed for the rather demanding RWSL application. RWSL light commands for 170 light fixtures on five circuits at Logan are provided to the LC every second by the Light Logic in the tower. This data rate is considerably higher than typical runway lighting applications that generally turn lights on at dusk and off at dawn. Further, multiple light fixtures are used by RWSL on the field to ensure visibility and there must not be any substantial difference in the simultaneous on-off response of the associated SXs. In order to make efficient use of the available communications bandwidth and to help ensure the simultaneous response of multiple SXs, *group commands* are employed. Each ADB SX can be a member of 20 preprogrammed groups. This means that when the LC issues a command to a particular group number, all SXs that are a member of the group will respond to the command. For example, all of the lights on the field or on a circuit can be simultaneously command "on" or "off" with a single command if they are all included in the same group. Clearly, communicating the same command to multiple SXs is much more efficient with group commands than by sending individual commands to each and every SX. This is particularly applicable to RWSL since the system naturally functions by controlling multiple lights.

It is clear from RWSL testing in the Warehouse and at Logan that the two most important system parameters dictating system response are: 1) the *number of groups* that can be programmed into each SX, and 2) the achievable *command rate* of each circuit. One or both of these parameters needs to be "large" in order to achieve rapid system response. For example, if there is a sufficient number of groups to handle all of the desired permutations and combinations of lights, only one or two groups must be commanded at each one-second command broadcast to control all of the lights: one group for the "on" command and a second group for the "off" command. With only one or two group commands, this maximizes the time available to poll for status before the end of the command interval. Of course, the negative aspect of this scheme is the need for a large number of groups to handle all required SX combinations, which may not be practical if the numerical value of "large" exceeds the capacity of the SX.

Based on simulation studies using actual operational scenarios recorded at Logan, realistic tradeoff values were determined for the required number of commands and the associated number of groups. It was determined that 13 groups per SX would support a command rate of 4 groups per circuit each second for all normal operations with an infrequent requirement for a peak command of 6 groups. The ADB SXs were procured with a maximum limit of 20 groups/SX, thereby providing sufficient room for additional groups if the required command rate is observed to be excessive. This tradeoff between the number of groups and the required number of circuit commands is specific to Logan operations and needs to be repeated for any new installation. The availability of 20 groups per SX is probably reasonable for most envisioned applications, although this parameter is easily adjusted by ADB when the SXs are manufactured.

Note that an SX may be commanded "on" with one group number and then subsequently commanded "off" with the same or a different group number. Selection of the most efficient groups for the sequence of on/off commands is accomplished with logic in the LCC with the goal of limiting the number of groups that must be commanded at any one time to four groups.

The groups for each fixture are identified in Table G-2, organized by circuit. This table is the actual configuration file used in the LC and is the key data file which controls the mapping of groups into specific SXs. The first column of the table identifies the circuit, the second column is the SX number (address), the third column is the light fixture identification ("R" prefix is for RELs and "T" is for THLs) controlled by the SX, the fourth column is the light number as defined in the LCC in the tower, and the remaining columns list the SX group numbers.

This configuration file provides the data and flexibility needed to transform between the various numbering schemes. Further, it provides a positive mechanism for enabling/disabling lights on the field. An SX can only be commanded if it is identified in the table. This same configuration file is used by the LC to download the groups into the nonvolatile flash memory of the SXs. When the LC is commanded (from its keyboard) to download the configuration, the indicated groups are transmitted to each of the SXs. If an SX is replaced on the field, the groups in the new SX are quickly and easily programmed from the LC using the same configuration file that is used operationally to interpret the group commands from the LCC in the tower. This facilitates configuration control and eliminates multiple input/definition of the same quantity.

Near the end of Table G-2 there are three sets of number-pairs associated with the keyword MapBlock. This dataset enables further flexibility in the definition of the group numbers. This is an added feature that was incorporated after a bug was discovered in the SX firmware of the installed units during system checkout and verification. The firmware bug manifested itself if an SX number on a circuit happened to have the same numerical value as a group number used on the same circuit. The most efficient fix was to map the group numbers commanded by the LCC in the tower into an acceptable set of numbers for use on the field. The group numbers listed for each SX are the group numbers used in the field, not by the LCC. The mapping of LCC group numbers into SX group numbers is accomplished with the MapBlock pairs. For example, LCC group 11 is mapped into SX group 151. If the LCC issues an "on" command for group 11, all fixtures associated with SX group 151 will be commanded on: R10A, R10B, R9A, R9B on Circuit 1. Note that this transformation is only required with the group commands and not the status reports because status is acquired by individually polling each SX. MapBlock mapping of groups is only used for the subset of lights on Circuits 1 - 3 that are impacted by the firmware bug. This bug has been corrected in subsequent releases of the ADB SXs and the MapBlock capability is probably unnecessary in future systems, although it does provide added flexibility.

TABLE G-2. LC CONFIGURATION FILE

Circuit	SX No.	Fixture	LCC No.	SX Groups
1	1	T8A	45	162,82,86,88,107,112
1	2	T7A	43	163,82,86,88,107,112
1	3	T6B	42	164,83,86,88,89,107,112
1	4	T5B	40	165,83,86,88,89,107,112
1	6	R10B	36	151,58,59,102,112
1	7	R10A	35	151,58,59,102,112
1	9	T4B	28	166,84,87,88,89,107,112
1	10	R7B	30	152,58,59,60,61,102,112
1	11	R7A	29	152,58,59,60,61,102,112
1	12	T3B	26	167,84,87,88,89,107,112
1	13	R6B	24	152,58,59,60,61,102,112
1	14	R6A	23	152,58,59,60,61,102,112
1	15	T2B1	18	168,85,87,89,107,112
1	16	R5B	22	152,58,59,60,61,102,112
1	17	T2B2a	19	168,85,87,89,107,112
1	18	T2B2b	20	168,85,87,89,107,112
1	19	R5A	21	152,58,59,60,61,102,112
1	20	T1B1	12	169,85,87,89,107,112
1	21	T1B2a	13	169,85,87,89,107,112
1	22	T1B2b	14	169,85,87,89,107,112
1	23	R4B	8	153,59,60,61,62,102,112
1	24	R4A	7	153,59,60,61,62,102,112
1	25	R3B	6	154,61,62,102,112,115
1	26	R3A	5	154,61,62,102,112,115
1	27	R1B	2	154,61,62,102,112,116
1	28	R1A	1	154,61,62,102,112,116
1	29	R2B	4	154,61,62,102,112,115
1	30	R2A	3	154,61,62,102,112,115
1	31	T1A1	9	169,85,87,89,107,112
1	32	T1A2a	10	169,85,87,89,107,112
1	33	T1A2b	11	169,85,87,89,107,112
1	34	T2A1	15	168,85,87,89,107,112
1	35	T2A2a	16	168,85,87,89,107,112
1	36	T2A2b	17	168,85,87,89,107,112
1	37	T3A	25	167,84,87,88,89,107,112
1	38	T4A	27	166,84,87,88,89,107,112
1	40	R9B	34	151,58,59,102,112
1	41	R9A	33	151,58,59,102,112
1	43	T5A	39	165,83,86,88,89,107,112
1	44	T6A	41	164,83,86,88,89,107,112
1	45	T7B	44	163,82,86,88,107,112
1	46	T8B	46	162,82,86,88,107,112
2	51	R22B	77	6,173,174,101,111,127
2	52	R22A	76	6,173,174,101,111,127

TABLE G-2 LC CONFIGURATION FILE (cont.)

Circuit	SX No.	Fixture	LCC No.	SX Groups
2	53	T12A	72	28,180,106,111
2	54	T11A	70	29,180,106,111
2	55	R20B	69	7,173,174,101,111,127,128,129,130
2	56	R20A	68	7,173,174,101,111,127,128,129,130
2	57	T10B	65	30,181,106,111
2	58	R18B	61	8,174,175,176,101,111,127,128,129,130
2	59	R16B	57	9,175,176,177,101,111,127,128,129
2	60	R15B	54	10,176,177,101,111,128
2	62	R16A1	55	9,175,176,177,101,111,127,128,129
2	63	R16A2	56	9,175,176,177,101,111,127,128,129
2	64	R18A	60	8,174,175,176,101,111,127,128,129,130
2	65	T9B	63	31,181,106,111
2	67	R13B	50	10,176,177,101,111,128
2	69	R15A	53	10,176,177,101,111,128
2	71	R13A	49	10,176,177,101,111,128
2	72	T9A	62	31,181,106,111
2	73	R17B	59	8,174,175,176,101,111,127,128,129,130
2	74	R17A	58	8,174,175,176,101,111,127,128,129,130
2	75	T10A	64	30,181,106,111
2	76	R19B	67	7,173,174,101,111,127,128,129,130
2	77	R19A	66	7,173,174,101,111,127,128,129,130
2	78	T11B	71	29,180,106,111
2	79	T12B	73	28,180,106,111
2	80	R21B	75	6,173,174,101,111,127
2	81	R21A	74	6,173,174,101,111,127
3	99	R24B4b	103	3,50,52,190,200,211,212,213,215,216
3	100	R25B	111	5,51,52,190,200,213
3	101	R26B	119	4,51,52,190,200,211,212,213,216
3	102	R27A1	120	2,50,52,190,200,211,212,214,215
3	103	R26A1	112	4,51,52,190,200,211,212,213,216
3	104	R26A4b	118	4,51,52,190,200,211,212,213,216
3	105	R26A4a	117	4,51,52,190,200,211,212,213,216
3	106	R26A3b	116	4,51,52,190,200,211,212,213,216
3	107	R26A3a	115	4,51,52,190,200,211,212,213,216
3	108	R26A2b	114	4,51,52,190,200,211,212,213,216
3	109	R26A2a	113	4,51,52,190,200,211,212,213,216
3	111	R25A4b	110	5,51,52,190,200,213
3	112	R25A4a	109	5,51,52,190,200,213
3	113	R25A3b	108	5,51,52,190,200,213
3	114	R25A3a	107	5,51,52,190,200,213
3	115	R25A2b	106	5,51,52,190,200,213
3	116	R25A2a	105	5,51,52,190,200,213
3	118	T14A	80	26,195,200
3	120	R24A1	90	3,50,52,190,200,211,212,213,215,216
3	121	R24A2a	91	3,50,52,190,200,211,212,213,215,216
3	122	R24A2b	92	3,50,52,190,200,211,212,213,215,216
3	123	R24A3a	93	3,50,52,190,200,211,212,213,215,216

TABLE G-2 LC CONFIGURATION FILE (cont.)

Circuit	SX No.	Fixture	LCC No.	SX Groups
3	124	R24A3b	94	3,50,52,190,200,211,212,213,215,216
3	125	R24A4a	95	3,50,52,190,200,211,212,213,215,216
3	127	R24B1	97	3,50,52,190,200,211,212,213,215,216
3	128	R24B2a	98	3,50,52,190,200,211,212,213,215,216
3	129	R24B2b	99	3,50,52,190,200,211,212,213,215,216
3	130	R24B3a	100	3,50,52,190,200,211,212,213,215,216
3	131	R24B3b	101	3,50,52,190,200,211,212,213,215,216
3	132	R24B4a	102	3,50,52,190,200,211,212,213,215,216
3	134	R23A1	82	5,51,52,190,200,213
3	135	R23A4b	88	5,51,52,190,200,213
3	136	R23A4a	87	5,51,52,190,200,213
3	137	R23A3b	86	5,51,52,190,200,213
3	138	R23A3a	85	5,51,52,190,200,213
3	139	R23A2b	84	5,51,52,190,200,213
3	140	R23A2a	83	5,51,52,190,200,213
3	141	R23B	89	5,51,52,190,200,213
3	142	T14B	81	26,195,200
3	143	T13B	79	27,195,200
3	145	R24A4b	96	3,50,52,190,200,211,212,213,215,216
3	146	R35B	129	1,50,190,200,211,214
3	150	R35A	128	1,50,190,200,211,214
3	152	R27B	127	2,50,52,190,200,211,212,214,215
3	153	R27A2a	121	2,50,52,190,200,211,212,214,215
3	154	R27A2b	122	2,50,52,190,200,211,212,214,215
3	155	R27A3a	123	2,50,52,190,200,211,212,214,215
3	156	R27A3b	124	2,50,52,190,200,211,212,214,215
3	157	R27A4a	125	2,50,52,190,200,211,212,214,215
3	158	R27A4b	126	2,50,52,190,200,211,212,214,215
3	159	R25A1	104	5,51,52,190,200,213
3	160	T13A	78	27,195,200
4	161	R37B	136	17,63,64,65,103,113,132,134,135,136,137
4	163	R37A	135	17,63,64,65,103,113,132,134,135,136,137
4	164	T15A	141	40,108,113
4	165	R39B	140	18,64,65,66,103,113,131,132,135,136,137
4	166	R39A	139	18,64,65,66,103,113,131,132,135,136,137
4	167	T16A	143	41,108,113
4	169	R42B	150	19,65,66,103,113,136
4	171	R42A	149	19,65,66,103,113,136
4	173	R41B	148	19,65,66,103,113,136
4	174	T16B	144	41,108,113
4	176	R41A	147	19,65,66,103,113,136
4	177	T15B	142	40,108,113
4	178	R38B	138	17,63,64,65,103,113,132,134,135,136,137
4	179	R38A	137	17,63,64,65,103,113,132,134,135,136,137
4	180	R36B	134	16,63,64,65,103,113,133,134,137
4	181	R36A	133	16,63,64,65,103,113,133,134,137

TABLE G-2 LC CONFIGURATION FILE (cont.)

Circuit	SX No.	Fixture	LCC No.	SX Groups
4	184	R32A	131	15,63,103,113,131,132,133,137
4	185	R32B	132	15,63,103,113,131,132,133,137
5	201	R44B	155	20,67,68,104,114,140,142,143,144
5	202	R44A1	153	20,67,68,104,114,140,142,143,144
5	203	R44A2	154	20,67,68,104,114,140,142,143,144
5	204	T17B	157	42,90,93,109,114
5	205	T18B	159	43,90,93,109,114
5	206	R45B	161	21,67,68,69,104,114,139,140,141,142,143,144,145
5	207	R45A	160	21,67,68,69,104,114,139,140,141,142,143,144,145
5	209	R48B	167	22,68,69,70,104,114,138,139,140,141,143
5	211	R48A	166	22,68,69,70,104,114,138,139,140,141,143
5	212	T19B	173	44,91,93,94,109,114
5	213	T21B	179	46,92,94,109,114
5	214	T20B	175	45,91,93,94,109,114
5	215	R51B	177	23,70,71,104,114,138,139,140,141,142,143,144,145
5	216	R51A	176	23,70,71,104,114,138,139,140,141,142,143,144,145
5	217	T22B	181	47,92,94,109,114
5	218	R52B	183	24,72,70,71,104,114,141,142,143,145
5	219	R52A	182	24,72,70,71,104,114,141,142,143,145
5	220	R53B	185	25,72,70,71,104,114,117,141,142,145
5	221	R53A	184	25,72,70,71,104,114,117,141,142,145
5	222	R54A	186	25,72,70,71,104,114,118,141,142,145
5	223	R54B	187	25,72,70,71,104,114,118,141,142,145
5	224	T22A	180	47,92,94,109,114
5	225	T21A	178	46,92,94,109,114
5	226	T20A	174	45,91,93,94,109,114
5	227	T19A	172	44,91,93,94,109,114
5	229	R50B	171	22,68,69,70,104,114,138,139,140,141,143
5	230	R50A	170	22,68,69,70,104,114,138,139,140,141,143
5	232	R46B	163	21,67,68,69,104,114,139,140,141,142,143,144,145
5	233	R46A	162	21,67,68,69,104,114,139,140,141,142,143,144,145
5	234	T18A	158	43,90,93,109,114
5	235	T17A	156	42,90,93,109,114

	SX Group	LCC Group
MapBlock	151	11
MapBlock	152	12
MapBlock	153	13
MapBlock	154	14
MapBlock	162	32
MapBlock	163	33
MapBlock	164	34
MapBlock	165	35
MapBlock	166	36
MapBlock	167	37

TABLE G-2 LC CONFIGURATION FILE (cont.)

Circuit	SX No.	Fixture
MapBlock	168	38
MapBlock	169	39
MapBlock	173	53
MapBlock	174	54
MapBlock	175	55
MapBlock	176	56
MapBlock	177	57
MapBlock	180	80
MapBlock	181	81
MapBlock	190	100
MapBlock	195	105
MapBlock	200	110
MapBlock	211	121
MapBlock	212	122
MapBlock	213	123
MapBlock	214	124
MapBlock	215	125
MapBlock	216	126

G.2.3 Repeaters

As previously noted, the communications path between the Master Brite and the SX may be rather long in distance and may suffer substantial loss of SNR. All of the mechanisms within the cable environment contributing to reduced SNR are not fully understood (at this time). It was found during system configuration that communications with certain SXs is more difficult than with other SXs and there is not always a direct correlation with the physical distance from the Lighting Vault. The physical routing of the cables within the conduit on the field is rather complex. Cables are in close proximity with other cables and in many locations the cables and equipment within the base cans are submerged in water. Communications with SXs at certain physical locations is more difficult and the exact reasons are not fully understood.

In order to improve communications reliability, ADB SXs can be configured to operate as a repeater, in addition to their normal operation as a SX. This repeater action is analogous to repeaters used in long-line telephone systems, such as underwater cables. In simple terms, communications signals received by a repeater are re-transmitted. The desired result of increasing the signal strength and improving the associated SNR. The associated down-side of this repeater scheme is the additional time delay (9 ms) associated with receiving and then re-transmitting the signal. This delay is relatively small compared to the fundamental command rate of one-per-second and is generally insignificant when group commands are being sent to the SX. However, a daisy chain of multiple repeaters can introduce a significant delay in the time to report the status of all SXs on the circuit.

The primary difference between the command and status reporting modes is that four group commands are generally all that are necessary to command all of the SXs on a circuit. The repeater-induced time delay for each group command is 9 ms times the number of repeaters (hops) the group command must transverse before reaching the SX. However, when SXs are polled for status they must respond one at a time. This means there is a time delay induced by the repeater chain during the poll for status and in the response from each and every SX on the circuit. Note that the status response must return through the same chain of repeaters as the polling request. Because the circuits are polled in sequence, the total time to receive status from the entire system is the sum of the times for each circuit. This means that multiple repeaters can significantly increase the time to gather the status of all SXs in the system.

When the ADB system was first installed at Logan it was immediately apparent that a number of repeaters are needed to communicate with all SXs in the system. This was a rather surprising observation since previous tests with approximately two miles of cable in the Volpe Warehouse and at ADB, along with field tests performed by ADB, suggested that at most one repeater per circuit may be needed. The actual number of repeaters used at Logan on each circuit is summarized in Table G-3. It can be seen that there is a positive correlation between the number of repeaters and the distance of the circuit from the Lighting Vault (see Fig. G-2.)

TABLE G-3 NUMBER OF REPEATERS AND MAXIMUM NUMBER OF HOPS ON EACH CIRCUIT AT LOGAN

Circuit	Repeaters	Max. Hops
1	9	4
2	7	4
3	5	3
4	4	2
5	8	5

Any of the available SXs can be configured as a repeater from the LC. To program a repeater, it is not necessary to remove the SX from the circuit since all programming is accomplished with special-purpose LC software using the same communications interface used for commands and status reporting. The process of selecting an SX to be a repeater is called "configuring the circuit" by ADB. There is no automated procedure and the process requires an experienced engineer. Once the configuration has been established, however, there does not appear to be a need to make further changes unless there is a significant change in the circuit topology or in the associated cable environment that impacts the SNR. The full complement of repeaters and the fixtures/SXs served by each repeater at Logan are identified in Table G-4. Note that fixtures that are shaded gray in Table G-4 were included in the original system design but a decision was subsequently made not to install these fixtures and their SXs. The right-hand column of the table contains notes regarding SX failures and replacements.

Although repeaters enable the system at Logan to function, the resulting repeater-induced time delays are a negative and render status reporting at Logan useful only for health monitoring. The time to receive updated status from all 170 SXs is on the order of 10 sec. Since commands are issued every second and can change within a given 10 sec interval, it is not always possible to uniquely associate the indicated status with the corresponding command. The second major negative associated with the use of repeaters is reduced system reliability/availability. Failure of a single RWSL SX does not present a critical operational problem since there are at least two SXs at every critical location on the field. However, failure of a repeater can disable multiple SXs—all of the units serviced by the repeater. This is highly undesirable since a major portion of a runway may become inoperative due to a single failure, thereby possibly rendering the entire system inoperative. This problem was recognized before operational testing started and pre-programmed "hot spares" are available on site for all of the repeaters. This enables overnight replacement of any failed repeaters, thereby minimizing the system downtime during system testing. This is a system reliability/availability issue that needs to be addressed in a fully operational system. As can be seen in Table G-4, SX failures, including remotes, has been a problem over the life of the system. "New Package" refers to an improved SX package design which became available after the winter of 1995 - 1996 when there was a number of SX failures due to ice and water damage within the fixture base cans.

One of the limitations of using an SX as a repeater is the two-way signal loss through the isolation transformer since the SX is on the secondary side of the isolation transformer. Another problem is that the transmitted power of the SX is approximately four times smaller than the transmitted power of the Master Brite, although essentially the same electronics are used in both units. The reduced power is associated with power supply voltage limitations in the SX. Both of these limit the range of the SX transmissions. Subsequent to system installation at Logan, ADB developed a new repeater that operates on the primary side of the isolation transformer. Test results are not available under the RWSL Program but it appears that this primary configuration may offer a solution to improving the circuit SNR with fewer repeaters. Minimizing the required number of repeaters has the added benefit of potentially improving the overall system reliability/availability.

TABLE G-4 RWSL CIRCUIT CONFIGURATION

Key: ▨ Not Installed

Fixture	SX Address	Repeater	Range	Previous Repeater	Next Repeater	Notes
T8A	1					
T7A	2	2	3 to 6	1	8	Failed 5/11 New Pkg 5/7, 5/22
T6B	3					
T5B	4					
R11A	5					
R10B	6	8	7 to 10	2	9	New Package
R10A	7					New Package
R8B	8					
T4B	9					
R7B	10	9	11 to 19	8	10	New Package
R7A	11					
T3B	12					
R6B	13					
R6A	14					
T2B1	15					
R5B	16					Failed 9/27
T2B2a	17					
T2B2b	18					New Package
R5A	19	10	20 to 23	9	0	
T1B1	20					
T1B2a	21					
T1B2b	22					
R4B	23					
R4A	24					
R3B	25					
R3A	26					
R1B	27					
R1A	28	14	24 to 27	13	0	New Package
R2B	29					
R2A	30					New Package
T1A1	31	13	28 to 30	12	14	
T1A2a	32					
T1A2b	33					
T2A1	34					
T2A2a	35					
T2A2b	36					

TABLE G-4 RWSL CIRCUIT CONFIGURATION (cont.)

T3A	37					
T4A	38	12	31 to 37	11	13	
R8A	39					
R9B	40					
R9A	41					
R11B	42					
T5A	43					
T6A	44	11	38 to 43	3	12	
T7B	45					Failed 5/22 New Package 6/6
T8B	46	3	44 to 45	1	11	
R22B	51	15	52 to 54	1	12	
R22A	52					
T12A	53					
T11A	54	12	55 to 59	15	13	
R20B	55					
R20A	56					
T10B	57					
R18B	58					Failed 6/25 New package 7/10
R16B	59	13	60 to 65	12	0	
R15B	60					
R14A	61					
R16A1	62					
R16A2	63					
R18A	64					
T9B	65					
R12A	66					
R13B	67					
R12B	68					
R15A	69					
R14B	70					
R13A	71	11	66 to 70	10	0	
T9A	72					
R17B	73					
R17A	74					Failed 6/17 New Package 7/10
T10A	75	10	71 to 74	14	11	Failed 4/25 Old Package 5/7
R19B	76					

TABLE G-4 RWSL CIRCUIT CONFIGURATION (cont.)

R19A	77					
T11B	78					
T12B	79	14	75 to 78	5	10	
R21B	80					
R21A	81	5	79 to 80	1	14	
R24B4b	99	7	127 to 136	1	3	
R25B	100	6	103 to 119	1	2	
R26B	101					
R27A1	102					Failed 4/25 Old Package 5/7
R26A1	103					Failed 4/25 Old Package 5/7
R26A4b	104					
R26A4a	105					
R26A3b	106					
R26A3a	107					
R26A2b	108					
R26A2a	109					
R25A4b	111					
R25A4a	112					
R25A3b	113					
R25A3a	114					
R25A2b	115					
R25A2a	116					
T14A	118	2	146 to 160	6	0	Failed 7/15 New Package 7/18
R24A1	120					
R24A2a	121					
R24A2b	122					
R24A3a	123					
R24A3b	124					
R24A4a	125					
R24B1	127					
R24B2a	128					
R24B2b	129					
R24B3a	130					Failed 4/25 Old Package 5/7
R24B3b	131					

TABLE G-4 RWSL CIRCUIT CONFIGURATION (cont.)

R24B4a	132					
R23A1	134					
R23A4b	135					
R23A4a	136	3	137 to 145	7	4	
R23A3b	137					
R23A3a	138					
R23A2b	139					
R23A2a	140					
R23B	141					Failed 6/25 New Package 7/10
T14B	142					
T13B	143					
R29B	144					
R29A	145					
R24A4b	145	4	120 to 126	3	0	
R35B	146					
R31B	147					
R31A	148					
R34A	149					
R35A	150					
R34B	151					
R27B	152					Failed 5/29 New Package 6/6
R27A2a	153					
R27A2b	154					
R27A3a	155					
R27A3b	156					Failed 7/18 New Package
R27A4a	157					
R27A4b	158					
R25A1	159					
T13A	160					
R37B	161					
R28A	162					
R37A	163	10	164 to 166	1	13	New Package
T15A	164					

TABLE G-4 RWSL CIRCUIT CONFIGURATION (cont.)

R39B	165					
R39A	166	13	167 to 172	10	0	New Package 5/18
T16A	167					
R40A	168					
R42B	169					
R43B	170					
R42A	171					
R43A	172					
R41B	173					
T16B	174					
R40B	175					
R41A	176					
T15B	177					
R38B	178					
R38A	179	12	173 to 178	9	0	Failed 7/15 New Package 7/18
R36B	180					
R36A	181					
R30B	182					
R30A	183					
R32A	184					
R32B	185	9	179 to 183	1	12	
R28B	186					
R33B	187					
R33A	188					
R44B	201					
R44A1	202	2	203 to 206	1	3	
R44A2	203					
T17B	204					
T18B	205					
R45B	206	3	207 to 209	2	4	
R45A	207					
R47A	208					
R48B	209	4	210 to 213	3	5	
R49B	210					

TABLE G-4 RWSL CIRCUIT CONFIGURATION (cont.)

R48A	211					
T19B	212					
T21B	213	5	214 to 217	4	6	
T20B	214					
R51B	215					
R51A	216					New Package
T22B	217	6	218 to 222	5	0	
R52B	218					
R52A	219					
R53B	220					
R53A	221					
R54A	222					
R54B	223					
T22A	224					
T21A	225					
T20A	226	13	223 to 225	12	0	
T19A	227					
R49A	228					
R50B	229					
R50A	230	12	226 to 229	11	13	
R47B	231					
R46B	232					
R46A	233					
T18A	234	11	230 to 233	1	12	Failed 4/30; New Pkg 5/7, Failed 5/14/97
T17A	235					

APPENDIX H

SYSTEM VARIABLES AND DEFAULT SETTINGS

An adaptation parameter is a site variable parameter which contains a value that may be changed within specified limits. The following tables describe the adaptation parameters available for the Light Manager. The capability to modify Light Manager adaptation parameters is provided by sub-menus available from the AMASS main menu.

H.1 Light Manager Options

The following options selectively enable and disable LM functionality:

TABLE H-1. LIGHT MANAGER GENERAL OPTIONS

Setting	Default Value	Alternative Values
REL Logic	ON-ALL RWYS	ON-TEST AREA; OFF
THL Logic	ON-ALL RWYS	ON-TEST AREA; OFF
LCC Communication	DISABLE	ENABLE
AMASS HoldBar Logic	DISABLE	ENABLE
Log Events to Disk	ENABLE	DISABLE
Events Log Filename(*.LML)	LMEVENTS	Eight character string
DOS Log File Simulation	DISABLE	ENABLE
Simulation Filename (*.LOG)	none	Eight character string

TABLE H-2. SITE CONFIGURATION OPTIONS

Setting	Default Value
Light Crossing Alarm Duration	30 seconds
Multi-Path Hist for Valid DEP	12 seconds
Target Tag Optimization Logic	Enable
LM Light Color	WHITE
Clutter Filter Win Radius - All Runways	60.0 feet

TABLE H-3. REL LOGIC FUNCTIONALITY

Setting	Default Value
Utilize Config Parameters From	Group B
REL Gate Display	ENABLE
REL Arming Display	DISABLE
REL Arming Logic	DISABLE
Discard Opposite Direction Arrival	ENABLE
Discard Opposite Direction Landing	ENABLE
Discard Opposite Direction Departure	ENABLE
Land&Hold Short 15L/33R (0409 Config)	DISABLE
REL Arming Distance - All Runways	500.0 feet

TABLE H-4. THL LOGIC FUNCTIONALITY

Setting	Default Value
Inters RWY High Speed Target Logic	ENABLE
RWY Xing Anticipated Separation Logic	ENABLE
AMASS's No-Projected-Velocity Logic	DISABLE
Extended Activation Region Logic	ENABLE
Bi-directional THL Logic	DISABLE
Display Armed Region	ENABLE
Land & Hold Short 9/27 (1509 Config)	ENABLE

H.2 REL Hot Zone Adaptation Parameters

The LM provides for two sets of REL hot zone adaptation parameters, referred to as Group A parameters and Group B parameters. Only one set of hot zone adaptation parameters (i.e., either Group A or Group B) will be active while the system is operational. The LM provides the capability to select either the Group A set or the Group B while the system is on-line.

The Group A values are based in large part on values suggested by the MIT Lincoln Labs algorithms. The Group A hot zone adaptation parameters will be set to the values shown in Table H-5. The Group B values were developed specifically to support the AMASS-LM assessment.

The Group B hot zone adaptation parameters will be set to the values shown in Table H-6. The assessment was performed using the Group B values at all times.

As indicated in the tables, these parameters are dependent on target state and runway. Based on context (i.e., target state and runway), the REL processing algorithms will use the appropriate adaptation value. The parameters in these tables are used in the algorithms specified in Appendix B. The mapping of table values to variables used in the algorithms is as follows:

a. The values in the Hot Zone column map to the hot_zone_time_param variable. They specify the length of the t-second hot-zone used to determine which lights in front of an aircraft should be illuminated.

b. The values in the Ant. Sep. column map to the anticipated_sep_param variable. They specify the small distance in front of the plane at which lights should be turned off in anticipation that the plane will soon pass them.

c. The values in the Hysteresis column map to the hyst_time_param variable. This is used to prevent lights from being turned off after they are turned on merely due to small inaccuracies in target position or velocity.

TABLE H-5. TARGET HOT ZONE ADAPTATION PARAMETERS (GROUP A)

Tgt State	RUNWAY											
	4L			22R			9			27		
	Hot Zone* (sec)	Ant. Sep. (sec)	Hysteresis (sec)	Hot Zone* (sec)	Ant. Sep. (sec)	Hysteresis (sec)	Hot Zone* (sec)	Ant. Sep. (sec)	Hysteresis (sec)	Hot Zone* (sec)	Ant. Sep. (sec)	Hysteresis (sec)
STP	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TAX	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
DEP	n/a (whole rwy)	4.5	n/a	n/a (whole rwy)	4.5	n/a	n/a (whole rwy)	4.5	n/a	n/a (whole rwy)	4.5	n/a
DBT	n/a (whole rwy)	4.5	n/a	n/a (whole rwy)	4.5	n/a	n/a (whole rwy)	4.5	n/a	n/a (whole rwy)	4.5	n/a
ARR	25	4.5	6	36	4.5	6	36	4.5	6	36	4.5	6
LDG	n/a (whole rwy)	4.5	n/a	n/a (whole rwy)	4.5	n/a	n/a (whole rwy)	4.5	n/a	n/a (whole rwy)	4.5	n/a
LDG Roll Out	25	4.5	2	36	4.5	2	36	4.5	2	36	4.5	2

* Targets in DEP, DBT, or LDG state use "whole runway" hot zones. These hot zones are not site adaptable to t-second hot zones.

TABLE H-6. TARGET HOT ZONE ADAPTATION PARAMETERS (GROUP B)

Tgt State	RUNWAY											
	4L			22R			9			27		
	Hot Zone* (sec)	Ant. Sep. (sec)	Hysteresis (sec)	Hot Zone* (sec)	Ant. Sep. (sec)	Hysteresis (sec)	Hot Zone* (sec)	Ant. Sep. (sec)	Hysteresis (sec)	Hot Zone* (sec)	Ant. Sep. (sec)	Hysteresis (sec)
STP	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TAX	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
DEP	n/a (whole rwy)	5.0	n/a	n/a (whole rwy)	5.0	n/a	n/a (whole rwy)	5.0	n/a	n/a (whole rwy)	5.0	n/a
DBT	n/a (whole rwy)	5.0	n/a	n/a (whole rwy)	5.0	n/a	n/a (whole rwy)	5.0	n/a	n/a (whole rwy)	5.0	n/a
ARR	25	4.0	50	36	4.0	50	36	4.0	50	36	4.0	50
LDG	n/a (whole rwy)	5.0	n/a	n/a (whole rwy)	5.0	n/a	n/a (whole rwy)	5.0	n/a	n/a (whole rwy)	5.0	n/a
LDG Roll Out	20	5.0	30	25	5.0	30	25	5.0	30	25	5.0	30

* Targets in DEP, DBT, or LDG state use "whole runway" hot zones. These hot zones are not site adaptable to t-second hot zones.

REL processing is not performed for arriving (ARTS) targets outside the arrival threshold area. The arrival threshold area is defined as a distance from the threshold line. An aircraft's distance from the threshold is calculated parallel to the runway.

TABLE H-7. ARRIVAL THRESHOLD AREA

Algorithm Variable	Group A	Group B
arrival_threshold_param	12000.0 feet	6000.0 feet

H.3 Movement State Parameters

Table H-8 shows the velocities that are used to determine the movement state of targets and the nominal acceleration used in the light logic algorithms.

TABLE H-8. MOVEMENT STATE PARAMETERS

Setting	Algorithm Variables	Default Value
Landing Deceleration	ldg_acc_param decel_nom_ldg_param	-9.7 ft/sec^2
RollOut Deceleration	rollout_acc_param	0.0 ft/sec^2
Departure Deceleration	decel_nom_dep_param	0.0 ft/sec^2
Departure Abort Deceleration	dbt_acc_param decel_nom_dbt_param	-9.7 ft/sec^2
Arrival Deceleration	arr_acc_param	0.0 ft/sec^2
Departure Acceleration	dep_acc_param accel_nom_dep_param	8.0 ft/sec^2
TAXI Acceleration		3.9 ft/sec^2
TAXI Deceleration		-3.9 ft/sec^2
RollOut Velocity	landing_rollout_speed_param	92.8 ft/sec
Maximum Departure Velocity	v_max_dep_param	303.5 ft/sec
Maximum Taxi Velocity		59.0 ft/sec
Minimum Taxi Velocity		4.0 ft/sec
Maximum Stop Velocity		12.0 ft/sec
Maximum Arming Velocity	arming_vel_threshold_param	59.1 ft/sec
Maximum Arrival Velocity		303.5 ft/sec
Landing-Abort Velocity Offset		70.0 ft/sec

H.4 THL Parameter Options

Table H-9 lists parameters used by the THL light logic algorithms.

TABLE H-9. ABLE THL PARAMETERS

Setting	Algorithm Variable	Default Value
Activation Radius - RWY 4L/22R	activation_width_param	165 feet
Activation Radius - RWY 9/27	activation_width_param	190 feet
Activation Radius - RWY 4R/22L	activation_width_param	165 feet
Activation Radius - RWY 15R/33L	activation_width_param	165 feet
Activation Radius - RWY 15L/33R	activation_width_param	165 feet
Intersection Radius		200 feet
Inters Window Clear Margin	safety_margin_clear_param	5.0 seconds
Inters Window Enter Margin		5.0 seconds
Exit Value for Clear Margin	safety_margin_clear_hys_param	7.0 seconds
Exit Value for Enter Margin		7.0 seconds
ARR Exit Value for Clear Margin	safety_margin_clear_param	8.0 seconds
ARR Exit Value for Enter Margin		8.0 seconds
RWY Alignment Takeoff Pos Angle	hold_pos_theta_param	65 degrees
Exit RWY Alignment Takeoff Pos	hold_pos_theta_hyst_param	75 degrees
Intersection Crossing Angle		35 degrees
Exit Intersection Crossing Angle		25 degrees

H.5 Early Departure Parameters

The minimum and maximum departure distance are used to determine when a target should be subject to the early departure algorithm, which attempts to determine when an aircraft has lifted off based on its ground effect. This is necessitated by the lack of altitude information in the target data provided by ASDE-3. The early departure algorithm will not be called for an aircraft until the aircraft reaches the minimum distance. An aircraft will automatically be declared to be lifted off when the maximum departure distance is reached. Various values are used for different size aircraft and based on the wind speed in the direction of takeoff.

The maximum departure distance is related to the algorithm variable dep_max_dist_param.

TABLE H-10. MINIMUM DEPARTURE DISTANCE

Runway ID	Calm Wind	Strong Wind
Small Aircraft	3000.0 feet	2000.0 feet
Medium Aircraft	4500.0 feet	3500.0 feet
Large Aircraft	6000.0 feet	5000.0 feet

TABLE H-11. MAXIMUM DEPARTURE DISTANCE

Runway ID	Group A	Group B
Small Aircraft	5000.0 feet	4000.0 feet
Medium Aircraft	6500.0 feet	5500.0 feet
Large Aircraft	8000.0 feet	7000.0 feet

Table H-12 defines parameters used by algorithms specific to REL or THL light logic to similarly compensate for the lack of altitude information for targets. These algorithms are separate from the distance-based early departure algorithms.

TABLE H-12. EARLY DEPARTURE DISTANCE

Setting	Default Value	Alternative Value
THL Parameters:		
Minimum Velocity	126.4 ft/sec	dep_thl_spd_param
Minimum Separation	2500.0 ft	dep_thl_dist_param
REL Parameters:		
Minimum Velocity	126.4 ft/sec	
Small Aircraft Max Extent	100 ft	
Large Aircraft Min Extent	200 ft	
Use of Acceleration Model	ENABLE	DISABLE
Head Wind Condition	CALM	STRONG

APPENDIX I

LIST OF HOODED TESTS ANALYZED

Table I-I shows the tests used to analyze discrepancies. Each entry in the table includes the test identifier[1], the runway configuration in use for the duration of the test, the start and end times of the test, the duration of the test in hours:minutes:seconds, the number of arrivals and departures, the total number of operations, and the average number of operations per hour. It should be noted that only those operations (arrivals and departures) which directly affect the operation of the system have been counted.

TABLE I-1. HOODED TESTS USED IN DISCREPANCY ANALYSIS

TEST ID	RUNWAY CONFIG	START TIME	END TIME	DURATION	ARR	DEP	OPS	OPS/HR
960222a	4/9	7:49:29	8:47:52	0:58:23	26	35	61	62.69
960222b	4/9	9:39:28	10:37:29	0:58:01	18	34	52	53.78
960222c	4/9	11:12:32	12:10:59	0:58:27	22	36	58	59.53
960223a	4/9	8:21:38	9:18:09	0:56:31	15	34	49	52.02
960223b	4/9	10:09:39	11:07:35	0:57:56	29	31	60	62.14
960223c	4/9	12:24:11	13:21:57	0:57:46	37	37	74	76.86
960226a	33/27	15:40:37	17:09:58	1:29:21	62	53	115	77.2
960226b	33/27	18:20:14	19:18:42	0:58:28	45	40	85	87.22
960227a	33/27	10:41:23	12:26:38	1:45:15	65	45	110	62.70
960227b	33/27	14:37:13	15:32:02	0:54:49	42	35	77	84.28
960227c	33/27	16:03:56	16:48:25	0:44:29	43	32	75	101.1
960228a	33/27	14:51:08	15:49:18	0:58:10	40	28	68	70.14
960228b	33/27	16:08:33	17:06:26	0:57:53	40	32	72	74.63
960229a	4/9	14:24:07	15:22:08	0:58:01	42	41	83	85.84
960229b	4/9	16:42:55	17:40:46	0:57:51	50	47	97	100.61
960229c	4/9	18:00:28	18:27:53	0:27:25	21	17	38	83.16

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[1] Test identifiers comprise two digits for the year, two digits for the month, two digits for the day, and a character which indicates the test sequence number for that day e.g., 960222A represents the first test (A) on February 22, 1996.

TABLE I-1. HOODED TESTS USED IN DISCREPANCY ANALYSIS (cont.)

960229d	4/9	19:03:30	20:01:53	0:58:23	34	53	87	89.41
960304a	33/27	15:04:40	15:55:45	0:51:05	37	37	74	86.9
960304b	33/27	16:42:45	17:40:47	0:58:02	49	41	90	93.04
960319a	4/9	8:34:15	9:20:18	0:46:03	23	37	60	78.18
960319b	4/9	10:01:41	11:00:06	0:58:25	31	34	65	66.76
960319c	4/9	13:15:26	14:13:36	0:58:10	40	33	73	75.30
960320a	33/27	16:40:19	17:37:59	0:57:40	51	36	87	90.52
960320b	33/27	17:57:38	18:56:08	0:58:30	49	51	100	102.5
960326a	33/27	10:15:13	10:47:09	0:31:56	19	9	28	52.6
960326b	33/27	11:15:10	12:13:22	0:58:12	32	28	60	61.85
960416b	15/9	15:51:34	16:49:47	0:58:13	35	36	71	73.17
960416c	15/9	17:40:27	18:08:39	0:28:12	20	18	38	80.85
960425c	4/9	12:40:05	13:38:42	0:58:37	41	42	83	84.96
960718a	27/22	8:47:07	9:45:32	0:58:25	38	51	89	91.41
960718b	27/22	9:46:07	10:44:52	0:58:45	35	41	76	77.61
960718c	27/22	10:45:47	10:56:55	0:11:08	12	9	21	113.1
960718d	4/9	11:07:32	11:53:58	0:46:26	30	38	68	87.87
960718e	27/22	13:09:25	14:07:51	0:58:26	40	48	88	90.35
960718f	27/22	14:07:51	15:06:19	0:58:28	50	42	92	94.41
960718g	27/22	15:06:59	15:39:01	0:32:02	25	29	54	101.1
960724a	4/9	10:55:15	11:54:30	0:59:15	44	41	85	86.08
960724c	4/9	13:33:15	14:31:57	0:58:42	44	49	93	95.06
960724d	4/9	14:33:23	15:32:12	0:58:49	48	50	98	99.97
960725a	27/22	8:39:58	9:40:28	1:00:30	42	54	96	95.20
960725b	27/22	9:45:53	10:45:07	0:59:14	43	45	88	89.00
960725c	27/22	10:46:48	11:45:21	0:58:33	43	37	80	81.98
960725d	27/22	13:02:53	13:35:10	0:32:17	23	21	44	81.77
960730a	4/9	8:24:41	9:22:35	0:57:54	44	43	87	90.16
960730b	15/9	9:18:27	10:16:25	0:57:58	43	43	86	89.01
960730c	15/9	10:16:00	11:15:00	0:59:00	42	42	84	85.42
960730d	15/9	11:15:43	12:02:02	0:46:19	33	33	66	85.49
960730f	4/9	13:53:54	14:51:30	0:57:36	46	46	92	95.83

TABLE I-1. HOODED TESTS USED IN DISCREPANCY ANALYSIS (cont.)

960730g	4/9	15:08:20	16:06:10	0:57:50	46	46	92	95.44
960731a	4/9	8:55:58	9:55:04	0:59:06	42	42	84	85.27
960731b	4/9	9:55:15	10:52:40	0:57:25	41	40	81	84.64
960731c	4/9	10:54:50	11:53:50	0:59:00	40	39	79	80.33
960731d	4/9	12:48:51	13:46:36	0:57:45	39	39	78	81.03
960731e	4/9	13:47:37	14:45:00	0:57:23	47	46	93	97.24
960801a	4/9	8:20:29	9:19:19	0:58:50	35	52	87	88.73
960801b	4/9	9:19:19	10:18:35	0:59:16	39	43	82	83.01
960801c	4/9	10:18:35	11:16:40	0:58:05	40	41	81	83.67
960801d	4/9	12:15:51	13:13:50	0:57:59	36	41	77	79.68
960801e	4/9	13:21:13	14:19:26	0:58:13	39	45	84	86.57
960801f	4/9	14:30:23	15:28:07	0:57:44	44	38	82	85.22
960802a	4/9	13:21:44	14:19:35	0:57:51	42	45	87	90.23
960802b	4/9	14:34:37	15:32:28	0:57:51	53	54	107	110.9
960805a	27/22	8:32:07	9:30:29	0:58:22	39	48	87	89.43
960805b	27/22	9:31:04	10:29:42	0:58:38	39	47	86	88.00
960805c	27/22	10:30:23	11:18:12	0:47:49	40	37	77	96.61
960805d	27/22	12:20:18	13:18:00	0:57:42	53	31	84	87.34
960805e	4/9	13:36:21	14:34:08	0:57:47	48	53	101	104.8
960805f	4/9	14:35:19	15:33:24	0:58:05	46	45	91	94.00
960806a	4/9	8:40:59	9:33:09	0:52:10	37	37	74	85.11
960806b	4/9	9:33:31	10:32:20	0:58:49	40	39	79	80.5
960806c	4/9	10:33:07	11:31:00	0:57:53	41	41	82	84.99
960806d	4/9	12:25:00	13:22:30	0:57:30	46	46	92	96
960806e	4/9	13:23:50	14:22:07	0:58:17	51	51	102	105.0
960807a	27/22	8:41:12	9:37:45	0:56:33	42	42	84	89.12
960807c	15/9	10:42:13	11:39:27	0:57:14	21	21	42	44.03
960807d	15/9	13:03:04	13:52:00	0:48:56	16	15	31	38.0
960807e	4/9	14:06:45	15:04:23	0:57:38	38	38	76	79.12
960808a	27/22	8:47:54	9:36:41	0:48:47	35	39	74	91.01
960808b	27/22	10:05:36	11:01:52	0:56:16	39	44	83	88.50
960808c	27/22	11:09:49	11:59:09	0:49:20	36	36	72	87.56

TABLE I-1. HOODED TESTS USED IN DISCREPANCY ANALYSIS (cont.)

960808d	27/22	13:21:22	14:21:04	0:59:42	57	43	100	100.5
960808e	27/22	14:21:22	15:19:54	0:58:32	36	46	82	84.05
960812a	27/22	8:50:26	9:49:32	0:59:06	44	50	94	95.41
960812b	27/22	9:49:57	10:32:32	0:42:35	25	31	56	78.90
960812c	15/9	10:54:09	11:48:18	0:54:09	41	42	83	91.96
960812d	15/9	12:49:45	13:48:53	0:59:08	44	49	93	94.36
960812e	15/9	13:48:53	14:48:31	0:59:38	45	47	92	92.56
960812f	4/9	15:08:22	15:53:54	0:45:32	34	41	75	98.8
960813a	4/9	8:23:38	9:22:09	0:58:31	36	53	89	91.25
960813b	4/9	9:24:22	10:23:24	0:59:02	38	43	81	82.32
960813c	4/9	10:23:25	11:23:57	1:00:32	41	37	78	77.31
960813d	4/9	13:31:40	14:04:20	0:32:40	23	26	49	90.00
960815a	4/9	11:04:17	11:25:28	0:21:11	16	14	30	84.97
960815b	4/9	12:54:00	13:53:33	0:59:33	52	51	103	103.7
960815c	4/9	13:54:18	14:53:26	0:59:08	50	47	97	98.42
960815d	4/9	14:54:56	15:52:17	0:57:21	39	47	86	89.97
960819a	4/9	8:53:59	9:51:16	0:57:17	36	48	84	87.98
960819d	4/9	14:29:12	15:27:55	0:58:43	53	46	99	101.1
960820a	27/22	8:29:54	9:32:39	1:02:45	49	63	112	107.0
960820b	27/22	9:36:32	10:35:11	0:58:39	38	44	82	83.88
960820c	27/22	10:38:58	11:36:58	0:58:00	46	41	87	90
960821a	27/22	9:15:10	10:13:13	0:58:03	36	48	84	86.82
960821b	27/22	10:14:34	11:12:59	0:58:25	44	44	88	90.38
960821c	27/22	12:08:59	13:10:43	1:01:44	53	45	98	95.24
960821e	27/22	14:41:57	15:40:00	0:58:03	40	48	88	90.95
TOTAL	4:00:40:04				4089	4209	8298	85.84

TABLE I-2 TESTS ANALYZED FOR COMPARISON OF LM SOFTWARE VERSIONS 16 AND 20

TEST ID	CONFIG	START TIME	END TIME	DURATION	ARR	DEP	OPS	OPS/HR
960228b	33/27	16:08:33	17:06:26	0:57:53	40	32	72	74.63
960229d	4/9	19:03:30	20:01:53	0:58:23	34	53	87	89.41
960730b	15/9	9:18:27	10:16:25	0:57:58	43	43	86	89.01
960730c	15/9	10:16:00	11:15:00	0:59:00	42	42	84	85.42
960730d	15/9	11:15:43	12:02:02	0:46:19	33	33	66	85.49
960730f	4/9	15:08:20	16:06:10	0:57:50	46	46	92	95.44
960730g	4/9	13:53:54	14:51:30	0:57:36	46	46	92	95.83
960731d	4/9	12:48:51	13:46:36	0:57:45	39	39	78	81.03
960731e	4/9	13:47:37	14:45:00	0:57:23	47	46	93	97.24
960801e	4/9	13:21:13	14:19:26	0:58:13	39	45	84	86.57
960805d	27/22	12:20:18	13:18:00	0:57:42	53	31	84	87.34
960805e	4/9	13:36:21	14:34:08	0:57:47	48	53	101	104.8
960805f	4/9	14:35:19	15:33:24	0:58:05	46	45	91	94.00
960812a	27/22	8:50:26	9:49:32	0:59:06	44	50	94	95.41
960812b	27/22	9:49:57	10:32:32	0:42:35	25	31	56	78.90
960813a	4/9	8:23:38	9:22:09	0:58:31	36	53	89	91.25
960813b	4/9	9:24:22	10:23:24	0:59:02	38	43	81	82.32
960813c	4/9	10:23:25	11:23:57	1:00:32	41	37	78	77.31
960815a	4/9	11:04:17	11:25:28	0:21:11	16	14	30	84.97
960815b	4/9	12:54:00	13:53:33	0:59:33	52	51	103	103.7
960815c	4/9	13:54:18	14:53:26	0:59:08	50	47	97	98.42
960815d	4/9	14:54:56	15:52:17	0:57:21	39	47	86	89.97
TOTAL				20:18:53	897	927	1824	89.79

APPENDIX J

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